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THE ENVIRONMENTAL HISTORY OF FENÉKPUSZTA WITH A SPECIAL ATTENTION TO THE CLIMATE AND PRECIPITATION OF THE LAST 2000 YEARS

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Abstract

This work presents the details of a multidisciplinary palaeoecological and geoarcheological study on the sedimentary sequences, including 2 undisturbed cores of the Little Balaton situated in the western part of Lake Balaton in Central Europe. The application of Quaternary palaeoecological analysis to peat and lacustrine deposits enables to identify long-term environmental changes in aquatic and terrestrial ecosystems. The principal aims were to shed light onto how former human societies and culture shaped and altered their natural environment on the one hand. Furthermore, to reconstruct the once existing environmental conditions within the framework of the natural evolution of the vegetation, soil, fauna and the catchment basin for the times preceding written historical records via the application of sedimentological, geochemical, isotope geochemical, palynological, macrobotanical, malacological and microfaunal analytical methods and approaches.

INTRODUCTION

This work presents the details of a multidisciplinary palaeoecological and geoarcheological study on the sedimentary sequences, including 2 undisturbed cores of the Little Balaton situated in the western part of Lake Balaton in Central Europe (*Fig. 1*). The application of Quaternary palaeoecological analysis to peat and lacustrine deposits enables to identify long-term environmental changes in aquatic ecosystems. The composition of aquatic plant and animal communities is largely influenced by the hydrological conditions prevailing in the basin harboring them.

The principal aims were to shed light onto how former human societies and culture shaped and altered their natural environment on the one hand. Furthermore, to reconstruct the once existing environmental conditions within the framework of the natural evolution of the vegetation, soil, fauna and the catchment basin for the times preceding written historical records via the application of sedimentological, geochemical, isotope geochemical, palynological, macrobotanical, malaco-logical and microfaunal analytical methods and approaches.

In the course of an international archaeological-research, the cooperation with the Archaeological Institution of the University of Leipzig and the Institute of Archeology Hungarian Academy of Sciences opened up the possibility to implement an environmental historical study in the western part of the Balaton region in relation to the Fenékpuszta settlement forming a part of modern Keszthely.

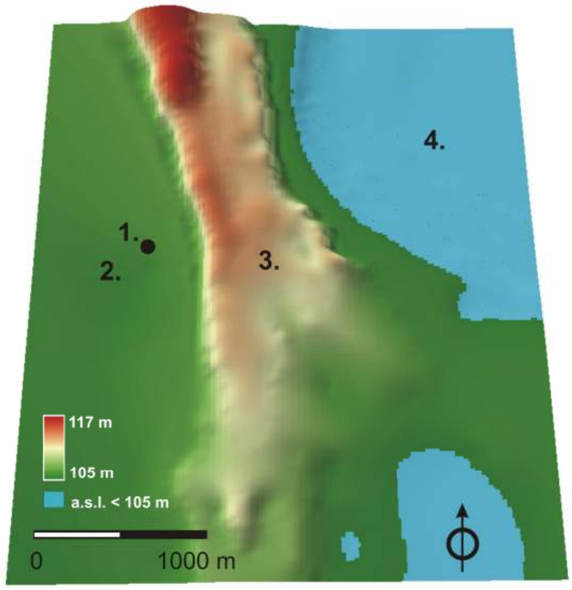

Fig. 1. 3D model of the study area with the sampling sites

The entire record goes back in time to the Pleistocene/Holocene transition, but this article mainly focuses on environmental events and conditions related to the settlement and its activities in the Migration Period. Special attention was paid to the records of the 4th-5th and the 8th centuries AD. This is justified by the fact that numerous historical interpretations published recently (Györffy – Zólyomi 1996, Rácz 2008) presented speculations about draughts and famines leading to a collapse of the local Avar Empire, based on interpretations of data from Iceland and Western Europe, but lacking regional environmental historical records from the area of the Carpathian Basin itself.

MATERIAL AND METHODS

For a complex environmental historical evaluation, the model and analytical system of Birks and Birks (1980) was adopted in our work. (*Table 1*, *Fig. 2*). To gain an overview of the subsurface geology and to highlight sites for undisturbed core retrieval about 20 probe cores were taken in the area of Fenékpuszta. This was later on complemented by two parallel cores taken by a modified Russian head corer (Sümegi 2001) yielding overlapping undisturbed core samples from the infilled lacustrine basin of the Kis-Balaton near Fenékpuszta (*Fig. 1*). After transportation to the laboratory, the cores were cut lengthwise for various analyses; the sections for palaeobotanical and geochemical analyses were stored at 4°C in accordance with the international standards. The samples submitted to lithological analyses were identical with the ones used for the palaeobotanical, macrobotanical, malacological and radiocarbon analyses. For the macroscopic description of the samples and the preparation of the lithological column the internationally accepted system of Troels-Smith (1955) was adopted. The core was divided into 1-4 cm samples. To gain information on the chronology, 13 samples of plant macrofossils were subjected to AMS (Accelerator Mass Spectrometry) radiocarbon analyses in the Radiocarbon Lab of Poznan, Poland. In order to allow comparison with other archaeological data, the raw dates were converted to calendric ages using the CALPAL calibration programme, and the most recent CALPAL-2007 HULU calibration curve. The original dates (^{14}C) are indicated as uncal BP, while the calibrated dates are indicated as cal BC.

Table 1. An overview of the methods of investigations implemented on the two undisturbed cores (N: 46º 42.621' and E: 17 º 14.048) with references describing the methods

Core	Sedimentological and geochemical analyses		Pollen and microcharcoal analyses	Macrobotanical and micro-zoological analyses	Mollusc analyses	^{14}C analyses
Sümegi, 2001	Troels-Smith, 1955; Dean, 1974; Dániel, 2004		Stockmarr, 1971; Clark, 1982	Jakab-Sümegi, 2004	Sümegi, 2004	AMS method
Core name	subsamples		subsamples	subsamples	subsamples	
Valcum I. and II.	79	85	85	35	70	13

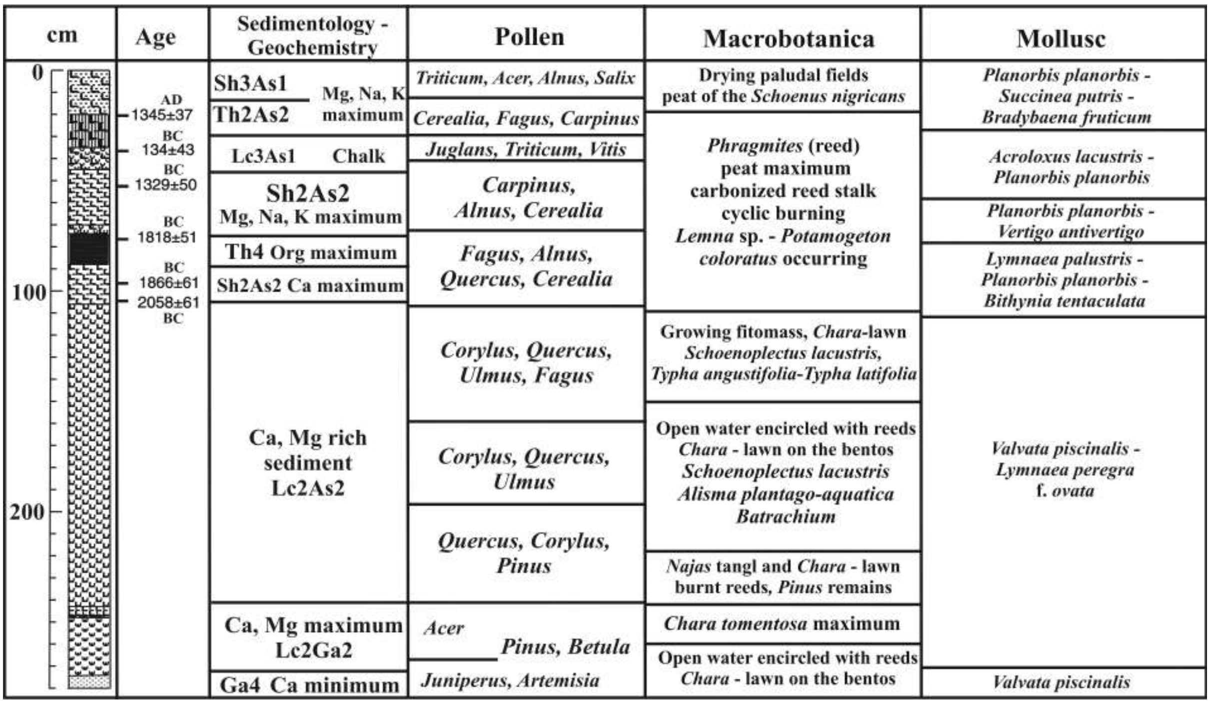

Fig. 2. Palaeoenvironmental analyses of Fenékpuszta (Kis-Balaton) cores

The organic and carbonate content of the samples were determined by Dean's (1974) LOI method. The inorganic content was further analyzed using the sequential extraction method. The so-called sequential extraction method of Dániel (2004) with a long established history in the analysis of geochemical composition of lacustrine sediments was adopted in our work. From the full procedure the step of water extraction for unseparated samples was sufficient to suit our analytical needs as it was shown by previous works (Dániel 2004), the most important palaeohydrological and palaeoecological data originates from water extraction samples. Elements of Na, K, Ca, Mg, Fe were determined using a Perkin-Elmer 100 AAS.

Sediment samples of 1 cm^3 were taken from the core at 1-4cm intervals for pollen and macrobotanical analysis using a volumetric sampler. For the extraction and description of macrofossils a modified version of the QLCMA technique (semi-quantitative quadrat and leaf-count macrofossil analysis technique) of Jakab et al. 2004 was adopted. For the extraction of pollen grains a modified version of the method of Stockmarr (1971) was adopted. A *Lycopodium* spore tablet of known volume (13911 spores per tablet) was added to all samples to give a desirable ratio for pollen to exotic spike to work out pollen concentrations. A minimum count of 500 grains per sample (excluding exotics) was made in order to ensure a statistically significant sample size. Charcoal abundances were determinated using the point count method (Clark 1982).

Mollusc shells were collected from 2 to 4 cm thick subsamples taken at regular intervals throughout the core. Following the palaeoecological classifications of Sümegi (2004), the aquatic malacofauna was divided into two groups: species demanding steady water inundantion (ditch group) and species tolerant to periodic water supply (slum group). Terrestrial fauna was grouped as follows: water bank (hygrophilous), mesophilous, xerophilous, cold-resistant, intermediate, thermophilous, open habitat preferring, ecoton habitat preferring and woodland habitat preferring species. Malacological record was also classified according to the recent geographical distribution of the species, following Sümegi (2001) and on the basis of palaeoclimatological indicator roles. Results from all analyses are plotted against depth using the PSIMPOLL programme (Bennett 1992).

THE STUDY SITE

Lake Balaton is the largest lake in Central Europe, with a modern open water area of 593 km^2. The lake basin has a maximum length of 77 km, and a width of 8-14 km with a mean water depth of only 3-4 m. The area of the Little Balaton is located west of the modern open water system in a separate neotectonic catchment basin forming an extensive marshland today. Based on historical maps of the first and second Austrian Military Survey the area of the Little Balaton used to be a part of the larger unregulated lake system in historical times preceding the 19^{th} century regulations.

The neotectonic basin of the Little Balaton is located between the peninsula of Fenékpuszta, the Zalavár geological ridge and Somogy Hills. The Zalavár ridge and the neck of the Fenékpuszta peninsula are composed of Pannonian and Pliocene deposits overlain by Late Pleistocene loess. The area of the referred catchment basin is about 50 km^2. Our samples were taken in a small embayment located on the northern part of the catchment basin known as the Fenékpuszta Embayment. This area was infilled as a result of natural vegetation succession of peatlands during the Holocene.

This region lies on the boundary of the moderately cool–moderately wet (Köppens Cf) and the moderately cool–moderately dry climatic zones (Köppens BS). The mean annual temperature is 9.8 ºC. The mean temperature of the growth season is around 15.5-16 ºC. The rate of annual precipitation is around 700 mm, 440 mm of which falls during the growth season. The climatic conditions of the region are favorable for forestry primarily. Nevertheless, these endowments enable the cultivation of less heat demanding species.

The region is part of the *Saladiense* regarding vegetation geography; the most common forest associations are oak-hornbeam forests (*Querco robori-Carpinetum*), sessile oak-hornbeam forests (*Querco petraeae-Carpinetum*), oak-ash-elm gallery woods (Querco-Ulmetum), and willow-poplar gallery woods (*Salicetum albae-fragilis*). The natural shrub level is dominated by white cinquefoil (*Potentilla alba*), vetches (*Vicia cassubica*, *V. oroboides*), large red deadnettle (*Lamium orvala*), cyclamen (*Cyclamen purpurascens*), prostrate rock-rose (*Fumana procumbens*), fescues (*Festuca vaginata*, *F. rupicola*).

Higher ridges are predominantly covered by brown forest soils (accounting for about two-thirds of the area), hosting arables, vineyards and hornbeam-oak forests in about even proportions. The soils of the catchment basin areas are hydromphic covered with gallery woods, meadows and pastures. The region is characterized by a flora typical for the Preillyricum between the Illyricum phytogeographical province of the western Balkans and the Pannonian region covering most of modern-day Hungary. Numerous Illyric*,* Submediterranean and Alpine floral elements thrive in the undergrowth of oak forests. Large stands of alder trees (*Alnus glutinosa)* dot the wet meadows with a constantly high water table. The open areas around the mires are utilised as arables and pastures.

ARCHAEOLOGY OF FENÉKPUSZTA

The area is characterised by a mix of cultures from an archaeological point of view. As shown by the archaeological data, the area was continually inhabited from the second half of the Neolithic. It is by no means accidental as the Fenékpuszta Isthmus, just like the Máriaasszony Island in Vörs belonging to the southern part of Lake Balaton, was the most important crosspoints of Lake

Balaton between the pointbars of Balatonberény which could have existed as early as the Antiquity (Sági 1968, Müller 1987). The area was populated during the Neolithic (M. Virág 1996) Copper and Bronze Ages by representatives of various cultural groups (see Bondár 1996, Horváth 1996). The area was also inhabited in the Iron Age by members of the Halstatt culture of the early Iron Age as well as the Celts in the late Iron Age.

The Celts managed to survive in the area at the time of the beginning of the Roman conquest in the 1st century AD (Müller 1996). The Romans appearing in this area in the Imperial Age thus settled in a highly modified so-called cultural rather than natural landscape. Based on archaeological data, a fortress was built where the roads running from Aquile to Aquincum and to Sirmium and Augusta Treverorum traversing diagonally Transdanubia met. The size of the fortress is astonishing with 44 round towers ranging 377 x 358 m fortress square meters. The building was constructed of ca. 87 000 m^3 stones. The walls were 2.6 m thick and 10 m high with possibly 4 gates. Traces of 22 edifices have turned-up so far which adjusted to the by-pass joining the north-southern gates. Out of these rise the more than $1000m^2$ big horreum and the building of the Early Christian basilica.

Based on the size and the edifices of the forests, a significant population engaged in advanced farming must have inhabited the area of Fenékpuszta in the Imperial Age. According to the archaeological and historical data gathered until now, the fortress was destroyed by Ostrogoths in October 455 AD. After its reconstruction, the fortress might have been the seat of Thiudimer, the Eastern-Gothic king, as the cemetery of the eastern Gothic people migrating to the East-Roman Empire was excavated just south of the fortress (Straub 2002). The ownership of the examined area is problematic in the following half century. There was an assumption that it belonged to Odoaker, the Italian king then the Suebians of the Danube spread their authority up to this region. According to another concept, a part of the leaving eastern Goths stayed and could have owned the fortress then the Lombards extended their authority over this area. Following the pullout of the Lombards in 568, the previous population could have lived on in Fenékpuszta, though they might have added new folk elements to their existed ones as more changes can be examined in the archaeological material.

Namely, parts of the jewellery, following the Avar conquest after 568, have no local antecedents and the new funerary practices and objects were in sharp contrast with the poor funerary adornments dated before 568. Parallel with this event, an Early Christian basilica was erected with three apses. Similar type of construction works were recorded only in Northern Italy and in the Balkans for the same period. The leaders of the area established their cemetery near the horreum after the second half of the 6th century.

The cemeteries, which were not looted, were started to be used around 568 and funerals took place here up to 630. At present, 460 graves are known from this period in the locality of Keszthely-Fenékpuszta. Most of the new findings are related to the Avars. In spite of this fact, we cannot take the factual Avar population's presence into account as probably a mixture of local population could have been formed here who paid tax to the Avars. However, the standpoint of researchers about the consistency of population is diverse. According to Károly Sági, the population of the fortress consisted of late antique and western Germanic population. László Barkóczi referred to the burying rituals with stones as a custom of the local survival population. István Bóna assumes the presence of a Byzantine or Lombard ruling class with Byzantine elements.

There are also theories of Alamans and Franks escaping to be under the Avars' authority. Moreover, the research has lately started to take the elements of Romanised Christians into account escaping from the southern part of Noricum and Pannonia. The research named this mixed ethnical group as the Keszthely culture. The ruling class and the followers of Keszthely culture disappeared after the siege of the fortress in 630, though burying sparsely happened in the commonality cemetery until the end of the 7th century A.D.

Following the decline and fall of the Avar Empire, the Karoling Age (Szőke 1996) came in the life of Fenékpuszta which existed as long as the Hungarian conquest and the occupation of the area in Transdanubia, so for a century or so. Based on the one hand on medieval archaeological findings, the medieval church and cemetery of Pusztaszentegyház as well as on on its dated bell originated from 1509, it was the place of a medieval village called Fenék (= Bottom). This settlement has been noted first in 1347 and last in 1594 (Vándor 1996). At this time the fortress might not have been used and by the end of the Turkish Empire, the area had become deserted.

In the 18th century, the population moved to Keszthely. The land, together with Fenékpuszta, was bought by the Festetics family in 1739. In the times came, they influenced the image of the area and established horse-breeder premises, carpenter and ship building plants. They have probably used the stones of the Roman fortress too, although the walls of it are also marked on an Austrian military map made in 1782 (Timár et al. 2006). At the same time, on the maps made in 1792 and in 1805, the fortress is not marked anymore. According to this, the total demolition of it might have happened between 1782 and 1792, so at the end of the 18th century.

RESULTS

Based on the collective evaluation of biotic and abiotic records a fairly complete history of the geological and environmental evolution of the area could have been drawn.

Fluvial sands giving the bedrock of our cores must have formed about 11 kys ago, at the end of the Pleistocene (Sümegi et al. 2008). This level is characterised by the presence of *Valvata piscinalis*, a moving-water gastropod as well as the smallest calcium and magnesium content and the most essential inorganic material content. The observed minima of water soluble elements seems to be congruent with the picture drawn from the evaluation of other records; i.e. the deposition of fluvial sediments and non-weathered silicates to the incipient neotectonic basin. This incipient catchment basin must have been fringed by pine woodland with stands of birch and reed.

The fluvial deposits are overlain by a slightly layered, pink lacustrine layer with highly varying carbonate content and spots of volcanic ash. This horizon marks the evolution of a larger lake system within the forming catchment basin as also marked by a maximum of Ca and Mg in the deposits among water soluble elements. The inferred 3 m deep, mesotrophic lake rich in carbonate must have existed in the area from the beginning of the early Holocene until the end of early Bronze Age (20^{th}-21^{st} century BC). The retrieved lacustrine deposits yielded a significant amount of stonewort algae as well as parts of floating read grass and shells of *Lymnaea peregra* f. ovate and *Valvata piscinalis* marking the presence of a well-lit, deep, calcareous lake in the area for the referred period.

The former coniferous woodland was replaced by a deciduous woodland dominated by oak, elm and hazel during the referred period as seen from the pollen record. Macrobotanical remains talk about the emergence of a wide belt of reeds, bulrushes and sedges on the shore before the gallery woodland.

From a depth of 106 cm up to the surface, representing the periods of the early Bronze Age to the Middle Ages a general decrease in the water level is inferred compared to the previous stage of the lake. Nevertheless, three distinct periods or cycles could have been identified when the continuous deposition of organic materials in a marshland setting halted and was exchanged by lacustrine sedimentation within the framework of an eutrophic lake (*Fig. 2*). This stage marked the end of the open lake system, and although these periodic water level rises significantly influenced the deposition of calcareous lacustrine muds into the basin, conditions like in the modern open lake system of Balaton never returned to the area afterwards.

Cycle 1. after the formation of an Early Bronze Age peat layer, in the period corresponding to the end of the early Bronze Age, beginning of the middle Bronze Age (beginning of the 19^{th} century BC), a dynamic but short rise of the water level occurred in the examined area based on the macrobotanical and malacological findings leading to the formation of a shallow eutrophic lake in the basin (*Table 2*). At the end of the same period, and in the second part of the middle Bronze Age peat deposition resumed leading to the formation of floating marsh and a closed peat layer at this part of Kis-Balaton. Then in the late Bronze Age, due to a rise of the water level, the peat formation halted again resulting in the deposition of a thin layer of lacustrine marls over the previous peat sequence.

Cycle 2: following the late Bronze Age, in the early Iron Age, a subsequent peat deposition could have been inferred (between the 8^{th} and 2^{nd} century BC) followed by another rise in the water level and the formation of another short shallow lacustrine phase. The high correlation between the observed concentrations of water soluble Mg, Na, K and the accumulated peat horizons is by no means surprising, as these elements tend to accumulate in aquatic plants. Around the end of the late Bronze Age, beginning of the Iron Age, besides the remains of plants and molluscs preferring a lacustrine environment, a drop in the amount of the referred elements could have been observed marking a phase of inundation (between 66-62 cm), followed by another stage of peat deposition between the depth of 62-48 cm. In the Iron Age, between the 8^{th} and 2^{nd} century B.C., a more pronounced inundation of the basin could have been inferred from a dynamic decrease of water soluble elements. Conversely, at the beginning of the Imperial Age, peat formation was dominant as seen from a gradual increase in Mg, Na and K in the deposits.

Cycle 3: following the deposition of lacustrine marls in the Late Iron Age another peat formation started from the Imperial Age. The Imperial Age also marked the end of these natural cycles of lake-marshland stages and conditions characteristic of a marshland seem to have stabilized for the forthcoming periods in the area. The speed of sediment accumulation also decreased probably because a part of the surficial peat deposits suffered incipient pedogenesis. From the shift observable in the geochemistry a short period of inundation could have been inferred at the end of the Imperial Age and at the beginning of the Migration Period. This might have been the outcome of a general increase in precipitation on the one hand. But this is not the only factor we must take into account while finding an explanation to the short rise in the water table within the catchment basin. As shown by written records Romans have devised a drainpipe system in the 3rd century AD, with which the level of Lake Balaton was kept artificially low. The rise in the water level at the time of the Migration Period, could be attributed to the fact that these drainpipes constructed by the Romans might have been clogged in the lack of general cleaning and maintenance. Nevertheless, the inferred rise in the water table in our area is congruent with the transformations observed in a more distant catchment basin of Nagybárkány located in the NE part of Hungary as well for the same period (*Fig. 3*). Here a general increase in the precipitation as inferred from pollen data and a rise in the water table could have been postulated (Jakab – Sümegi 2005). Similar changes were

Table 2. Results of radiocarbon analysis

cm	BP	+/-	cal BP	+/-	cal BC/AD	+/-	Lab code
20-21	610	30	605	37	1345 AD	37	Poz-20847
22-23	1050	30	966	23	984 AD	23	Poz-20915
25-26	1235	30	1175	61	775 AD	61	Poz-20840
29-30	1355	30	1290	13	660 AD	13	Poz-20888
30-31	1400	30	1318	18	632 AD	18	Poz-20838
31-32	1480	30	1366	16	584 AD	26	Poz-28408
34-35	1875	30	1813	48	137 AD	48	Poz-21486
36-37	2110	30	2084	43	134 BC	43	Poz-20889
40-41	2750	30	2840	35	890 BC	35	Poz-28407
52-53	3050	35	3279	50	1329 BC	50	Poz-20848
76-77	3485	35	3768	61	1818 BC	51	Poz-20849
96-97	3540	35	3816	61	1866 BC	61	Poz-20850
104-105	3670	35	4008	61	2058 BC	61	Poz-20890

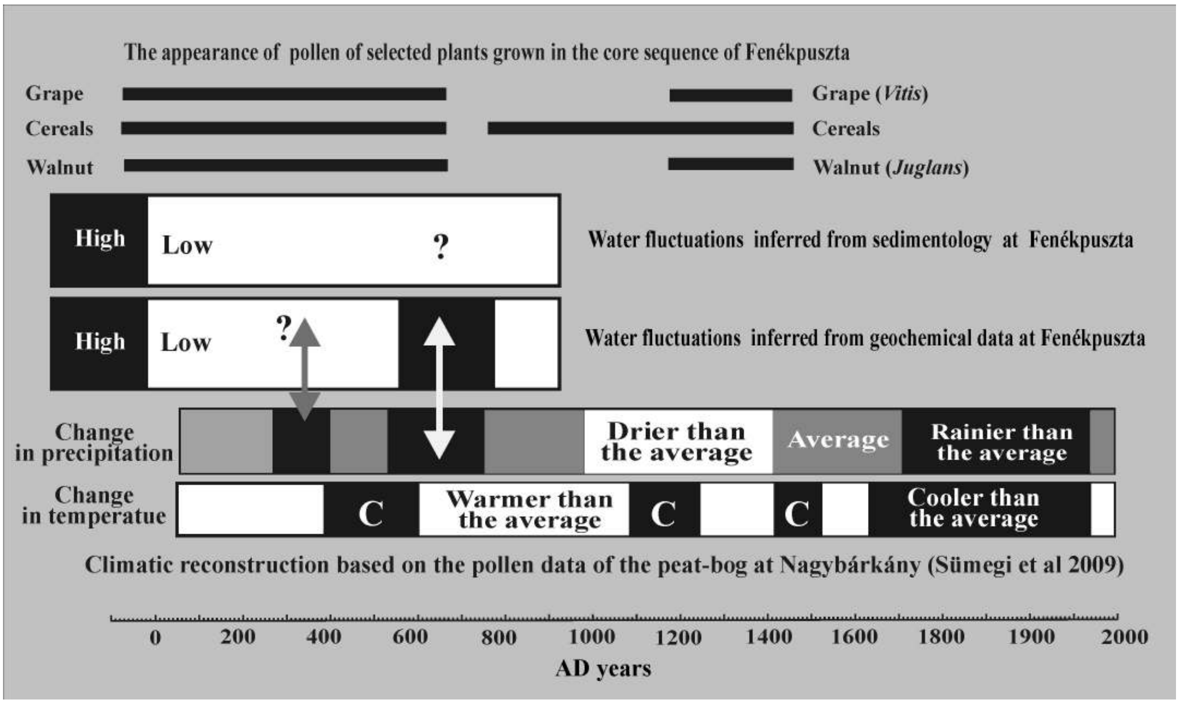

Fig. 3. Comparison of the Fenékpuszta and Nagybárkány (see Sümegi et al. 2009) investigations

observable on the core section corresponding to the Imperial Age from a nearby lacustrine-marshland system at Lake Baláta (Jakab – Sümegi 2007) in the south western part of Transdanubia, which enjoys similar climatic endowments as the site of Fenékpuszta. Many historians put forth numerous postulations about long-lasting draughts and severe consequences on the population of the Carpathian Basin for the period of Great Migrations (Györffy – Zólyomi 1996, Rácz 2008). Some of them went as far as stating that the main push factor for migration of Eastern European tribes was the general aridity of the climate resulting in long-lasting draughts. The cornerstone of these statements was the observed low water level of the Caspian Lake during the referred period followed by a subsequent inundation of the coastal harbors (Györffy – Zólyomi 1996, Rácz 2008). The inferred paleoclimatological reconstructions of these authors raise significant problems from several points and are challenged by modern paleoecological data:

1./ Fluctuations in the water table of the Caspian Lake are not related to fluctuations in the precipitation to the Eurasian steppes forest steppe areas because the drainage of this lake system is located in the highland region of the Caucasus and Central Asia on the one hand, as well as the taiga belt on the north (Rodionov 1994). Thus making inferences about the precipitation of the steppes based on fluctuations of the water level of the Caspian Sea is not accurate.

2./ The majority of the harbours, inundated later on from the end of the Antiquity and the early Migration Period, are located in a tectonically highly active area in the northern part of the Caspian Sea. Plus, at the edge of the Volga delta. Consequently, we have two geological forces working in the referred area which might have resulted in an inundation of the coastal areas and harbours independently of fluctuations in precipitation (Aladin – Plotnikov 2000). The continuous sinking of the northern bed of the Caspian Lake (inland sea) is of striking importance here (Degens – Paluska 1979). Although this process causes annually only a few millimetres of change, within hundreds of years it might have lead to even a one meter rise of the water level in the coastal areas. The other force is related to the sediment carrying capacity of the River Volga leading to a rapid infilling of the accommodation space in the coastal areas, which again might be a cause of water level increase there.

3./ According to the data retrieved by geologists, climatologists and geographers (Mayev et al. 1983) working in the area, the water level of the Caspian Sea was extremely high at the end of the Antiquity and the beginning of the Migration Period, because the water balance of this inland sea is influenced by not only the precipitation coming through the rivers which is a significant factor, but also the temperatures around the inland sea (Klige – Myagkov 1992). According to the data we have at hand, the development of a cooler phase in the Central-Asian area can be inferred at the beginning of the Migration Period. So it is not surprising that a quite high water level was reconstructed for the Caspian Lake in this period which is in sharp contrast with the statement given by the referred Hungarian historians. At the same time, the data prove that in the course of the past 2000 years, quite significant changes have happened in the water level of the Caspian Lake. But these changes had connections primarily to the development of temperature and only secondly to the precipitation coming through the rivers (Budyko et al. 1988).

Thus water level changes in the referred lake system are related to fluctuations in the precipitation of Central Asia, the Caucasian highlands and the Eurasian taiga belt, as well as the temperature fluctuations of Central Asia. Thus the climatic and demographic models made by historians for the area of Central Europe for the period of Great Migrations seem to be in sharp contrast with the paleoecological information for the area of the Caspian Sea and those of the Carpathian Basin as well and as such need adverse correction.

Returning to the environmental history of Keszthely-Fenékpuszta in Kis-Balaton, the beginning of the Migration Period, which was characterized by a rise in the water level with highly ambiguous causes, was followed by another dynamic increase in the water soluble elements of Mg, Na, K marking peat formation. Peat formation initiating during the Imperial Age continued during the Migration Period as well. Nevertheless pedogenesis was also observable in these peat horizons. Thus from the period of the Imperial Age and the subsequent period of Great Migrations the emergence of a stable marshland could have been inferred for the northern parts of the Fenékpuszta Isthmus. These conditions survived until the closure of the Middle Ages in this part of the Kis-Balaton. This peat formation might have been continuous from the time of the Great Migrations. But the element content of the near-surface layers could have been dynamically modified by hydromorphic soil formation which took place in the Middle Ages. This hampered the reconstruction of water level fluctuations in the area from the end of the Migration Period onwards.

Besides precipitation, various forms of agricultural activities could have been captured in our record as well. Based on the pollen content a widespread cultivation of corn and extensive animal husbandry could have been inferred for the area of the Fenékpuszta Isthmus from the Middle Bronze Age. Yet, the most powerful human influences are related to the Imperial Age. From the end of the Iron Age the proportion of open-area loving plants, weeds, Gramineae, Artemisia increased significantly, together with numerous plants marking intensive horticulture such as *Juglans, Vitis*. As for the pollen results, cultivation of *Juglans*, *Vitis* and *Triticum* survived until the 7th century AD based on radiocarbon dates. On the basis of this, we can conclude that agricultural activities with sub-Mediterranean characteristics of cereal production and horticulture developed at the end of the Iron Age and the beginning of the Imperial Age in this region. Communities having proper production experiences and engaged in the referred form of agriculture populated the study area until the second half of the 7th century after the Migration Period (*Figs. 2, 3*).

The pollen of *Juglans* and *Vitis* vanished from the section while the pollen of cerealia, though in a subordinate ration, but survived from the second half of the 7th century. According to this, an extremely dynamic change in the economy of the examined area can be assumed. The referred communities, having farming experiences with Submediterranean characteristics, and establishing quite dynamic environmental changes as well as farming records in the Imperial Age and operating a well developed farming system at the end of the late Iron Age, might have been driven out of the examined area. Based on radiocarbon data these transformations must have taken place between 604 and 673 AD (95% probability).

SUMMARY OF FINDINGS

Based on the collective evaluation of biotic and abiotic records a fairly complete history of the geological and environmental evolution of the area could have been drawn (*Table 2*). In the first phase at about 10-11 kya, a neo-tectonic basin developed giving the foundation of the emerging lacustrine system. The infilling of this catchment basin initiated even at this stage leading to the deposition of fluvial sands. The juvenile lake was surrounded by a coniferous woodland with stands of birch on the shores and an extensive reed belt. At around 10 ky BC a mesotrophic lake emerged and the gallery forest fringing the lake and dominated by pine, birch and hazel were replaced by woodlands dominated by hazel, elm and oak. The rate of silting-up was generally low during this period enabling the preservation of lacustrine conditions for a long time. The infilling of the basin was more rapid during the second half of the Neolithic as well as the Copper Age. This was the period when pollen taxa marking plant cultivation, stock farming first appeared in our catchment basin, and fluctuations in the concentrations refer to the emergence of increased agricultural activities in the surroundings of the Fenékpuszta Isthmus from this time onwards.

Lacustrine conditions were preserved till the beginning of the Bronze Age yet pronounced transformations in the surrounding vegetation could have been inferred attributable to human activities. Based on the long preservation of lacustrine conditions we may assume that the subsidence of the basin and the development of the general accommodation space must have kept pace with the rate of deposition for about 7000 years. This system and the fragile equilibrium was broken as a consequence of intensive human activities from the Neolithic onwards. As a result of these events, three major cycles could have been identified in the area in the form of alternating marshland and lacustrine conditions from the Middle Bronze Age to the Middle Ages. The alternating shifts among these stages are related to the natural succession of the marshland and resulted in distinct periods of lowstand and highstand in the basin. The first lowstand is observable at the end of the early Bronze Age and at the beginning of the middle Bronze Age, followed by a significant rise in the water level during the middle Bronze Age. The second cycle evolved during the late Bronze Age and Iron Age also characterized by successive lowstand and highstand conditions. The third cycle is connected to the period of the late Iron Age and Imperial Age. This third cycle is of outstanding importance in understanding the environmental history of the period of Great Migrations.

In this third cycle peat formation seem to have stabilized following an eutrophic lacustrine stage creating a stable marshland which survived from the Imperial Age through the Migration Period up to the Middle Ages. Besides peat formation, soil formation also took place in equilibrium creating marshland hydromorphic soils.

At the end of the late Iron Age and the beginning of the Imperial Era one of the most essential agricultural economies evolved, a Submediterranean type of crop cultivation and horticulture of wine and walnut. This form of agriculture appeared around 0 AD lasted until the 7th century AD in the area. Thus Roman type Submediterranean agricultural activities must have characterized the area during the Migration Period as well.

From the 7th century AD onwards there is a marked change in the pollen record, implying the abandonment of this former Submediterranean type of agriculture and the establishment of agricultural activities based on mainly stock farming during the 8-9th centuries AD. Data indicating resumed horticultural activities and crop cultivation could be inferred from the 10-11th centuries onwards in the area.

TEMPERATURE AND PRECIPITATION CONDITIONS OF THE LAST 2000 YEARS

As it can be seen on the climate reconstructions prepared on the basis of paleoecological data (*Fig. 3*), the first 400 years following the birth of Christ was characterized by temperatures above the average values for the past 2000 years. Then in the 5th and 6th centuries a pronounced cooling could have been inferred, which was followed by a warmer period again with temperatures higher than the average for about 500 years in the Carpathian Basin. Fluctuations in precipitation for the same period are characterized by much higher amplitudes than those inferred for the temperature. In the first 200 years precipitation was around the average of the past two millennia. The 3rd and 4th centuries AD are characterized by higher precipitation values with rates returning to near average in the 5th century. Another period of higher precipitation follows spanning the interval from the 6th to the 8th centuries.

If we compare these findings with records of grape, walnut and cereal production characterizing a Submediterranean type agricultural economies in the area (*Fig. 3*), it can be clearly observed that the presence or absence of these plants in layers from the Middle Ages and the Migration Period is independent of climatic fluctuations and are largely related to the production experiences of the referred societies. Water level fluctuations inferred from sedimentological and geochemical proxies talk about a different story (*Fig. 3*) According to sedimentological results, a highstand characterizing the Iron Age was followed by a continuous lowstand. The geochemical data is somewhat congruent with this picture with some minor differences. The Iron Age highstand is clearly observable in both records, but the general lowstand following was interrupted by a short phase of highstand between the 5th and 7th centuries AD in accordance with higher inferred precipitation rates.

According to our findings, lake level fluctuations inferred for the area of the Kis-Balaton can be correlated with those of the Alpine lakes (Magny 2003), while the evolution of the temperature record seems to be correlated with the fluctuations (Holzhauser et al. 2005) of Alpine glaciers. To sum up in one sentence, the climatic and environmental evolution of our site seems to follow that observed in the Eastern Alps for the past 2000 years. Thus making inferences about the climate of this region based on data from Central Asia is by no means accurate.

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ASSESSING TEMPERATURE SIGNAL IN X-RAY DENSITOMETRIC DATA OF NORWAY SPRUCE AND THE EARLIEST INSTRUMENTAL RECORD FROM THE SOUTHERN CARPATHIANS

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Abstract

Radiodensity data derived from Norway spruce were studied from a southern Carpathian site. Maximum density record showed significant positive relationship (r=0.59) with the growing season (April-September) air temperature and minimum density (MND) record showed clear and significant negative response (r=-0.41) to June-July mean air temperature. This significant MND response to climate is a novel result as traditionally this densitometric parameter was regarded not to carry any meaningful climatic signal. Derived temperature sensitive proxy records were compared to instrumental data of Sibiu (Nagyszeben/Hermannstadt) the oldest available regional station. Results of the running window correlation analysis pointed out notable inhomogeneities in the instrumental data before 1906. The Sibiu temperature series should be subjected to scrutiny revision to clean it from inhomogeneities.

Key words: maximum latewood density, minimum earlywood density, Picea abies, inhomogeneous instrumental temperature, dendroclimatology, Romania

INTRODUCTION

Norway spruce (*Picea abies* (L.) Karst.) is the main species of the Carpathian coniferous belt. Its longevity is documented to reach 576 years (Schweingruber F. H. – Wirth C. 2009). Norway spruce deserves special attention in the regional tree-ring research due to its importance from viewpoints of silviculture, dendroclimatology and dendroarchaeology. Several studies have been already conducted to decipher climatic information preserved in ring width variability of spruce in the Carpathians (e.g. Bednarz Z. et al. 1998-99, Szychowska-Krapiec E. 1998, Popa I. 2003, 2004, 2005, Savva Y. et al. 2006, Kaczka R. – Büntgen U. 2007, Kern Z. – Popa I. 2007, Popa I. – Kern Z. 2007, Bouriaud O. – Popa I. 2009), while other parameters were analysed solely in the Tatras (Büntgen U. et al, 2007). However, wood density data from spruce are also available from three eastern and the southern Carpathian sites. These sites were sampled in the frame of a global dendrochronological sampling campaign. These southern Carpathian stands were used to assess spatial teleconnections in the network (Schweingruber F. H. 1985) and in a broad scale dendroclimatological comparison (Schweingruber F. H. et al. 1987). Nevertheless, the climatic signal preserved in the radiodensity data has never ever been explored separately. The fact that Schweingruber F. H. (1985) defined an individual densitometric zone in the European coniferous belt centred on the southern Carpathians gives even further interest for the climatic interpretation of the southern Carpathian archive wood density data.

An additional motivation of this study was to test the earliest instrumental temperature record of the region (Ro-Sibiu/H-Nagyszeben/G-Hermannstadt) in order to see if its known inhomogeneities might be tracked comparing with climate sensitive proxy records. Curiosity emerged as proxy/data comparisons suggested biased early instrumental data for many sites in Europe (e.g. Moberg A. et al. 2003, Frank D. et al. 2007a, Winkler P. 2009), and corrections were recommended for some temperature data even before the 1900s.

MATERIAL AND METHODS

Radiodensity data

Wood density data originated from ITRDB database (Schweingruber F. H. 2000, NOAA 2009), from which database a southern Carpathian timberline site (45.30N, 23.67E, 1650 m a.s.l.) near Novaci in the Parang Mts (*Fig. 1*) was selected for this study. Sampled species was Norway spruce. The archive dataset contains 30 series of maximum and minimum density from 15 trees (each tree represented by two series). The wood density data were developed by the X-ray densitometric technique (Polge H. 1970, Schweingruber F. H. et al. 1978) in the framework of a global dendrochronological sampling network of conifers (Schweingruber F. H. 1985). Maximum and minimum density values are the characteristic parameters of the radial wood density structure. In a given tree ring the density maximum is linked to latewood and minimum is linked to earlywood (Schweingruber F. H. et al. 1978).

The Novaci dataset covers a 178-years long period, 1804-1981 AD, so despite its almost tridecadal antiquity it

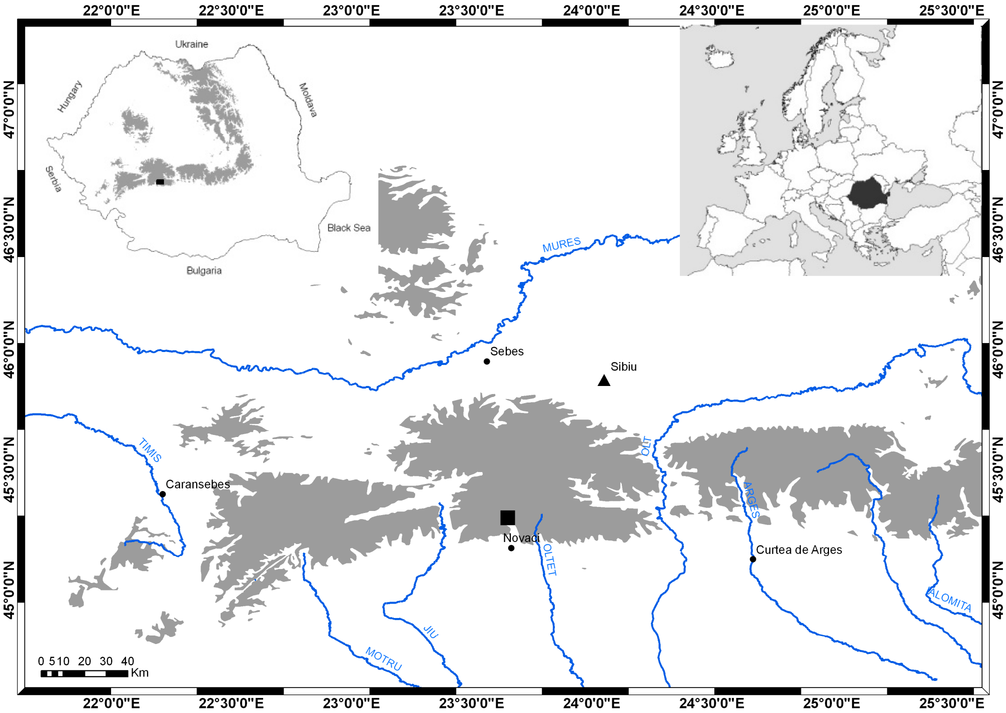

Fig. 1 Location of the sample site (filled square) and Sibiu (filled triangle) the earliest meteorological station of the region of southern Carpathians. Right corner: Location of Romania shown by black shading. Left corner: Black rectangle shows the location of the site in the southern Carpathians

is still the longest wood densitometric record from the entire eastern and southern Carpathian domain. Mean tree age is 88 years and ranges from 35 to 178 years. Replication decays before AD 1944 down to 4 at AD 1827 (*Fig. 2*). A sole series dates before AD 1821. Average maximum and minimum density of the population is 0.769 and 0.256 g/cm^3, respectively. Average maximum density value fits nicely in the range found for Norway spruce in the Tatras (Büntgen U. et al. 2007), but lower than the value reported from a Slovenian alpine spruce stand (Levanič T. et al. 2009). Average minimum density fits similarly well in the range presented for spruce in the Alps (Schweingruber F. H. et al. 1978).

Standardization, Index calculation

Raw density data were subjected to standardization procedure to eliminate non-climatic trends and emphasize climatic signal (Cook E. R. et al. 1990). A relatively stiff cubic spline function (50% frequency cut-off at 300yrs) was fitted to each individual series (Cook E. R. – Peters K. 1981). Raw density data were converted into index values as ratio between measured and modelled values. Final population indices for maximum density (MXD) and minimum density (MND) were computed as biweigth robust mean (Cook E. R. 1985). Variance of derived MXD and MND chronologies was adjusted to minimize bias due to changing sample replication (Osborn T. J. et al. 1997, Frank D. et al. 2007b). Stability of climate related signal preserved in the index series was controlled by the Expressed Population Signal (EPS) statistics applying the standard acceptance threshold of 0.85 (Wigley T. et al. 1984). Mean interseries correlation (Rbar) and EPS were calculated for 40 yrs moving window with 20 yrs steps. Standardization and index calculation procedure was carried out using the ARSTAN software (Cook E. R. – Krusic K. J. 2006).

Instrumental data

For climate response analysis monthly temperature means of grid-box enclosing the Novaci tree-ring site (*Fig. 1*) were extracted from the CRU TS2.1 database (Mitchell T. D. – Jones P. D. 2005) from 1901 to 1981.

The longest instrumental temperature record of the southern Carpathian region originates from Sibiu a prominent town of Transylvanian Saxons (*Fig. 1*). Observations at Sibiu began in 1851. Monthly mean temperature data since 1851 are available via the Climate Explorer (van Oldenborg G. J. et al. 2005). Sibiu is regarded as the most precise and most reliable temperature record in the region (Ţîştea D. at al. 1966). However, location of observation as well as termini and calculation method of daily mean temperature had changed a couple

Table 1 Recorded changes of observation conditions of the Sibiu/Nagyszeben/Hermanstadt station (source: Ţîştea D. et al. 1966). Row-head codes: A: date of change; B: location of observation; C: Termini (time of regular thermometer readings) and calculation method of daily mean temperature. Note the width of cell is not proportional with the duration of the represented period!

<table>
<tr><td>A</td><td>1851
January</td><td>1861</td><td>1880</td><td>1887
May</td><td>1897
August</td><td>1900
July</td><td>1905
October</td><td>1921</td><td>1940
September</td><td>1947
August</td></tr>
<tr><td>B</td><td>Weinanger platz 14</td><td>Saggasse 15</td><td>Elisabethgasse 9</td><td>Schiffbäumel 3</td><td>Langgasse 5</td><td>Reisbachgasse 9</td><td colspan="2">Webergasse 6</td><td>Strada Riului 5</td><td>Dimitri Anghel 3</td></tr>
<tr><td>C</td><td colspan="2">6-14-22
arithmetic mean</td><td colspan="5">7-14-21
arithmetic mean</td><td colspan="2">7-14-2*21
Kaemtz-method</td><td>8-14-20
Köppen-formula</td></tr>
</table>

of times during the station's history (*Table 1*). For instance, daily and inherently monthly mean temperatures are positively biased by the (T7+T14+T21)/3 calculation method compared to (T7+T14+2*T21)/4, the so-called Kaemtz-method (see Dall'Amico M. – Hornsteiner M. 2006). Nevertheless mean temperatures are obviously suffering negative bias due to the earlier morning (6 vs. 7 a.m.) and the later evening (22 vs. 21 p.m.) readings before 1880.

Climatic signal analysis

Pearson's correlation coefficients have been computed between MXD, MND and gridded monthly mean air temperature to assess the temperature effect of each month on the annual radiodensitometric characteristics of spruce. Months from the June of the previous year to October of current year of tree-ring formation were involved in the analysis. After the first trial, bimonthly means of August-September (AS) for MXD and June-July (JJ) for MND were also invoked. In addition, the April-September (AMJJAS) mean temperature was also included into the MXD comparison. Correlation coefficients were compared to 95% significance level derived from Student's t-test to evaluate their importance. Investigation was restricted to the period after 1906, because the first five years were designated as biased instrumental data (see later).

Temporal stability of relation between MXD/MND and Sibiu record was investigated by running correlation computed in 21-year moving windows. Moving window correlation technique is a standard tool to trace temporal stability in proxy-climate correlations (Aykroyd R. G. et al. 2001). The choice of any window width is somewhat arbitrary but the applied 21-year window over the screened 130-year long period is an acceptable compromise between a very narrow window (with a higher sampling error) and boarder window (which approximate the behaviour of the full dataset) (Aykroyd R. G. et al. 2001) and it is in conformity with choice of similar dendroecological studies (e.g. Carrer M. et al. 2007, Friedrichs D. A. et al. 2009). Timing of detected unusual shifts was compared to events in station history.

RESULTS AND DISCUSSION

Novaci spruce MXD and MND record

Both density indices (*Fig. 2a*) preserve quite strong common signal as evidenced by the high and stable signal strength statistics. Mean Rbar (EPS) is 0.44 (0.95) and 0.27 (0.91) for MXD and MND, respectively. Same statistics calculated in moving windows (*Fig. 2b,c*) showed exceptional signal stability and present that the relatively higher values found in mean values for MXD is permanently valid through the entire studied period. EPS values exceed the 0.85 threshold level suggesting robust chronology for both radiodensitometric parameters. The correlation between MXD and MND is 0.02, indicating that independent environmental information is preserved in the proxies. Wimmer R. and Grabner M. (2000) also found that in a spruce stand the density measured in earlywood (e.g. MND) were widely independent from latewood, suggesting that they are not under the same control.

Relationship between temperature and maximum/minimum density of spruce wood

In the case of MXD, August and September yielded the largest coefficients among monthly means 0.56 and 0.39, respectively (*Fig. 3a*). These findings broadly agree with the previous observations carried out at various sites in the Carpathians (Schweingruber F. H. et al. 1987). However, comparison with April, May and June showed also significant positive coefficients. The coefficient of July has not reached the 95% significance level but still positive and exceeds the other monthly responses. Regarding AS bimonthly mean temperature the coefficient slightly improved, and the multi-monthly AMJJAS presented even bit higher coefficient (0.59). The latter one was found as the optimal target season corresponding to the climate information of spruce MXD in the Tatras (Büntgen U. et al. 2007) and in the Alps (Frank D. – Esper J. 2005). The weakened mid-summer temperature response seems to be a characteristic pattern of the spruce MXD response. Both for the Alps and Tatras June coefficient dropped below 95% significance level (Frank D. – Esper J. 2005, Büntgen U. et al. 2007). In the case of the southern Carpathian spruce MXD chronology a bit different pattern was found. June coefficient is significant while for July it showed low values.

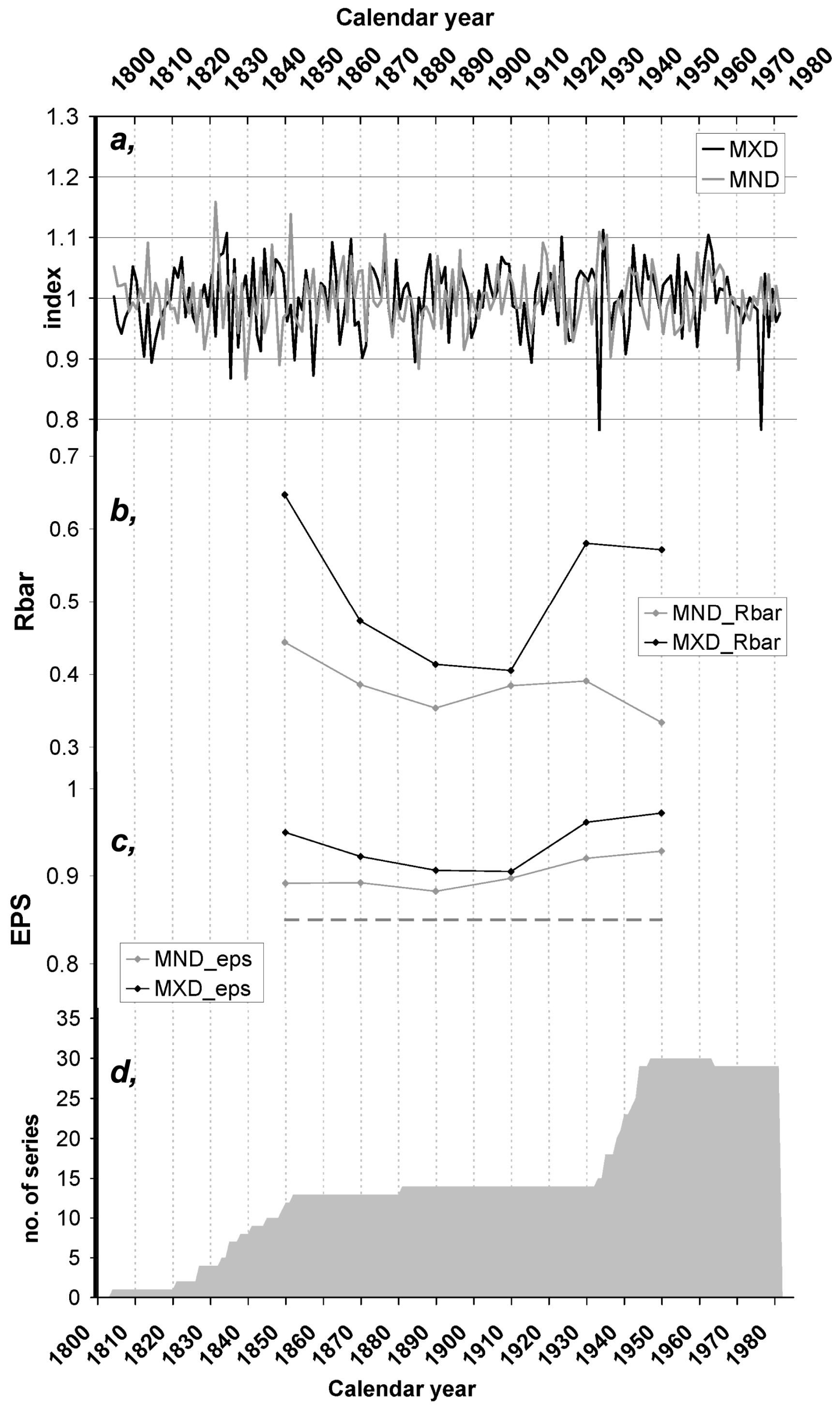

Fig. 2 Radiodensitometric chronologies of spruce from Novaci and graphical illustration of signal strength statistics calculated for 40 yrs moving window with 20 yrs steps, where black (grey) curves and symbols show MXD (MND) records. a: indices of maximum (MXD) and minimum (MND) density;. b: interseries correlation (Rbar); c: expressed population signal (EPS). Dashed horizontal line denotes the 0.85 threshold level; d: sample depth

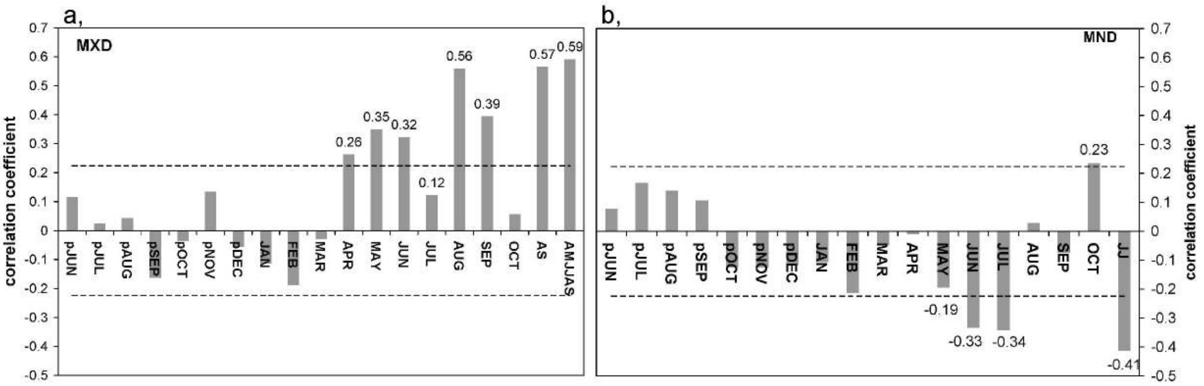

Fig. 3 Columns indicate the Pearson's correlation coefficients computed between monthly and multi-monthly mean air temperatures and maximum (a) and minimum (b) density indices over the 1906-1981 interval. Few coefficients are given near to the corresponding column. Horizontal dashed lines denote the 95% significance level

Interesting to note that in a recent study on two Slovenian spruce stands reported September mean temperature as the main climatic driver of cell wall thickening (Levanič T. et al. 2009). This discrepancy between the Slovenian and south Carpathian spruce MXD responses, however, can be easily explained as the growing season at the more temperate Slovenian sites is longer compared to the more continental southern Carpathian timberline. The shorter vegetation period means earlier cell maturation as well.

None months from the year before tree-ring growth showed significant effect on cell wall thickening during the subsequent year. This lack of responses from the year preceding the growth is normal for the MXD (Schweingruber F. H. et al. 1987).

In the case of MND June and July showed the strongest results -0.33 and -0.34, respectively (*Fig. 3b*). Regarding JJ bimonthly mean temperature the correlation further improved (-0.41). May mean temperature yielded similarly negative coefficient albeit it slightly lags behind the 95% significance level. This response is especially exciting as the pioneer milestone study of radiodensitometric dendroclimatology conducted in the Alps (Schweingruber F. H. et al. 1978) experienced no any clear relationship between this densitometric parameter of spruce and climate variables, consequently MND was usually neglected in later researches. A sole exception is the study of Wimmer R. and Grabner M. (2000) from the following 30 years. They analysed 16 anatomical variables (including also MND and MXD) averaged from 20 Norway spruce trees over a relatively short, 40-year long, tree-ring sequence. They found poor climatic response in MND.

However the neglected potential of MND as climate archive can be emphasized referring to a very recent study. Grabner M. et al. (2009) investigated MND record

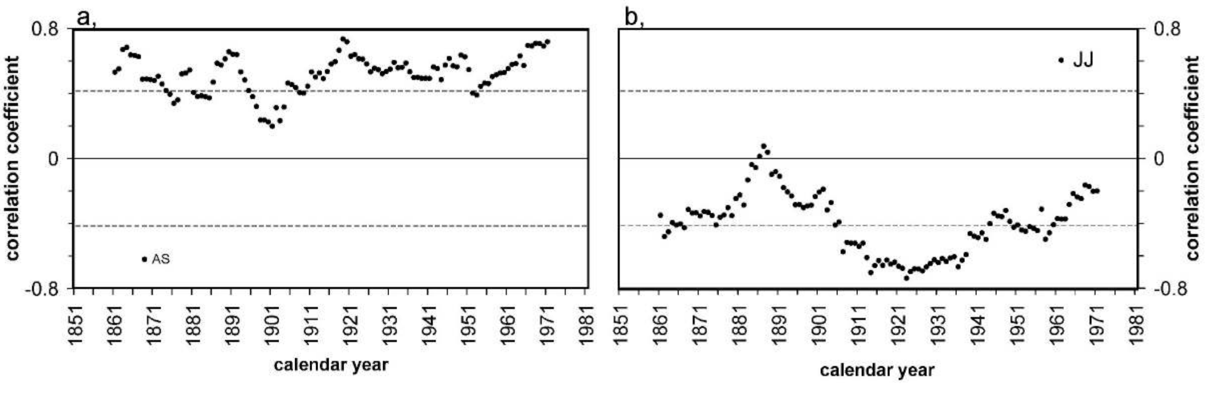

Fig. 4 Fluctuation of coefficients of 21yrs moving window correlation computed between radiodensitometric indices of Novaci spruce samples and their optimal bimonthly temperature target from the Sibiu record. a: maximum density vs. AS, b: minimum density vs. JJ. Dashed horizontal lines denote the 95% significance levels

in a dataset of juvenile spruce stands. Surprisingly they found stronger correlation between MND and climate variables than with MXD.

Statistical results suggest that dominantly June-July thermal conditions determine the minimum earlywood density of spruce tree ring in the southern Carpathians. Higher June-July air temperature seems to retain cell wall thickening and/or to produce larger lumen diameter in the earlywood. May also has some minor role in this process. We propose that only the late half of May preceding June affects the process, and the corresponding coefficient become non-significant as the monthly means integrates also the daily temperatures from the early half of the month.

The relatively high positive coefficient of October lacks explanation as cell maturation in the earlywood section is probably ceased for mid-autumn. Even more, it might be a fake response due to biased instrumental reference (see later).

Comparison with the earliest local instrumental temperature record

For the sake of brevity out of the many prepared moving window correlation (hereafter MWC) analyses only a few arbitrary selected graphs are presented. They were chosen to best illustrate our conclusion.

Fig. 4 shows the temporal fluctuation of the correlation coefficient calculated with the optimal bimonthly mean temperature target of both radiodensitometric parameters (i.e. AS vs. MXD; JJ vs. MND). Although MND lost significance in the last decade, coefficients generally exceed the significance levels over the last seven decades. In contrast, coefficients of both densitometric parameters drop below significance level at 1905-1906. The coefficients reach significance level again before 1896 and 1880 for MXD and MND, respectively. Each date can be found in the station movement history. This suggests that between 1880 and 1905, when the location of observation frequently changed settling in one place, as short as 3 to 9 years homogeneity of observation conditions were failed to maintain. As gridded temperature data largely relies on Sibiu record before 1920 in the region, this is the reason why the proxy/climate relationship was finally analysed on the truncated record from 1906.

Coefficients of MWC calculated between MXD and April monthly mean temperature are presented in *Fig. 5a*. Coefficients are well above significance level during the early decades, they start to decline from 1880, and sink permanently below significance level from 1886. They fluctuate around zero level over few decades, afterwards abruptly increase from 1922, and exceed the significance level from 1924. The period of weakened even more non-significant coefficients coincide with the era of T07-T12-T21 readings, but also include the hectic station movements. The date of sudden recovery of positive correlation relationship coincides with the introduction of Kaemtz-method. The last sudden drop from 1943 to 1944 is a sole event which is not mirrored in station history. However, its time is equally near to a station movement (i.e. 1940) and a methodological change (introduction of Köppen-formula) which was accompanied with station movement, as well.

MWCs calculated between MND and May and October monthly mean temperatures are presented in *Fig. 5b*. Temporal evolution of MWC coefficients show strange shifts again. May coefficients fluctuate slightly below the 95% significance level through the main part of the studied period. Some decline can be seen during the last decade but a very unusual drift appears at the earliest time. Coefficients steadily increase before 1883,

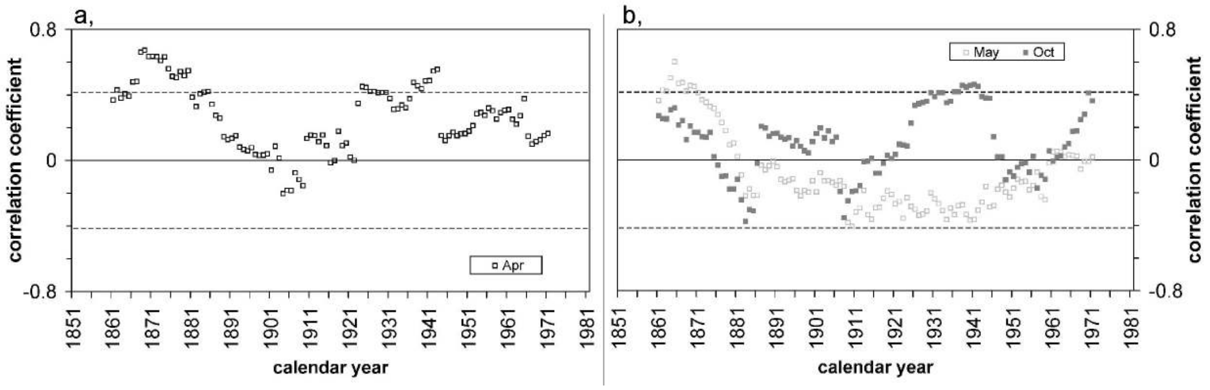

Fig. 5 Fluctuation of coefficients of 21yrs moving window correlation computed between radiodensitometric indices of Novaci spruce samples, and a few arbitrary chosen monthly mean temperature targets from the Sibiu record. a: maximum density vs. April, b: minimum density vs. May (open squares) and October (filled squares). Dashed horizontal lines denote the 95% significance levels

change sign at 1881, and become significant before 1878. The period of unusual positive coefficients broadly coincides with the era of T06-T12-T22 readings. October coefficients show more sudden changes. The first from 1886 to 1887 when coefficients change from negative to positive, and the second after 1906 when swap sign again. Both date link to station movement. The coefficients are close to zero for a decade, then start a gradually rise from 1921, and abruptly jump to significance level after 1925. Coefficients fluctuate around significance level until 1946, after drop suddenly to zero level. The period of positive, occasionally even significant, MWC coefficients of October coincides with the utilization of the aforementioned Kaemtz-method. We suspect that the found positive response to October mean temperature might be the effect of the Kaemtz-method.

CONCLUSIONS

Climatic information was evaluated for archive Norway spruce maximum and minimum radiodensity data from a southern Carpathian location. Spruce MXD record showed significant positive relationship with the growing season (May-September) air temperature. Similar response was found for the same species in the Tatras and the Alps. However, some characteristic discrepancy was also experienced (i.e. July vs. June signal weakening). The southern Carpathian MXD response showed distinct difference compared to the Slovenian one, too (i.e. strongest reaction for August vs. September). These small differences compared to surrounding areas could plausibly explain the existence of the individual densitometric provenance defined by Schweingruber F. H. (1985) for the southern Carpathians.

Spruce MND record showed clear and significant negative response to June-July mean air temperature. This is a novel result as traditionally this densitometric parameter was regarded not to carry any meaningful temperature signal.

Hitherto dendroclimatological research focused exclusively on radial growth properties in the southern Carpathians (e.g. Soran V. et al. 1981, Popa I. – Cheval S. 2007, Kaczka R. – Büntgen U. 2007). In the present study, however, we point out that densitometric properties have also great potential both in ecological and palaeoclimate reconstructions, and future researches are recommended in this field.

Derived temperature sensitive proxy records were compared to instrumental data of the oldest available regional station. Results of the moving window correlation analysis showed strange shifts coinciding with changes in station history. Considerable inhomogeneities can be suspected in the instrumental data before 1906. The Sibiu temperature record would have eminent importance in the regional historical climatology due to its completeness and exceptional length. Nevertheless, this prominent secular record is hardly usable as temperature target in regional proxy paleoclimatological research until a scrutiny revision is done.

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DOCUMENTARY EVIDENCE ON WEATHER CONDITIONS AND A POSSIBLE CRISIS IN 1315-1317: CASE STUDY FROM THE CARPATHIAN BASIN

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Abstract

In the last decades, climate variabilites of the fourteenth century gained great interest and became a subject of numerous research papers. Due to the relative lack of sources referring to the climate of the Carpathian Basin, merely based on written evidences continuous climate reconstruction of the period is not possible. Nevertheless, there are cases when, due to available contemporary evidence, still some conclusions can be drawn. In this paper an investigation is carried out on one specific environmental crisis characterized by several flood events of European rivers caused by repeated abundant rainfalls; moreover, summer and winter temperatures were lower than the average of the preceding century. As a result of unfavorable environmental and economic conditions, a great number of Western and Central European sources reported on famines caused by the destruction of cereals. Mainly based on Austrian and Czech narratives as well as Hungarian charters, in the present paper an attempt was made to collect all the available sources on prevailing weather conditions and their possible effects in the Hungarian Kingdom mainly referring to the period of 1315-1317.

Key words: climate variability, environmental crisis, weather events, floods, documentary evidence

WEATHER CONDITIONS IN THE 14TH CENTURY

Climatic conditions of the Middle Ages is a subject of several research papers, either as long-term investigations (e.g. Brázdil R. – Kotyza O. 1995, Pfister C. et al. 1998, Glaser R. 2001, Shabalova M. V. – Van Engelen A. F. V. 2003) or in the form of case studies on extremes events (e.g. Kiss A. 2003, Rohr C. 2005). Being already a part of the Little Ice Age, the 14th century is still considered as a transitional period between the Medieval Warm Epoch and the Little Ice Age, and this period poses several questions concerning variabilities of climate. A number of investigations pointed out that during this century temperatures in Western and Central Europe started to decrease (e.g. Lamb H. H. 1988, Pfister C. et al. 1996, Pfister C. et al. 1998, Yan Z. et al. 1999). In the Alps, the Aletsch Glacier started to advance from the 1120s and reached its maxima at around 1350 (Holzhauser H. 1997) which can be related to the decrease of temperature in the Alps from the second half of the 12th century to the 14th century. Climatic changes in the Czech lands are more questionable, since it is not possible to provide clear evidence on such phenomena in the first decades of the century (Brázdil R. – Kotyza O. 1995).

In this period temperature decreased and also wet years became more frequent, especially in the Western European territories. In Central and Eastern Europe there is no definite evidence for precipitation increase. For example, climate research of the Czech lands did not show an increase of precipitation during the 14th century (Brázdil R. – Kotyza O. 1995). Nevertheless, water-level increase was detected in the mines of Goslar (in Germany) and Iglau (today Jihlava in Czech Republic) (Steensburg A. 1951). Investigations on the Great Eastern European Plain pointed out a drier period (Lamb H. H. 1982). However, the water level of the Caspian Sea was several meters higher than nowadays (Gumilëv L. N. 1968), which does not reinforce the theory of a drier period in Eastern Europe.

From the 13th century the number of climatic extremes increased in Western Europe and so did the number of sea floods in the Northwestern European region (Lamb H. H. 1995). On the other hand, Central European investigations do not provide evidence on an increasing number of climatic extremes in the first half of the 14th century (Brázdil R. – Kotyza O. 1995).

Therefore, the weather of Western Europe was cooler and wetter than in the previous centuries. Weather conditions of Europe started to change and it had an effect on the food supply of the European population. During the 14th century crop prices increased (Le Roy Ladurie E. 2004, Pustil'nik L. A. – Yom-Din G. 2004) and in the years of the famine (1315-1317) the price of cereals were extremely high (Lucas H. 1930).

CONSEQUENCES OF EXTREME WEATHER IN EUROPE BETWEEN 1315 AND 1317

The second decade of the 14th century gained special attention among climate scientists. The 1310s was the decade in which "years without summer" occurred (Pfister C. 1992). In the mid-1310s a serious famine took place all over Europe (Jordan W. C. 1996). In England, for example, unfavorable weather conditions started from 1314 with precipitation increase and temperature decrease, whereas prices were so high that in 1315 the king had to fix the maximum price of ale and meat (Kershaw I. 1973). In France, continuous rains started in May 1315. Due to great abundance of rains, cereals could not come to maturity and food shortage caused serious famine. There was no vintage in 1315, and the price of wine was high in 1316 (Alexandre P. 1987). According to Emmanuel Le Roy Ladurie (2004), in 1316 three million people died partly because of the lack of food. Same weather conditions and problems occurred in the Netherlands: the years of 1315-1317 were wet and serious famine occurred in Ypres and Bruges (Le Roy Ladurie E. 2004, 2006).

In the Mediterranean, historical records also indicate floods mainly in Northern Italy, in the area of Parma and Modena (Alexandre P. 1987). Historical records of the Iberian Peninsula are not yet published, but a dendroclimatological research indicates warmer period in the first half of the 14th century than in the preceding decades (Büntgen U. at al. 2008).

Table 1 Floods of rivers in the surroundings of Hungary between 1315 and 1317

Year	*Month*	*Source*	*Place*	*Flood of River*
1315	September	Chron. de gest. prin. MGH SS rer. Germ. Vol. 19. 84.	-	rivers in Austria
1315	After 25 July	Chron. Aul. Reg. 365.	Czech Kingdom	Rivers in Bohemia and Moravia
1316	23, 24, 28 June	Cont. Canon. S. Rud. Salis. 822.	-	Triplex flood of the Danube
1316	28 June	Ann. Burgh. MGH SS Vol. 24. 62.	-	Danube
1316	-	Anon. Leob. Chron. 33-34.	Austria, Hungary	Danube and Mura rivers
1316	-	Anon. Leob. Chron. 33.	Werfen, Austria	Salzach river
1316	-	Chron. Austr. 241.	-	Danube
1316	-	Ann. Mellic. Cont. Zwetl. Ter. 659.	-	Danube and its tributaries
1316	-	Mart. Meist. Ann. Gorl. 8.		Neisse river
1316	-	Chron. Aul. Reg. 379.	Czech Kingdom, Austria	Floods
1317	-	Ann. Zwetl. 681.	-	Danube and its tributaries
1317	-	Ann. Mellic. Cont. Zwetl. Ter. 666.	Czech Kingdom, Austria, Hungary	Danube

Records are as well available related to the German territories: annals and other narrative sources inform about flood events and extreme weather conditions from Bavaria to Estonia (Glaser R. 2001, Alexandre P. 1987). Besides the historical records dendroclimatologic data from the valley of the Rhine also supports the theory of the consecutive wet years (Le Roy Ladurie E. 2003).

EVIDENCE REFERRING TO SURROUNDING AREAS

Historical records from Austria and the other neighboring territories of the Carpathian Basin are very important in the light of the fact that narrative sources and annals from the Hungarian Kingdom are rare in the Middle Ages. In Austria, investigations were carried out based on historical records (Pautsch E. 1953, Rohr C. 2005, 2007), which provide further evidence to a possible comparison. It is interesting to note that according to some investigations based on O_{18} content of stalagmite records, summer temperatures in this period (Mangini A. et al. 2005) were not lower than in the preceding centuries. Nevertheless, according to Pfister (1996) winter temperatures were in the decade of the famine 1.7°C lower in the region of the Alpes than nowadays. Moreover, a number of annals and chronicles mention floods on the rivers of Austria in 1315, 1316 and 1317 (Table 1). From the Czech lands data are available on dry weather conditions before 25 July 1315; however, after this time chroniclers reported on great floods and famine (Chron. Aul. Reg. 365.) which continued in 1316. The same chronicle mentions bad harvest in 1317.

In the western neighborhood of Hungary, in Austria and the Czech lands these three years were rich in flood events. Record on famine is as well available referring to Austria, the Czech Kingdom and as well to Poland (Ann. Cist. in Hein. 546.). Fluctuation of crop prices in the 1310s also reflects unfavorable weather conditions (Table 2).

As a conclusion we can say that, similarly to Western Europe, in the neighbouring countries west and north to Hungary, presumably connected to weather conditions, floods and famine occurred, negatively affecting local population occurred in 1315-1317.

Table 2 Corn prices in the 1310s in the countries surrounding Hungary

Date	*Place*	*Barley (hordeum)*	*Wheat (triticum)*	*Wheat (siligineus)*	*Oat (avena)*	*Conditions*	*Source*
1312	Zwetl	70 denarius	½ talentum	3 solidus and 15 denarius	60 de-narius	On the 26th of March.	Cont. Zwetl. Ter.
1312	Morvavia	--	30 grossi of Prague	--	--	After bad harvest	Chron. Aul. Reg.
1312	Zwetl	--	10 talentum	--	--	Around Easter	Ann. Zwetl.
1312	Mattsee	--	--	3 solidus	60 de-narius	Serious fam-ine	Ann. Mat.
1312	Austria	60 denarius	4 solidus	3 solidus	60 de-narius	Famine	Chron. Austr.
1313	Zwetl	--	6 denarius	4 denarius	--	Good harvest	Ann. Zwetl.
1313	Zwetl	4 denarius	6 denarius	4 denarius	4 de-narius	Good harvest, cheapness	Cont. Zwetl. Ter.
1313	Salzburg	--	3 solidus and 2 denarius	--	--	At Easter	Cont. Can. S. Rud. Salis.
1317	Salzburg	--	--	5 denarius	--	Famine	Cont. Can. S. Rud. Salis.
1317	Burghausen	--	--	--	--	Great famine	Ann. Burgh.
1319	Prague	--	--	1 grossi of Prague	--	Low prices after good harvest,	Chron. Aul. Reg.

INFORMATION ON CLIMATE OF HUNGARY IN THE EARLY 14TH CENTURY

Referring either historical or present Hungary, due to relative scarcity of available contemporary written evidence, research on climatic conditions as well have to rely ont he results of natural scientific research and archaeological investigations. Some studies in the field of archaeological research suggest that a drier period prevailed in the 13th century. However, it is very probable that the climatic conditions of Hungary started to change in the beginning of the 14th century and the climate became wetter in these decades (Rácz L. 2006).

It is, however, a general problem of natural scientific and archaeological research that in most cases changes can be detected, but it is difficult to differentiate the main reasons: it is uncertain whether mainly human impact or a possible climate change is more responsible for the changes. This question arises, for example, in current results of sand-dune research or waterlevel-change investigations of larger lakes of the Carpathian Basin. Sand-dune studies, for example, referring to the Danube-Tisza Interfluve indicate sand-movement in the first half of the 14th century (Kiss T. et al. 2005). Investigations on the main water-level tendencies of Lake Balaton pointed out that the water level had an increasing trend during the 14th century (Sági K. 1968, Kiss A. 1999b). Geoarchaeological investigations show a cooling period in the 14th century (Sümegi P. et al. 2005). A 1000-year dendroclimatological reconstruction is as well available on summer temperatures, referring to the Eastern Carpathians (Romania), which show cool years around 1300; however, this research points out hot summers in the 1310s (Popa I. – Kern Z. 2008). Nevertheless, due to the location of sample site, this reconstruction might not completely refer to the conditions of the Carpathian Basin in general, and the influence of more easterly areas should be as well considered. Thus, based on the presently available information, only a rather mosiac picture can be drawn. It is, however, appear rather clearly that a general change in environmental conditions can be detected in the early 14th century Hungary.

Concerning contemporary documentary evidence of Hungary, some investigations were already carried out referring to weather conditions of the 1310s in Hungary (Kiss A. 1999a). Moreover, a case study on the comparison of conditions between western Europe and Hungary in the mid-1310s suggested that, unlike west and north to us, no traces of a major crisis in 1315-1317 occurred in the Hungarian kingdom (Szántó R. 2005). Nevertheless, according to our opinion a deeper comparison of contemporary evidence of the neighbouring areas, as well as some additional, newly investigated domestic evidence can provide a not only slightly different, but clearly more detailed picture of what happened in the Carpathian Basin in the years of 1315-1317.

WEATHER-RELATED DOCUMENTARY EVIDENCE IN HUNGARY: 1315-1317

Largest number of contemporary evidence can be investigated first in the summary (regesta) collection of the Angevin Chartulary (An. Okl. Vol. I–XIV.), in which all presently available charter evidence of the reference period in Hungary are listed. Thus, the basis of our investigation was not only the years of 1315-1317, but a wider time-scale, namely the period of 1301-1330. it is due to the fact that, as we will see, clear evidence referring to the investigated period is available in charters issued after 1317. Apart from Hungarian charters, annals and chronicles of neighbouring countries were also examined (Table III and Fig 1). Despite the fact that only a low number of weather-related data is available concerning the first decades of the 14th century, some of the evidence provide interesting information. For example, one charter evidence (DL 63093) dated to 1309, referring to the village of Lehatha (today Horná Mičiná in Slovakia), reports on frequent previous flood events of the Garam (today Hron in Slovakia) river, which might show some connections to the increase of flood frequency in the period around 1300 occurred in Western Europe.

A charter from 1343 (DL 71639), transcribes another document from 1312 that is important for highlighting the food supply in the 1310s. The charter is seemingly a simple document which puts an issue in the sale of an estate on paper. The estate which is sold in this charter is called Pethunye (Petenia, Romania), but what has to be emphasized here is that the reason for selling one sixth of this estate complex was supposed shortages in the near future. The charter was issued on 25 June, 1312, exactly the period of the usual date of the grain harvest, which indicates that the harvest was very poor. It does not mean that the harvest was poor over a broader region as the charter does not specify the reason for the supposed shortage or food supply in the coming year, but it is possible that it was due to weather conditions.

A chronicle on the history of Szepesség (today Spiš-region in Slovakia) compiled in the 17th century by Caspar Hain (Hain G. 1910-1913), partly based on the local archival evidence, indicates a famine during three years around 1312 and mentions that cannibalism might have been present among the population. According to, for example, Lucas (1930) this phenomenon was not unique in time of famines but in this case it could as well be the vivid imagination of a 17th century author. In spite of probable exaggerations and the fact that it is not a contemporary source, this chronicle can have a great importance from our point of view. The author of this chronicle was the mayor of Lőcse/Leutscha (today Levoča in Slovakia) and thus, had an easy access to the town archives. Some of his reference suggest that he was familiar with, by now lost, medieval narratives, and thus, his descriptions about medieval period should be as well have to be considered (Hain G. 1910-1913). Thus, it is quite probable that Caspar Hain had access to reports referring to the early 14th-century famine. Thus, it is quite probable that some time in the early or mid-1310s a famine took place in Hungary. Although Hain dates this event to three years around and after 1312, but he also adds that the exact date is not sure (Hain G. 1910-1913).

Table 3 Weather related events in Hungary 1315-1317

No.	*Year*	*Day, Month*	*Source*	*Place*	*Event*
1	1309	-	DL 63903.	Lehotka (Slovakia)	Frequent floods of river Garam
2	1312	25 June (date of issue)	DL 71639	Petenia (Romania)	Presumed food shortage in the future
3	1312	-	Hain G. 13	Szepesség (Slovakia)	Serious famine in Hungary, cannibalism
4	1316	-	Anon. Leob. Chron. 33-34	Hungary	Serious floods
5	1316	-	Chron. Aul. Reg. 379	Hungary	Serious floods caused by continuous rains, unusual weather
6	1317	24 February (date of issue)	DL 1884.	Sava valley (Croatia)	Hard conditions because of winter
7	1317	-	Ann. Mellic. 511.	Hungary	Floods of rivers
8	1318	-	DL 50333	Keserű (Romania)	Serious famine in the past

Concerning 1315, no direct evidence is available related to weather events of the Hungarian Kingdom. Thus, it is yet uncertain whether or not abundant precipitation and floods, occurred from England through France to Austria, reached the Carpathian Basin. However, contrary to 1315, some source evidence is available about the next year, 1316. The *Anonymus Leobiensis Chronicon* informs about serious floods destroying villages along the

Danube in Austria and Hungary. The *Chronicon Aulae Regiae* (Bohemia) reports on succeeding unusual weather events, and floods caused by continuous rains. Thus, in this year not only the precipitation was greater than usual, but the number of weather extremes as well increased in the areas west to us.

Serious flood of River Mura was reported in 1316, which probably as well reached Hungary (Anon. Leob. Chron. 33-34). In the same period, King Charles Robert passed the Drava river (takes the water of river Mura) with his army and we do not have any source reporting on difficulties. Based on this we cannot state that this flood undoubtedly reached and caused problems in Hungary.

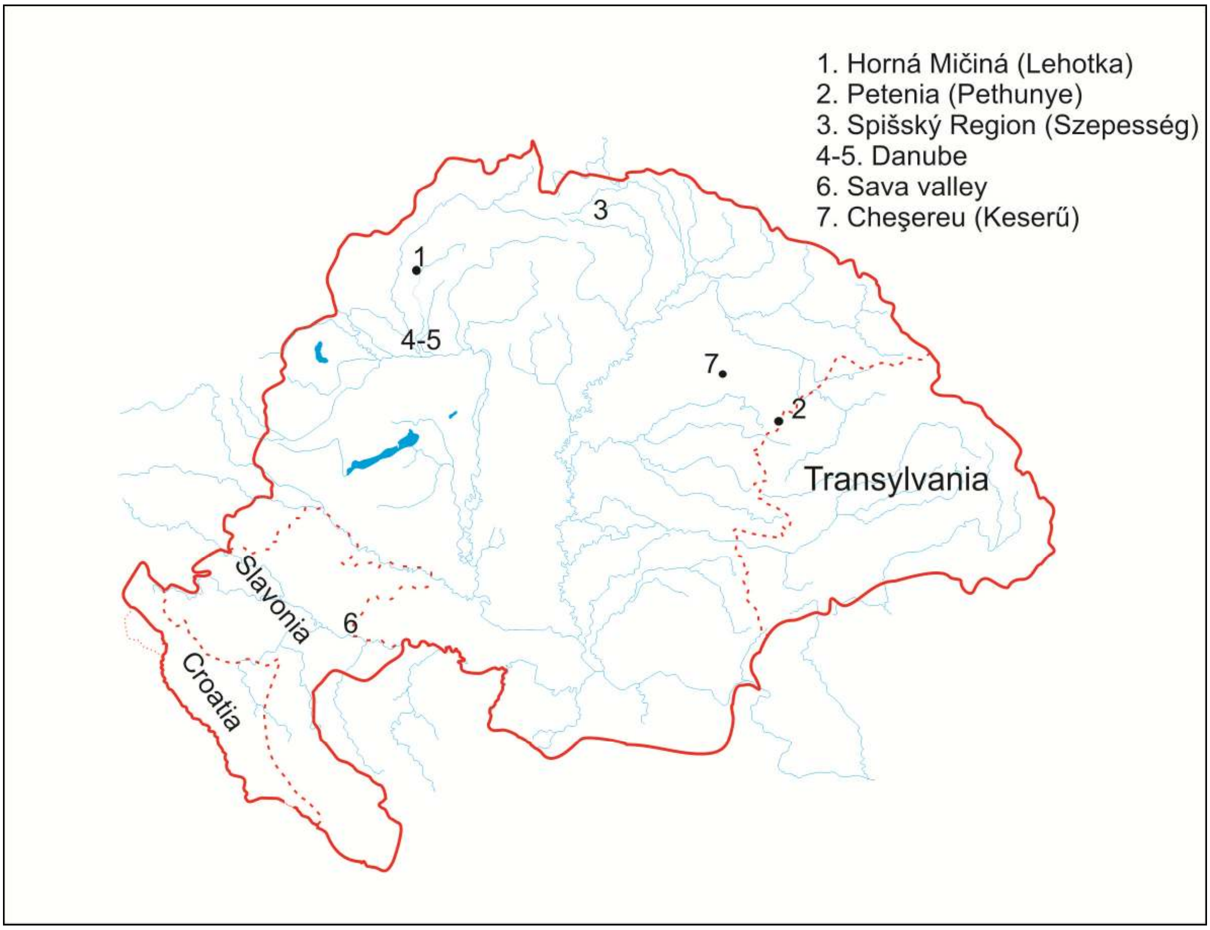

Fig. 1 Geographic names in medieval Hungary, referred in the article

A charter written in 1323 (DL 1884) transcripts the text of another charter dating back to 24 February 1317 provide evidence on the great difficulties of the royal army when, caused by hard winter conditions, they crossed the Sava river. As no more details are available, no clear statement can be provided on the actual weather conditions disturbing the army from crossing the Sava river. Nevertheless, the winter of 1317 was, according to the *Chronicon Aulae Regiae*, extremely long and cold (lasted until 28 March) in the Czech lands. Thus, there is a high probability that the winter of 1317 was also colder than usual in Hungary. However, a deeply frozen Sava river in itself would have allowed an easier pass to the king's army.

The last data to be discussed here is a, dated to 1318 (DL 50333). The charter mentions a certain Stephen who gave proof of his charity when he helped his family during a time of serious famine. This is the only unquestionable contemporary written evidence from the Carpathian Basin which refers to famine in the preceding period. It does not specify when the famine took place, but the charter is a continuation of another document dating back to 1311, which means the famine mentioned in the charter took place some time between 1311 and 1318. The charter from 1318 was issued by the monastery of

Várad (Oradea, Romania) concerning an estate called Keserű (Cheşereu, Romania). Seemingly, there was a famine in that region, which does not mean that it touched the whole country. However, the fact that the scribe did not specify which famine the charter refers to may indicate that it was a well known event and affected a broader geographical area.

Even if only a few written evidence is available related to a famine and possible environmental crisis of the mid-1310s (see *Fig 1*), these sources provide clear evidence that the crisis, mainly in the form of high prices and famine indeed reached Hungary.

CONCLUSION

Great parts of Europe were clearly affected by the weather anomaly of the mid-1310s. As a result, great famine occurred in western and central Europe. Crisis clearly affected territories in the immediate neghbourhood: unfavourable weather conditions and famine occurred in Austria, the Czech lands and Poland. Whereas some case studies suggested that no contemporary information can support the idea that crisis also reached Hungary in 1315-1317, it seems that some contemporary charters indeed suggest that signs of the same crisis and famine were present and caused problems in different parts of contemporary Hungary.

Acknowledgements

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ABBREVIATIONS OF PRIMARY SOURCES

An. Okl. = Anjou-kori oklevéltár. Documenta res Hungaricas tempore regnum Andegavensium Illustrantia. Vol. I–XIV. Ed.: Almási T. – Blazovich L. – Géczi L. – Kőfalvi T. – Kristó Gy. Szeged – Budapest: JATE, 1990-2004

Ann. Burgh. = Annales Burghausenses. In: Pertz G. H. (ed.) Monumenta Germaniae Historica. Scriptores. XXIV. Hannoverae: Hahn, 1866. pp. 61-62

Ann. Cist. in Hein. = Annales Cisterciensium in Heinrichow. In: Pertz G. H. (ed.) Monumenta Germaniae Historica. Scriptores. XIX. Hannoverae: Hahn, 1866. pp. 543-547

Ann. Mat. = Annales Matseenses. In: Pertz, G. H.: Monumenta Germaniae Historica. Scriptores. IX. Hannoverae: Hahn, 1851. pp. 823-835

Annales Mellic. = Annales Mellicenses. In: Pertz G. H.: Monumenta Germaniae Historica. Scriptores. IX. Hannoverae: Hahn, 1851. pp. 480-501

Ann. Mellic. Cont. Zwetl. Ter. = Annales Mellicenses Continuatio Zwetlensis Tertia. In: Pertz G. H.: Monumenta Germaniae Historica. Scriptores. IX. Hannoverae: Hahn, 1851. pp. 654-669

Ann. Zwetl. = Annales Zwetlenses. In: In: Pertz G. H.: Monumenta Germaniae Historica. Scriptores. IX. Hannoverae: Hahn, 1851. pp. 677-684

Anon. Leob. Chron. = Anonymus Leobiensis chronicon. Ed.: Zahn J. Graz: Leuschner & Lubensky, 1865

Chron. Aul. Reg. = Chronicon Aulae Regiae. In: Loserth J.: Fontes Rerum Austriacarum. Vol. 1. 8. Wien: In commission bei K. Gerold's Sohn Buchhändler der Kaiser Akademie der Wissenschaften, 1875

Chron. Austr. = Chronica Austriae. In: Lhotsky A.: Monumenta Germaniae Historica. Scriptores Rerum Germanicarum Nova Series. XIII. Berlolini, Turici: Weidmann, 1967

Chron. de gest. prin. = Chronica de gestis principum. In: In: Pertz G. H.: Monumenta Germaniae Historica. Scriptores rerum Germanicarum. XIX. Hannoverae: Hahn, 1866. pp. 47-106

Cont. Canon. S. Rud. Salis. = Continuatio Canonicorum S. Rudberti Salisburgensis. In: Wattenbach W..: Monumenta Germaniae Historica. Scriptores. IX. Hannoverae: Hahn, 1851. pp. 819-823

DL = Archives of Diplomatics (Hungarian National Archives, Collection of medieval charters)

Hain G. = Hain Gáspár lőcsei krónikája. Ed. Bal J. – Förster J. – Kauffmann A. Lőcse [Levoča]: Reiss Ny., 1910-1913.

Mart. Meist. Ann. Gorl. = Martinus Meisterus. Annales Goerlicenses. In: Hoffmann C. G.: Scriptores Rerum Lusaticarum antiqui et recentiores. 1. / 2. Lipsiae – Budissae: David Richter, 1719

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BLOWN SAND MOVEMENTS AT KISKUNHALAS ON THE DANUBE-TISZA INTERFLUVE, HUNGARY

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Abstract

The largest blown-sand area of Hungary is located on the Danube-Tisza Interfluve. Here the most significant aeolian activity took place during the Pleistocene, however the aeolian transformation of the landscape occurred also in the Holocene and even in historical times. The aims of the study were (1) to reconstruct the relief at different historical periods; (2) to determine the periods of sand remobilisation during historical times; (3) to identify the changing of climatic conditions and possible types of human activities enabling aeolian activity and (4) to specify the spatial extension of sand movements. To reconstruct the spatial characteristic of sand and palaeosoil layers a 3D-model of the deposits at the archaeological site was created using total station measurements and Surfer 8.0 software. In order to determine the exact time of blown-sand movement optically stimulated luminescence (OSL) measurements (6) were applied. Based on the results, the lowermost sandy-loess layer had a late Pleistocene age, on which sequences of palaeosoils and blown-sand layers were formed during the Holocene. The spatial extension of the palaeosoils and sandy layers suggest that the relief has changed significantly over historical times. The former Pleistocene blowout depression has altered because of both the climatic conditions and the human impact on the environment. Blown-sand movements in historical times filled up the blowout depression. The sand sheets reshaped the original morphology and soil properties. Today the surface is more elevated and even, the site is covered by dry and slightly humic sandy soils.

Keywords: environmental changes, Holocene, blown sand, OSL dating, archaeology, human impact

INTRODUCTION

The population, the development of agricultural techniques and the changes in land use caused human induced environmental changes, which became increasingly significant in history. Good examples can be found on the Danube-Tisza Interfluve where the change in climatic conditions and the anthropogenic disturbance together caused aeolian activity during historical times. Therefore, the original geomorphological setting of the area transformed, and Pleistocene forms were reshaped by Holocene sand-movements.

The earliest blown sand movements on the Danube-Tisza Interfluve took place in the Inter Pleniglacial of the Pleistocene (Sümegi P. – Lóki J. 1990, Sümegi P. 2005) and subsequently there was aeolian activity during the Middle Pleniglacial of the Pleistocene after 25 200 ± 300 year ago (Krolopp E. et al. 1995, Sümegi P. 2005). According to earlier researches on the Danube-Tisza Interfluve the most significant aeolian activity occurred during the Upper Pleniglacial (Borsy Z. 1977ab, 1987, 1989, 1991, Sümegi P. et al. 1992, Sümegi P. – Lóki J. 1990, Sümegi P. 2005). Later, the two cold and dry periods, the Older Dryas and Younger Dryas in the Pleistocene were convenient for aeolian rework (Borsy Z. et al. 1991, Hertelendi E. et al. 1993) which is supported by radiometric, optical and thermo-luminescence measurements too (Gábris Gy. et al. 2000, 2002, Gábris Gy. 2003, Ujházy K. 2002, Ujházi K. et al. 2003).

Sand dunes, formed under cold and dry climate in the Pleistocene, were gradually fixed as the climate changed to warm and humid during the Holocene. However, researchers draw attention to the possibility of sand movement in the Holocene too. The warmest and driest Holocene phase (Boreal Phase) was the most adequate for dune formation (Borsy Z. 1977a and b, 1987, 1991, Gábris Gy. 2003, Kádár L. 1956, Marosi S. 1967, Ujházy K. et al. 2003), though, certain investigations claim that the second half of the Atlantic Phase could also be dry enough for the remobilisation of sand (Borsy Z-né – Borsy Z. 1955, Borsy Z. 1977a and b, Gábris Gy. 2003, Ujházy K. et al. 2003). Nevertheless, the latest, usually local signs of aeolian activity can be related to various types of human impact. Former investigations consider that sand movement could occur during the Turkish occupation (16th-17th century AD) and subsequently in the 18th -19th century AD due to deforestation (Borsy Z. 1977a and b, 1987, 1991, Marosi S. 1967).

Based on archaeological investigations and OSL measurements on the Danube-Tisza Interfluve aeolian activity occured in the Bronze Age (Gábris Gy. 2003, Ujházi K. et al. 2003, Nyári D. – Kiss T. 2005a and b, Kiss T. et al. 2006, 2008, Nyári D. et al. 2006a and b, 2007a and b, Sipos Gy. et al. 2006), then the surface became stable for a long period, until the 3rd-4th centuries AD. As later the climate turned dry (Rácz L. 2006, Persaits G. et al. 2008) and the anthropogenic disturbance became more significant conditions became suitable for aeolian activity, which is proved by several researchers (Lóki J. – Schweitzer F. 2001, Kiss T. et al. 2006, 2008, Nyári D. et al. 2006a and b, 2007a and b, Sipos Gy. et al. 2006, Knipl I. et al. 2007). Sand movement was also characteristic in the Migration Period, especially during the 6th-8th century AD, which was the realm of the Avars (Nyári D. – Kiss T. 2005a and b, Kiss T. et al. 2006, 2008, Nyári D. et al. 2006a and b, 2007a and b, Sipos Gy. et al. 2006) Subsequent aeolian activity occurred also in the high medieval period (11th-13th centuries AD, Lóki J. – Schweitzer F. 2001, Gábris Gy. 2003, Ujházy K. et al. 2003, Nyári D. et al. 2006a and b, Knipl I. et al. 2007, Kiss T. et al. 2008) and when the Cumans inhabited the territory (13th century AD, Sümegi P. 2001, Kiss T. et al. 2006, 2008, Nyári D. et al. 2006a and b, 2007a and b, Sipos et al. 2006). The latest aeolian activity occurred in the 15th century BC (Nyári D. et al. 2007a, Kiss T. et al. 2008).

The present research provides evidence on sand movements in historical times caused by changing in climatic conditions and human impact on the environment. The aims of the study were (1) to reconstruct the relief at different historical periods; (2) to determine the periods of sand remobilisation during historical times; (3) to identify the changes of climatic conditions and possible types of human activities enabling aeolian activity and (4) to specify the spatial extension of sand accumulation.

STUDY AREA

The 9 km^2 large blown sand covered study area is situated on the southern part of the Danube-Tisza Interfluve, northeast from Kiskunhalas (*Fig. 1*). The altitude of the area varies between 122 and 138 m a.s.l. Low-lying flat areas dominate the southern part, where greater depressions are situated. On the northern part, a higher sandy area characterises the landscape. The forms stretch from NW to SE, and clearly mark the direction of prevailing winds during aeolian periods (*Fig. 2*).

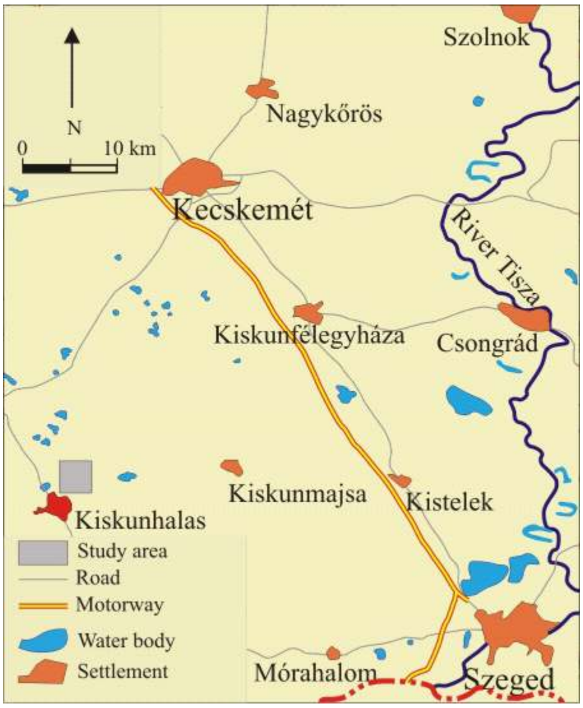

Fig. 1 Location of the study area

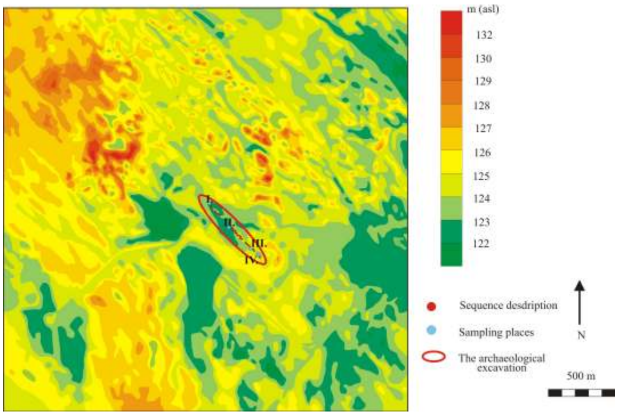

Fig. 2 Relief of the study area, the archaeological site and the sampling places

The 550 m long and 6 m wide, 1.2-2.5 m deep excavated site was located along a future pipeline on the middle of the study area in a blowout depression, providing an exceptionally good example on Holocene aeolian reshaping (*Fig. 2*).

METHODS

OSL measurements

The optically stimulated luminescence (OSL) determines the last exposure of sediments to sunlight. Therefore, the method is especially suitable for identifying the depositional age of wind-blown sands (Aitken M. J. 1998). Altogether six samples were collected from three profiles. Measurements were made on an automated RISOE TL/OSL-DA-15 type luminescence reader at the Department of Physical Geography and Geoinformatics, University of Szeged. Laboratory techniques and measurement protocols can be found (Sipos Gy. et al. 2009).

Investigation of archaeological findings

By investigating the findings of the site the activities and environment of earlier inhabitants of the area can be reconstructed. Previous archaeological analyses (Wicker E. 2000, Rosta Sz. 2007) allowed us to study the morphological situation of findings and to couple historical settlement pattern with landforms. This analysis enabled us to reconstruct the type, intensity and the geomorphological results of human impact.

Geomorphological mapping

The relief and geomorphological map of the investigated area were compiled on the basis of field measurements and 1:10,000 scale topographic maps. First the major aeolian morphological units: erosion-transportation and accumulation zones, the basic morphological features: blowout depressions, blowout ridges, blowout dunes or hummocks, parabolic dunes, sand sheets, deflation areas and the brink lines of dunes were identified.

3D-modelling

To model the landscape at different historical periods a 3D terrain model was created on the basis of layers along the archaeological excavation using total station measurements and Surfer 8.0 software.

RESULTS

Based on the geomorphological map of the area, the northern part of the investigated area represents an accumulation zone, where the most typical forms are blowout depressions, blowout ridges and blowout dunes (hummocks). On the southern part the erosion and transportation zones are situated with unclear boundaries and covered by less of forms, which are predominantly deflation areas, blowout depressions, blowout ridges and sand sheets (*Fig. 3*).

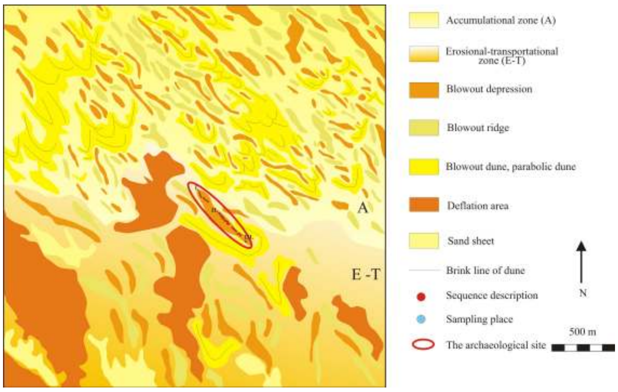

Fig. 3 Geomorphological setting of the study area

Samples for OSL dating were collected from three profiles along the excavated site. Based on the results the lowermost sandy-loess layer was formed at 12.7 ± 1.2 ka in the Pleistocene, on which a 35-110 cm thick soil evolved during 9000 years in the Holocene.

According to the OSL measurements subsequent aeolian reactivations took place 2.9 ± 0.3, 1.74 ± 0.2, 1.59 ±0.2 and 1.2 ± 0.19 ka and resulted a 30-180 cm thick layer consisted of sand and poorly developed soil layers. Sequences of blown-sand layers and soils suggest that the relief of the surface during different historical times was not the same as today. The wind continuously filled up the former blowout depression. Later, as the surface was stabilised again, a relatively thick and dark soil layer could develop.

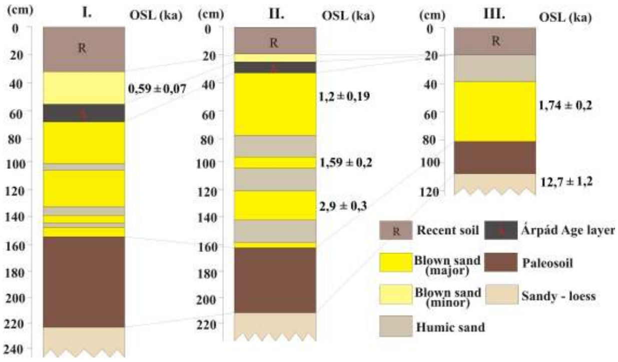

Fig. 4 Profiles, depositions and the OSL data

However, according to the OSL measurements, around 0.59 ± 0.07 year ago aeolian activity restarted and created a 30-100 cm sandy deposit on the top of the layers (*Fig. 4*).

DISCUSSION

The age and depositional data of the profiles were compared to archaeological evidence on the site and in the region (Wicker E. 2000, Rosta Sz. 2007). For the reconstruction of spatial characteristic of land surfaces at different historical periods a 3D model of the layers was created. All these enabled the reconstruction of the type, intensity and the results of human impact on the environment in different historical periods.

Until the 9th centuries BC a blowout depression was located at the excavated area. Its altitude varied between 122-124 m a.s.l. and a very thick soil was developed on the surface (*Fig. 5*). Southeast from the blowout depression a higher sand dune was situated, which is still visible today.

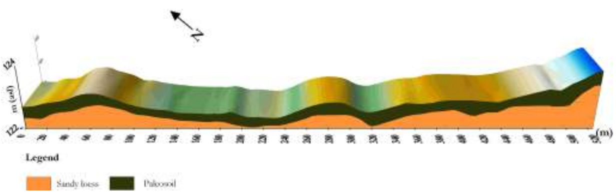

Fig. 5 Surface profile: before the 9th century BC

As the result of several sand movements, 30-180 cm thick sand layer was deposited (*Fig. 6*). In the 9th century BC (OSL: 2.9 ± 0.3 ka) a thin sand layer covered the deepest part of the depression. Since then sand movement took place in the Subboreal Phase, which was cool and wet (Járainé K. M. 1966, 1969), the role of climatic controls on the remobilisation of sand is certainly insignificant. On the other hand the findings around Kiskunhalas from the 9th century BC (Wicker E. 2000) provide an evidence for the presence of a dense result of human disturbance at this time. Subsequently, until the 2nd century BC soil development occurred. During the 2nd-5th century AD Sarmatians inhabited the territory (Rosta Sz. 2007), who were engaged in agriculture and kept large livestock on the pastures. The excavated Sarmatian trenches and wells were found on the elevated surface of the paleosoil, while marks of livestock treading in the deepest part (*Fig. 6*).

Fig. 6 Animal foot prints (foto: István Knipl)

These indicate that the low-lying, wet area of the blowout depression was used for watering, while the higher surfaces were pastures or plough-fields. Sarmatian animal breeders and farmers with large population meant an intensive burden on the environment, thus the chance for wind erosion increased on bare surfaces caused by over-grazing or ploughing. Due to these reasons aeolian activity appeared on the territory in the 3rd and 5th century AD (OSL: 1.74 ± 0.2, 1.59 ± 0.2 ka) and the area of the blowout depression was covered by a sandsheet. However, in this case the role of climatic control could be more significant, as this was the time of the "Roman Warm Period", which generally characterised by warmer and drier weather conditions (Rácz L. 2006). In the 8th century AD (OSL: 1.2 ± 0.2 ka) aeolian activity was possibly induced by the Avars (Wicker E. 2000). At this time the climate was cold and dry (Rácz L. 2006), being ideal for sand movement especially when anthropogenic impact was superimposed. As a consequence of the sand movement between the 9th century BC and the 8th century AD, the blowout depression was filled up, thus a more homogenous surface developed at a higher elevation (*Fig. 7*).

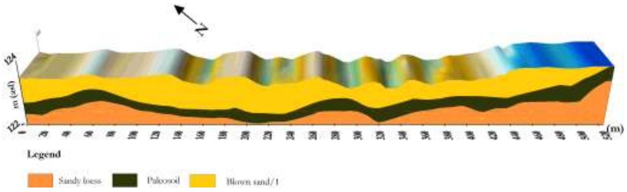

Fig. 7 Surface profile: 8th century BC

Subsequently, a longer stable period came without sand movement, which coincides with the generally more warm and wet "Medieval Warm Period" (Rácz L. 2006). During this time the surface was stabilized and a humic sandy soil developed (*Fig. 8*).

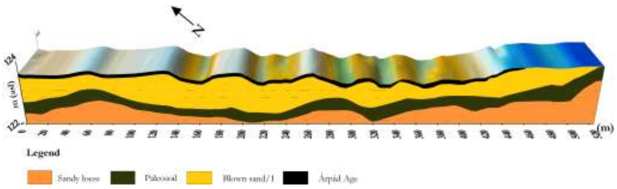

Fig. 8 Surface profile: 13th century BC

People settled down in this area in the Árpádian Period, between the 13-14th century AD. Based on plough marks stretching, from north to south along a 60 m long section (*Fig. 9*), the area functioned as a plowland in the 13th century when a 20-30 cm anthropogenic layer was formed (*Fig. 10*). Based on the stockyards, house remains, potteries and bones later it might have been used for animal husbandry as well as for settling down from the turning of 13-14th centuries (Rosta Sz. 2007).

Fig. 9 Plough marks stretching from north to south (foto: Szabolcs Rosta)

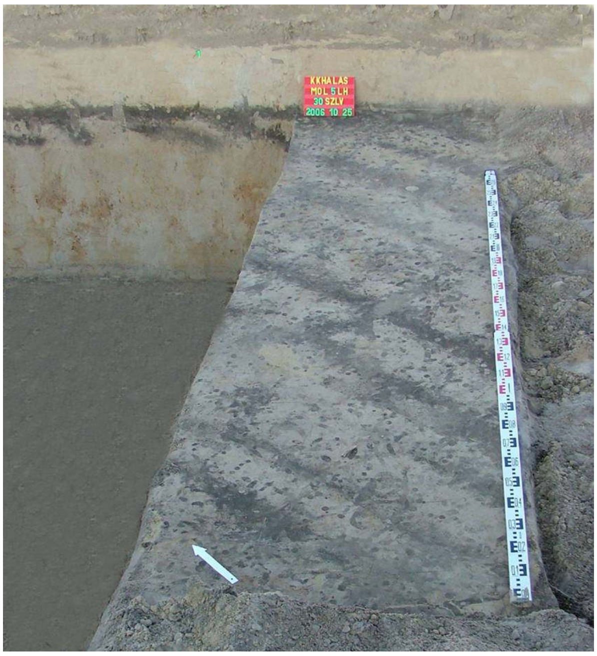

Fig. 10 Anhtropogenic layer above the plough marks

On this palaeosoil, another sand layer can be found (*Fig. 11*), which was formed in the 15th century AD (OSL: 596±68 y). The sand movement is probably also the result of human disturbance as a well was found indicating inhabitance. At this time the climate was generally unfavourable for aeolian activity as it belongs to the “Little Ice Age”.

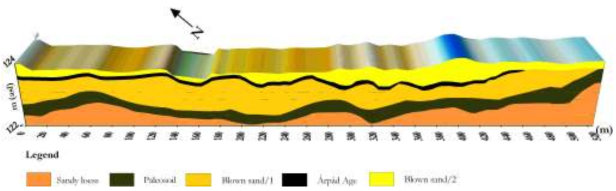

Fig. 11 Surface profile: the 15th century BC

Thus, the aeolian activity levelled the surface even more on the altitude of 124 m a.s.l., which can be seen today. Now the area functions as a plough land and the modern ploughing techniques destroyed the former layers (*Fig. 12*).

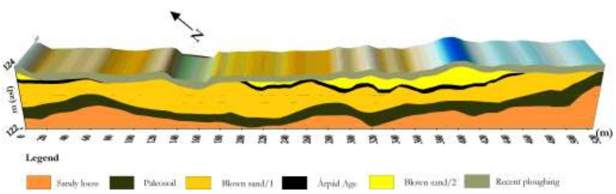

Fig. 12 The surface in 2007

CONCLUSION

The Holocene morphological evolution of the investigated area is complex. The Pleistocene forms were reshaped and transformed, thus at certain locations the original morphology can hardly be identified. Remobilisation and reshaping were especially intensive during historical times (*Fig. 13*). The former landscape changed mostly because of the combined effects of climate and human impact on the environment. Blown-sand movements in historical times filled up the blowout depression.

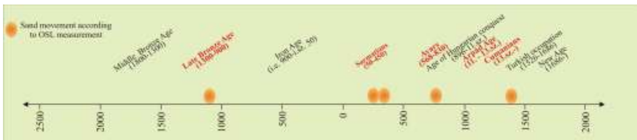

Fig 13 The OSL ages and the archaeological relicts of the area

Sand sheets reshaped the original morphology covered several generations of palaeosoils. Today the surface is higher and more even; a dry and slightly humic sandy soil covers the area of the former low-lying and wet blowout depression which was filled up by thick organic sediment and soil.

Acknowledgments

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FLOODS AND WEATHER IN 1342 AND 1343 IN THE CARPATHIAN BASIN

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Abstract

Concerning weather, weather-related extremes and catastrophic consequences, 1342 was an extraordinary year in most parts of Central Europe, even in such an extraordinary decade as the 1340s. Accounting with the seven flood events (including one Danube flood) mainly of great magnitude, at present 1342 is the most important known flood year of medieval Hungary. Moreover, in this year extraordinary weather conditions, such as a mid-autumn snowcover were also reported. However, in the eastern parts of the Carpathian basin not only 1342 but also 1343 was a significant flood year with six reports on flood events occurred in the upper and upper middle sections of the Tisza catchment.

In the present study, an overview of these events is provided, based on the information preserved in the most typical contemporary, well-dated source type of medieval Hungary, namely charters. The aim of the study is, on the one hand, to draw attention to the flood and weather-related evidence found in charters, and to provide a methodological background for further evaluation and utilisation of this source type in historical weather and flood research, through the very typical example of the years of 1342 and 1343. On the other hand, another aim is to discuss and analyse the unique nature of these two years in medieval Hungary, and (beyond the well-known year of 1342) to draw attention to the, up to now somewhat neglected, year of 1343.

DEEP SNOW, ICE FLOOD, EXTREME RAINFALL AND A DEVASTATING MILLENNIAL SUMMER FLOOD EVENT: 1342 (AND 1343) IN (WEST) CENTRAL EUROPE

1342 became famous for its hard winter with abundant snow and very rainy summer as well as autumn in Central Europe and beyond. These weather conditions caused in large parts of (Central) Europe three main flood waves: one in February, a second one in April and a third one in July. Out of these three flood waves the summer flood happenned to be an extreme, millennial flood event with disasterous consequences which, together with the next year's unfavourable wet weather conditions (mild winter, cool and wet spring, wet summer), caused great hunger and famine in most of the German areas by 1343 and 1344 (Glaser R. 2008). Although two of the flood waves, namely the February and April floods caused great damages in the Czech areas, there is no report available about any damages concerning the summer of 1342 (Brázdil R. – Kotyza O. 1995). Moreover, in the area of the eastern Alps none of the three floods had so disasterous effects as in other parts of West Central Europe (Rohr Ch. 2007).

About the 1342 weather and floods a concise overview of the international literature was presented by Brázdil and Kotyza (1995). Another, detailed overview of the 1342 events, from various viewpoints including causes, damages and other consequences, was provided by Rohr (2007), as well as by Glaser (2008). Large-scale geomorphological and landscape-change consequences of the disasterous summer flood event were studied by Bork and his colleagues (e.g. 1998). In contrast with the great attention turning towards the events of the year 1342, there is not much available about 1343 in the scientific literature. Almost all information about the somewhat special, unusually wet character of this year and its possibly also hard consequences were only detected in Germany. In this case, together with the catastrophic events of the previous year, the unfavourable weather conditions were also blamed for the famine concerning the southern German areas (Glaser R. 2008). Some other evidence, however, might suggest that the Danube in Bavaria caused problems also in other times during these two years, since flood damages were reported at the monastery of Oberaltaich concerning autumn 1342 and spring 1343 (Rohr Ch. 2007).

What happenned in the Carpathian basin in the same time? The special character of the 1340s and 1342 in the Carpathian basin was partly emphasised by Kiss (1996, 1999). Nevertheless, on the basis of an enlarged database of legal documentary evidence (charters), a new, more complete overview and analysis can be presented.

CHARTERS: AN UNIQUE WELL-DATED MEDIEVAL LEGAL EVIDENCE

Concerning these two extraordinary years, information about the events occurring in the Hungarian kingdom, which covered almost the entire Carpathian basin – including the present-day areas of Hungary, Slovakia, and parts of Ukraine, Romania, Serbia, Croatia, Slovenia and Austria – is mainly available in legal documentation, namely charters (see Kiss A. 1996, 1999). Characteristic advantages and disadvantages of this type of weather and flood documentation lie in their legal character: the main aim of preparing these documents was to document and preserve the most important points, objectives of the legal process as a proof of ownership patterns for the future (often for centuries). Consequently, flood or weather circumstances are mentioned only if they obstructed the completion of the legal procedure during field survey. In other (less frequent) cases, flood/weather circumstances obstructed travel and thus legal procedure/trial had to be postponed and this fact (together with circumstances) had to be reported to the higher authorities or permission to be asked for postponing/prolongation of procedure. Occasionally, weather-related information (e.g. proof of a late harvest) can be detected in other cases, such as witnessed illegal harvesting or using force during (well-dated) harvesting time etc.

Clear advantages of charter evidence are, compared to most types of medieval documentary evidence, their exact and highly reliable dating (legal-administrative documentation), the punctuality of location and the several elements, main environmental conditions of the area, often described in the main text body. Disadvantages are that the date(s) of observation is not necessarily the date of the beginning and the end date of the flood event, but only a day or days of the ongoing flood and weather events. Moreover, the beginning and end dates of flood events/weather phenomena and their main (e.g. material, human) consequences are mainly unknown. In this sense, a major difference from (western or other) narrative evidence is that in charters mainly flood appears as a natural hazard while in narratives flood is mainly reported because of its catastrophic consequences. Similarly, the area a charter usually refers to is often restricted to a small location and thus, in the majority of cases little is known about medium- or large-scale patterns.

Except for one case (town burning down in 1342), all weather- and flood-related information concerning the years of 1342 and 1343 has survived in charters. The spatial distribution of reported weather and flood events of 1342 and 1343 is presented in *Fig. 1*. The present analysis provides us with fragmentary picture on what happenned in 1342-1343 in the Carpathian basin, not only related to weather, but also flood events: data available only for those dates and in those cases, areas when and where legal procedure took place and later weather- and/or flood-related information was included in the charter. Thus, we can presume that large-scale patterns would have shown a certainly more complex, and possibly even more 'serious' picture, especially concerning flood events.

A FRAGMENTARY PICTURE? WEATHER REPORTS FROM 1342 AND 1343

Only sporadic information is directly available concerning the weather of 1342: these data preserved in charter evidence. Amongst this evidence, a reference can

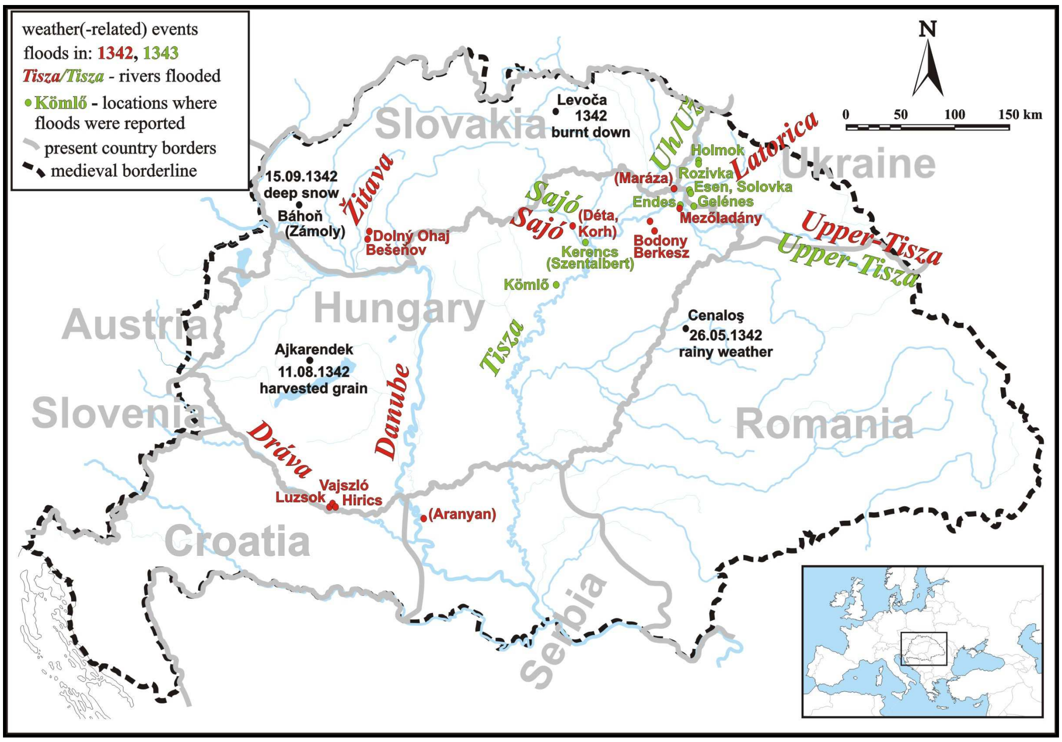


Fig. 1 Floods and weather events (or related information) documented in 1342-1343 in the Hungarian kingdom (described here together with the Croatian kingdoms). Deserted settlements are determined with brackets

be found in a charter concerning rainy weather (’*et quia eadem die pluuiosum tempus asseruisset*’), reported on 26 May in 1342 (Nagy I. 1884), due to which reason the field survey of *Chalanus*, located in historical Bihar county (today Cenaloş in Romania), could not be carried out on that day (see *Fig. 1*).

On 11 August in 1342 during the perambulation of *Rendec* (today Ajkarendek) landed posession at the boundries of *Ayca* (Ajka) and *Louuld* (today Kislőd/Városlőd), located in the central Transdanubia along the Torna river (DL 66126; Piti F. 2007a; see *Fig. 1*), the owners of some arable lands prohibited others to take the harvests from their arable lands and also to take the already harvested shooks of grain (’*de quindecim iugeriis fruguum quindecim capecias similiter prohibuissent quas in eadem terra seminatas inuenissent*’). Although no medieval harvest date series are yet available for this region or for Hungary, a significant amount of data can be found for the early modern period in the somewhat cooler and wetter Szombathely (ca. 205 m a.s.l.), located approximately 80 km west to Rendek (ca. 250-280 m a.s.l.). In the 17th and 18th centuries, the share of harvesters, fixed towards the end of the harvest (of mainly wheat and rye), usually occurred around mid- and late July, sometimes earlier (Szombathely town council protocols, Vas county archives V/102a). Late harvest(-ending)s could occur in early August (e.g. 5 August in 1675 and 1696, 6 August in 1700, 7 August in 1697, 9 August in 1705), too. In our present mid-14th century case, by 11 August one part of the crops have been already harvested, but still kept on the field, while another part was still waiting for harvesting. Even if harvesting lasted probably longer in the 14th century than in the 17th century (see Belényesy M. 1956), this means a rather late harvest time (especially if taking the 10-day difference between Julian and Gregorian calendars also into account), which presumably refers to cool late spring, early and mid-summer conditions.

On 15 September in 1342 (Nagy I. 1884, Piti F. 2007a) a perambulation of the doubted boundary-line between *possessio Bahun* (today Báhoň in Slovakia) and *possessio Zamul* (later deserted land) took place (medieval Pozsony county; see Házi J. 2000). Nevertheless, because of the hard times (or the difficult weather conditions) and the magnitude of snow (!), it was not possible to perambulate the boundaries, and measure the area of lands (’*propter temporis gravitudinem et nivei magnitudinem reambulantes determinative mensurare non potuissent*’). Original dating of the perambulation is clearly defined ('*in predictis octavis festi Nativitatis beate virginis*'), and based on the earlier course of the legal debate (previous meeting: 1 August; later meeting: 8 November) no very different (much earlier or later) dating is possible. As such, we can presume that in the areas of present western Slovakia the perambulators witnessed in a lowland area (ca. 150-180 m a.s.l.) extraordinary weather conditions with a significant amount of snow at a very early date, namely in mid-September.

According to the (contemporary) *Georgenberger Chronik*, referring to the town of *Lewtscha* (today Levoča in Northeast-Slovakia) one of greatest reported (medieval) fires occurred in 1342 (Szentpétery I. 1938: ’*Anno dni MCCCXLII …. Czu der selbin czeit ist dy stat Lewtscha verprant, vnd also sein auch dy altin prife des lanids des meiste teil verprant.*’). Although applying different words, the same information was included in Caspar Hain’s 17th-century regional chronicle (Bal J. et al. 1910-1913), based on (local) archival evidence. Since no more data is available (e.g. in which part of the year the fire occurred), even if it is clear that weather conditions had to be at least partly responsible for this disasterous event (e.g. strong wind, drought and/or hot/very frosty, cold weather), no firm conclusions can be drawn on prevailing weather conditions.

The scarcity of known weather events, remained to us reported in the Carpathian basin, does not allow us to draw further conclusions. Nevertheless, the report on a potentially quite late harvest in the Mid-Transdanubia, and the extraordinary mid-September deep snow in the lowland areas of present western Slovakia suggest generally preavailing cool conditions for late spring-summer and around early-mid autumn in 1342. No weather-related reports are yet known concerning 1343. What makes these two years really special is the unusually great amount of flood reports, reflecting on the possibly extraordinary (wet) weather conditions and especially intensive large-scale cyclonic activity.

1342: THE MOST IMPORTANT FLOOD YEAR IN MEDIEVAL HUNGARY?

Due to its flood events of great magnitude (e.g. summer), the year of 1342 is accounted for in most of the contemporary European narratives. Up to date, no European narrative is known to mention that these or any other flood events in 1342 would have as well appeared in Hungary. The seven reported flood events of this year, presented here concerning Hungary, can be detected merely in domestic legal documentation: only charters preserved their memory (for locations, see *Fig. 2*).

The great winter flood in a broader context

The first known flood event of 1342 occurred in early February. At the (former) lower course of the Hejő

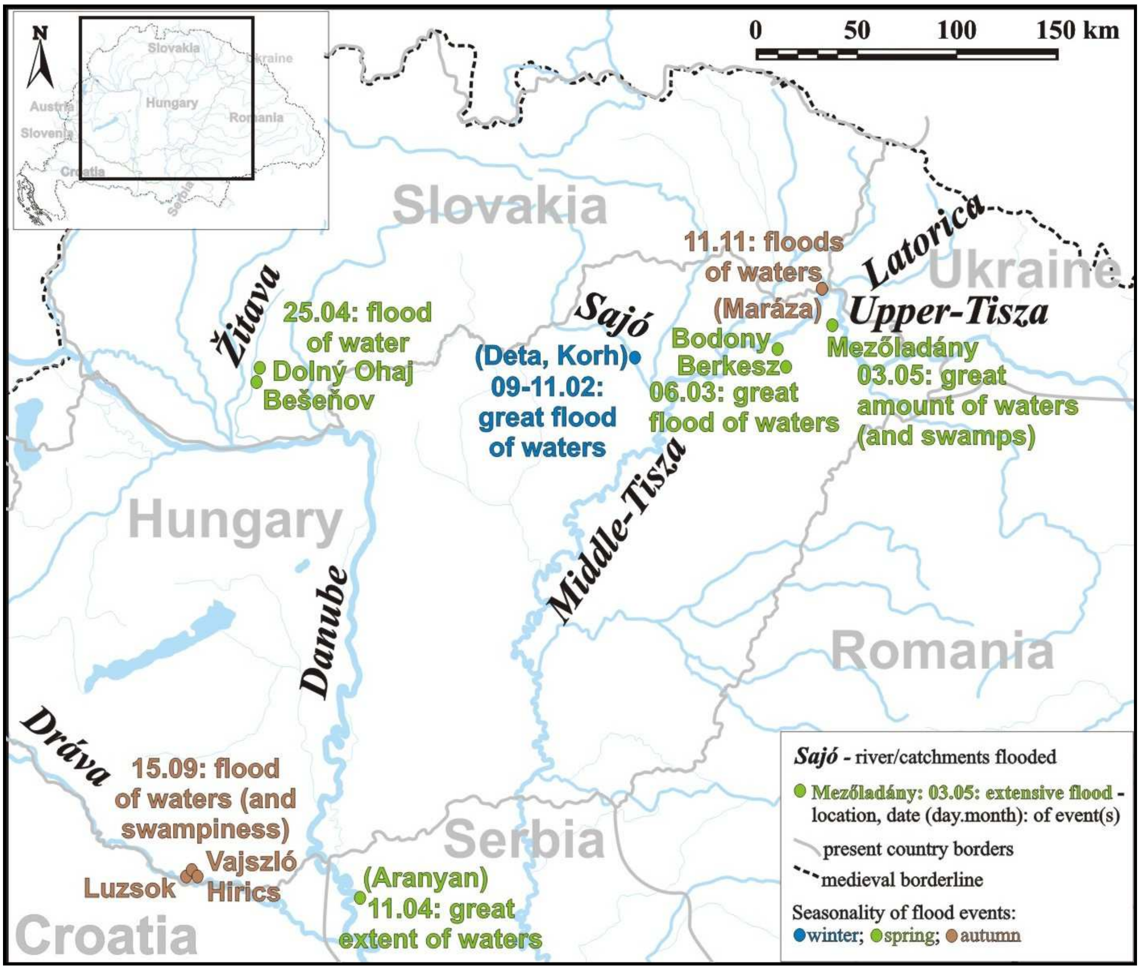


Fig. 2 Flood reports in the year of 1342 in the Hungarian kingdom. Note that the medieval borderline, running along the ridge of the Carpathians, also defines a geographical and hydrological boundary line (of major catchment areas – e.g. Tisza). Deserted settlements are signed with brackets

and Szinva waterflows, close to the Sajó river, the perambulation of the former *Deta* and *Korh* landed possessions (both were deserted later: Györffy Gy. 1987) in Borsod county was obstructed by a great flood event (’*nimia aquarum inundacio*’). A speciality of the description is that on 9 and 10 February perambulators could not even approach the areas, although they did make attempts. On the next day, on 11 February there was already no problem with reaching and surveying the area, but still they could not measure the debated landed portion, they could only estimate the size of the land (DL 75835, 3448, 40902; see also Piti F. 2007a).

For the February events good parallel can be the description of *Franciscus Pragensis*, who dedicated a long description for the great flood event: from his notes we can learn that on 1 February warm air masses arrived which were followed by rains. This mild weather, after the preceding hard winter conditions, melted the snow, broke up the ice, and caused great ice flood (Loserth J. 1875; for the analysis of Vltava, Elbe and Upper-Morava flood events, see Brázdil R. – Kotyza O. 1995). According to the Swiss Johann von Winterthur, flood flashed through the upper, alpine sections of the Danube on 2 February, and in the same time sea surge caused damages in Venice (Baethgen F. 1924).

Spring floods

On 6 March, the division of the landed possessions of Berkesz, Bodony and Harabur, located in historical Szabolcs county along the Tisza river (Csánki D. 1890; Németh P. 1997), was obstructed by the great flood of waters, which occurred in those areas (’*nimia aquarum inundacio*’) (DL 31242; see also Piti F. 2007a). Since Bodony was located at the Upper-Tisza, the great flood of waters could most probably refer to the Tisza and partly to its upper tributaries.

On 11 April great extent of waters was observed, at this time during the perambulation of Aranyan landed possession (today deserted land in Serbia close to Apatin; see Györffy Gy. 1987), in historical Bodrog county (Nagy I. 1884). In the text not the usual '*inundacio*(*nes*) *aquarum*/*aque*' appeared, but a broader information, namely the great amount and magnitude of waters, in the extensive floodplain of the Danube ('*abundancia et multitudo aquarum*') where the lands of Aranyan were located. The mentioned great waters make it probable that it was not the mere result of one flood (mainly of the Danube), but we might have to count with more than one flood waves, culminating in this low-lying, extensive floodplain, and probably also with the influence of the Drava river whose inflow is located south to the study area. Additionally, the appearance of inland excess waters, which in wet years often occur parallel or after flood events, is also quite probable. Moreover, as a factor obstructing the legal process, this great extent of waters probably also means a longer-term inundation in the area. The charter itself is important since the hydrological conditions of the area cannot be separated from that of the Danube (and also partly the Drava) and thus, the high water level, or flood level of the Danube.

Dated to the beginning of April flood, caused by the melting of great amount of snow, is mentioned by the Cistercian monk, Johann von Viktring, which affected the waterflows of Europe, and according to the description, the result was catastrophic (Schneider F. 1910; for more analysis, see: Rohr Ch. 2007). However, due to the little difference in time, the Danube flood in South-Hungary cannot be the continuation of the West-Central European flood event. As there is no significant waterflow coming to the Danube between its upper and lower Carpathian-basin sections, there should have been at least one flood event of the Danube in March at the upper sections of the Carpathian basin. There is a good possiblity that a flood wave at that time was already coming from the west; this case shows parallels to another (waves of) flood event, occurred in June of 1402 (see 27 June in Hungary: DL 78505; 29 June in Austria: Pertz G. H. 1851).

Still in the same month, at the end of April in 1342, another flood event ('*inundacio aque*') obstructed perambulation and land measurements along the Zsitva river (Žitava in Slovakia). On 25 April the perambulation of a land portion between the landed possessions of Ohaj and Besenyő (today Bešeňov and Dolný Ohaj in Slovakia) had to be stopped close to the river due to the flood (Nagy I. 1884).

During a perambulation, taking place on 3 May at the northeastern sections of the Middle-Tisza, the swamps and the uninhabited lands caused by the great amount of waters ('*propter paludes et terras inhabitabiles propter multitudinem aquarum*') is mentioned as an obstructing environmental circumstance which did not allow perambulators to proceed with the survey (DL 105741; see also Piti F. 2007a). The landed possession of *Ladan*, mentioned in the charter, is the present-day Mezőladány (Németh P. 1997), located at the main course of the Tisza river in historical Szabolcs county. Since Mezőladány is located in the immediate neighbourhood of the river, partly surrounded by wetlands (oxbows: former Tisza-beds), the documentation of such wetlands in itself does not necessarily mean current hydrological problems, i.e. unusually much water in the area. The fact that some of the lands, exactly because of the great extent of waters, could not be reached (or even occupied by water) and some of the lands could not be measured suggests actual problems. Namely that the extent of waters was presumably (much) larger than usual in the area. What is more, lands were mentioned to be uninhabited because of the great extent of waters, which – similar to the Danube case in April – might easily also mean the (long-lasting) presence of inland excess waters in the area.

Summer signal: missing or not?

As we could see already at the beginning of the paper, perhaps the greatest flood event of the Middle Ages, with immense magnitude and damages, occurred in some parts of Europe. This, however, does not seem to appear in medieval Hungarian documentary evidence. One likely reason, as always, can be that it was simply not documented in the charter materials due to the fact that no legal procedure took place at that time in the problematic areas or documentation disappeared with time. Nevertheless, the lack of documentation can also mean that there was in fact no such significant summer flood event in the Carpathian basin at all. In West Central Europe one of the greatest known flood series occured around 21-24 July (Brázdil R. – Kotyza O. 1995; Rohr Ch. 2007; Glaser R. 2008). This, however, was less characteristic in the eastern alpine region or in the Czech lands (Brázdil R. – Kotyza O. 1995; Rohr Ch. 2007).

As appears in the next case, even if the mid-summer signal is missing, a wet late summer-early autumn period may be responsible for a flood event reported in the southwestern part of the Carpathian basin.

Autumn flood(s)?

The early autumn (15 September) flood observation, close to the Drava river at the landed possessions of Vajszló, Hirics and Luzsok, can be taken as an indicator of a late summer or early autumn flood. The debated landed portion among the above-mentioned villages was inundated, and due to the swampiness and flood of waters (’*propter paludinositatem et inundacionem aquarum*’) – although the perambulation could be carried out –, exact land measurements had to be replaced by simple estimation (Nagy I. 1887). The summer origin of this flood event is even more probable, counting with Central and Western European parallels, especially if we presume that this inundation of waters was in direct connection with the Drave river and thus its alpine catchment. However, the flood also could be (at least partly or entirely) the result of inland excess waters.

The rest of the autumn did not pass away without a flood event either. On 11 November along the Tisza river (again at the northeastern part of the middle section), in medieval Zemplén county, a land measurement could not take place because of the ongoing floods (’*propter aquarum inundaciones mensurare nequivissent*’) or an inundation as a result of series of flood events (Nagy I. 1887). Areas of the medieval *Maraza* landed possession (Maráza: later deserted, see Csánki D. 1890) are today located in the neighbourhood of Vel'ké Trakany and Čierna (in Slovakia) along the Tisza but also close to the Latorica river. Since in the catchment area of the Latorica river secondary (autumn) precipitation and flood maximum is especially important (Hajósy F. 1954), there is quite a good chance that the waters in flood were both the Tisza and the Latorica, and maybe also other waterflows in the area.

Mid- or late-autumn flood events are usually connected to the arrival of warm air masses rich in precipitation, driven by southern, southwestern winds from the Mediterrannean. It is interesting to mention that great flood damages in Padova and other parts of Lombardia were documented by the contemporary chronicler Johann von Winterthur, which floods were caused by great November rains, accompanied by lightenings and thunders (Baethgen F. 1924).

ANOTHER IMPORTANT FLOOD YEAR: 1343

While in most of the western literature 1342 is emphasised as a major year of floods, 1343 gained up to now very little attention, even if contemporary authors of western narratives, for example Johann von Winterthur, did spend quite much space to describe floods of this year. The year of 1343, apart from its special geographical extension (described below), shows rather interesting characteristics in the Carpathian basin.

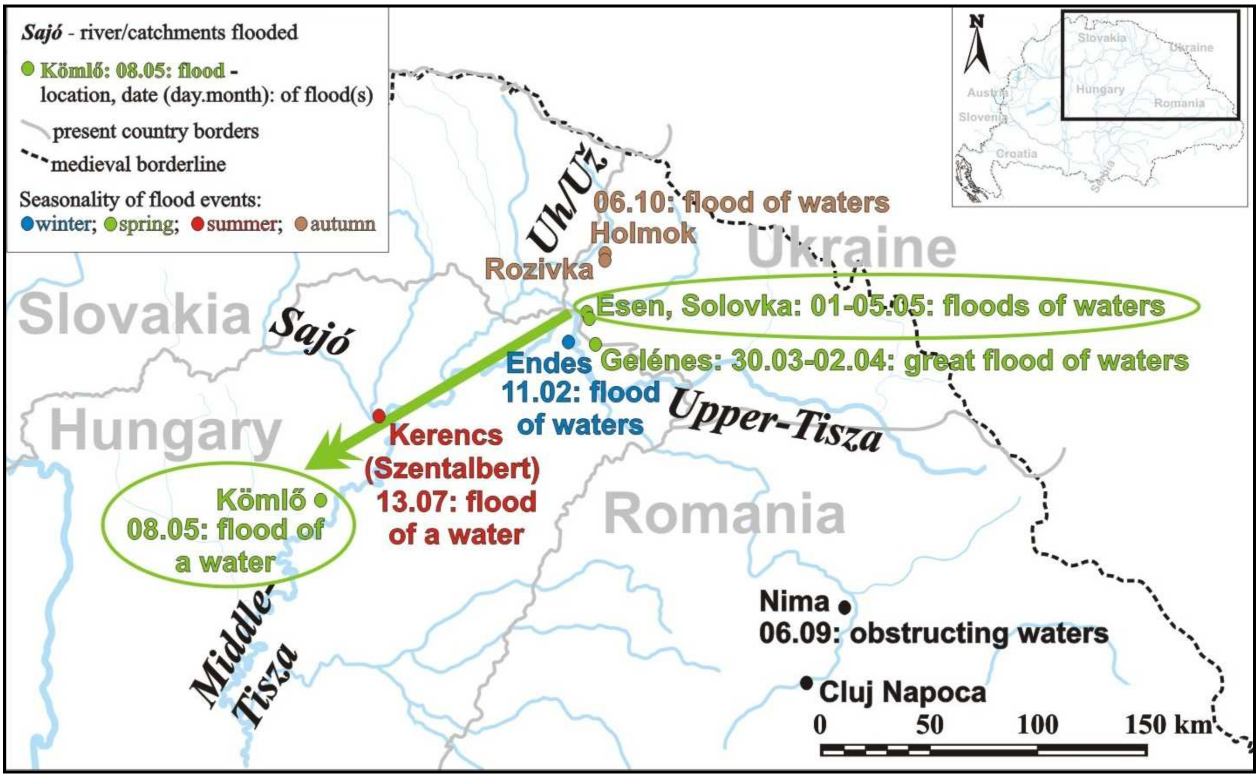


Fig. 3 Floods in the year of 1343. Green arrow shows the presumable connection between the two, early May cases: the Upper-Tisza flood waves reported on the Middle-Tisza (as one flood) with ca. one week delay

In medieval Hungary, the testimony of as many as six flood reports remained to us: all occurred in the northeastern parts of the Carpathian basin, in the upper and upper-middle parts of the Tisza catchment (for locations, see *Fig. 3*). As we will see, in the flood history of the Tisza catchment, the year of 1343 has rather great importance.

Winter flood of the Tisza river

The first winter case was observed on 11 February (and the days after) at the Tisza river. The perambulation, taking place around the medieval landed possession of *Endes* (as the northern neighbour of the above-mentioned Mezőladány) located in historical Szabolcs county along the Tisza river (Csánki D. 1890; today part of Mezőladány: Németh P. 1997), had to be stopped at a fishing place caused by the fact that perambulators could not cross due to a flood of waters ('*aquarum inundacio*'). Therefore, areas of the last sections of the planned perambulation were only estimated by 'eye-observation' (DF 209593; see also Piti F. 2007b).

Spring floods

The next spring flood case was observed at the end of March and beginning of April, when, in order to introduce into the possession of a land in the former *Gelenes* (Gelénes; for location: Csánki D. 1890) in historical Szatmár county, not all the interested parties could reach the area because of an ongoing great flood event ('*nimia aquarum inundacio*'). Those, who were able to attend the legal process were waiting for the others between 30 March and 2 April, yet without any success (DL 85252; Piti F. 2007b).

Another spring flood was observed on 1 May and the following four days, during the perambulation process of *Zalouka* and *Esen* (Csánki D. 1890, Németh P. 1997; today Solovka and Esen in Ukraine) located in historical Szabolcs county close to the Tisza river. The debated land portion at the *Zomua*/*Zomaua* waterflow could not be surveyed due to floods of waters ('*inundaciones aquarum*'), and thus, the size of the land was only estimated (DF 233635, 233634; see also Piti F. 2007b). The affected lands are located in the immediate vicinity of the Tisza, so the waterflows and the area were clearly under the direct influence of the river.

Perhaps the same flood event on the Tisza river reached the landed possession of *Kumleu* (Kömlő) in historical Hevesújvár county in some days time and thus, maybe the effects of the same flood or those of a previous flood wave was reported. On 8 May, caused by the flood of water and great difficulties ('*propter inundacionem aque et densitatem gravaminum reambulare nequivisset*'), it was not possible even to start the perambulation or settle any of the landmarks, and thus, measurements of debated lands could not take place either (Nagy I. 1884).

As a parallel it has to be mentioned that, for example, Johann von Winterthur did mention concerning 1343 that there were great rains around Easter time. These great rains caused flood, and problems did as well continue in summer when, for example, the Rhein also flooded. Moreover, series of flood events, caused by rainfall, continued in September. Much rain and bad harvests, accompanied by floods and other problems, caused several problems: especially in the German areas high prices and hunger developed (Baethgen F. 1924).

Summer and autumn floods

The only known, clearly summer flood event occurred at the Sajó river, only some kilometers from the place where the river enters the Tisza. The unsuccessful perambulation process of Szentalbert and Kerencs landed possessions in Borsod county was due to a flood event ('*inundacio aque*'), observed on 13 July (Dedek L. C. 1924). Since the area where the flood was reported is located at the Sajó river, but very close to the inflow of the Hernád river, and also close to the Tisza, there is a good possibility that the Hernád, but probably also the Tisza were in flood or had high water levels in those days.

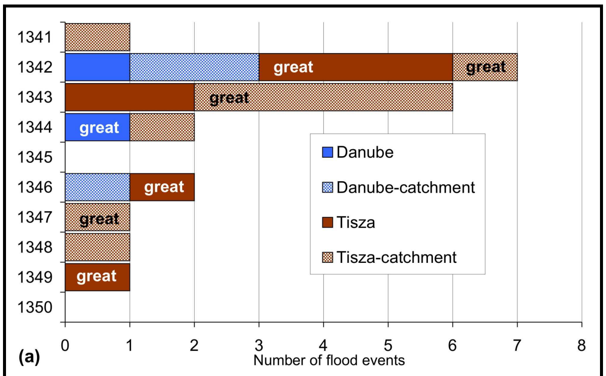
Although it is not a direct flood evidence, it is still worth mentioning that, related to a land purchase, on 6 September a number of old charters were transcribed by the convent of Kolozsmonostor (Cluj-Mănăştur; today part of Cluj Napoca in Romania) caused by the fact that the owner (*Pethew* from *Neema*; today Nima in Romania) of the landed possession (*Beeke* or *Beche*) did not dare to carry the originals with him. Among the reasons the dangers of roads and obstructive waters ('*propter viarum discrimina, aquarum impedimenta et hospitiorum incendia*') were mentioned (DL 27829; see also Piti 2007b). The above-mentioned settlements are all located in Central Transylvania, in the vicinity or along the Kis-Szamos river (today Someşul Mic in Romania).

On 6 October at the landed possessions of Homok and Ketergény (today Holmok and Rozivka in Ukraine) in historical Ung county a debated land portion could not be measured, only estimated, due to a flood event (DL 69670; see also Piti F. 2007b). The mentioned lands are located in the catchment area of the Ung (today Už) river, in which area October as a secondary flood maximum is rather pronounced in the 20th century, and clearly shows the arrival of Mediterranean humid air masses (see e.g. Hajósy F. 1954).

The spatial and seasonal distributions of the 1343 flood events suggest that we talk about an especially important flood year when ongoing flood events were observed in each season, at the upper and upper-middle parts of the Tisza catchment. Whereas floods of 1342 affected both main catchment areas, namely those of the Danube and the Tisza rivers, all six reports referring to 1343 reflect on the flood events of the (upper and upper middle sections) of the Tisza catchment. Thus, concerning the eastern parts of the Carpathian basin 1343 has at least the same or even more importance than 1342.

HOW SPECIAL WERE THESE TWO YEARS AMIDST THE KNOWN FLOOD RECORDS OF MEDIEVAL HUNGARY?

In late medieval Hungary the decade of the 1340s was rather special: far the greatest amount of flood events is known from this decade. Out of the twenty one presently-known flood events, thirteen occurred in these two years of 1342 and 1343 (*Fig. 4*). In general, most of the flood events, for which we have reports, occurred in the Tisza catchment or on the Tisza river itself: out of the five Danube-catchment flood events of the 1340s, three were witnessed in 1342; out of the two Danube floods of the decade one with a great extent of waters took place in 1342, and another (great) one in 1344 (*Fig. 4a*). Typically, almost all great flood events occurred in the more continental eastern river catchment of the Tisza. Seasonality patterns are also interesting and typical: in this case the overwhelming importance of (great) spring flood events have to be emphasised. Winter floods were reported in every second, third year; every year between 1342-1344. Interesting is the fact that only one summer flood is known from the whole decade (*Fig. 4b*).



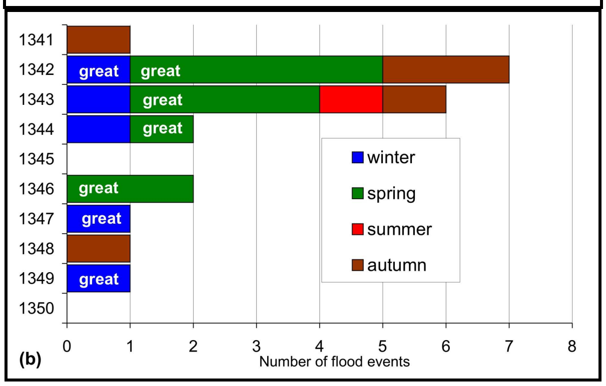


Fig. 4 Floods reported in the 1340s according to major catchment areas (*a*), and seasonality of flood events (*b*) (for detailed information, see Kiss 2010; submitted)

As we could see, accounting with numbers of the two years subject to discussion, floods were reported seven times in 1342, while six floods in different places were witnessed in 1343. As such, 1342 and 1343 are the most prominent flood years known in the later Middle Ages. Other 'famous' flood years, according to our present knowledge, were with four-four mentionings in 1399 and presumably in 1440, three-three in 1338 and probably also in 1346, 1454 and 1499, respectively (see *Fig. 5*).

In 1342, one winter flood (Tisza catchment), four individual spring floods (two-two in both catchments), and two autumn floods (one-one in both catchments) were reported, and there is a complete lack of summer floods documented (*Figs. 2* and *6*). Therefore, except for winter when flood event was reported only in the Tisza catchment and summer when flood signal is lacking as such, spring and autumn flood events affected both main catchment areas of the Carpathian basin. Both the winter and two spring floods were great in magnitude, while both the Danube in early April and the (Upper-)Tisza in early May were surrounded by a large extent of inundated areas, in which case not only flood but also the appearance and negative effects of inland excess waters were rendered.

Concerning numbers, 1343 is a flood year of upmost importance in the Tisza catchment and the eastern part of the Carpathian basin. Floods occurred in all seasons, but reported exclusively in the Tisza catchment: one-one in winter, summer and autumn; while three separate reports are available for spring Tisza floods. Out of the three spring floods two refer probably to the same flood wave(s) on different sections of the river, with approximately one week difference. In 1343 (only) one event was reported as a great (Tisza) flood (see *Figs. 3* and *6*). Similarly 1342 and also to the whole 1340s, Tisza floods in 1343 were exclusively reported on the lower parts of the Upper-Tisza and the uppermost sections of the Middle-Tisza, and thus, no evidence is available referring to most of the middle and lower sections of the river and its catchment area.

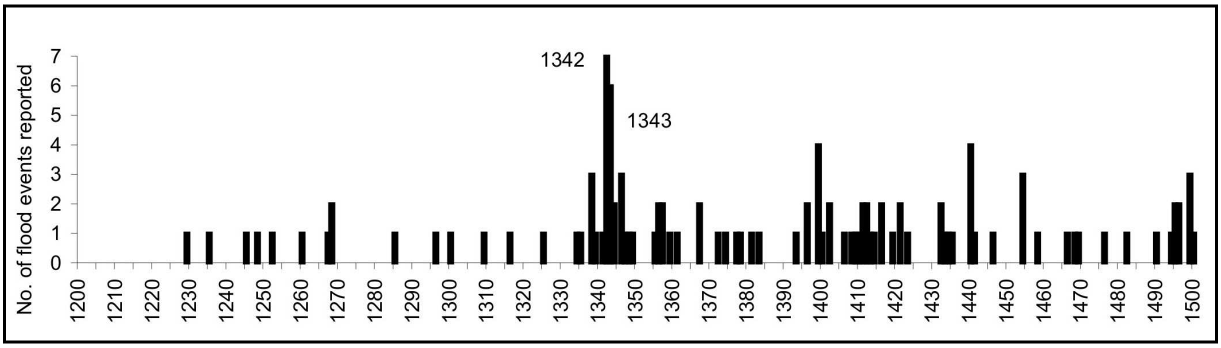


Fig. 5 Annual distribution of known flood reports in late medieval Hungary (a developing database – Kiss 2010 in prep.). Note the outstanding amount of flood events reported in 1342 (7) and 1343 (6)

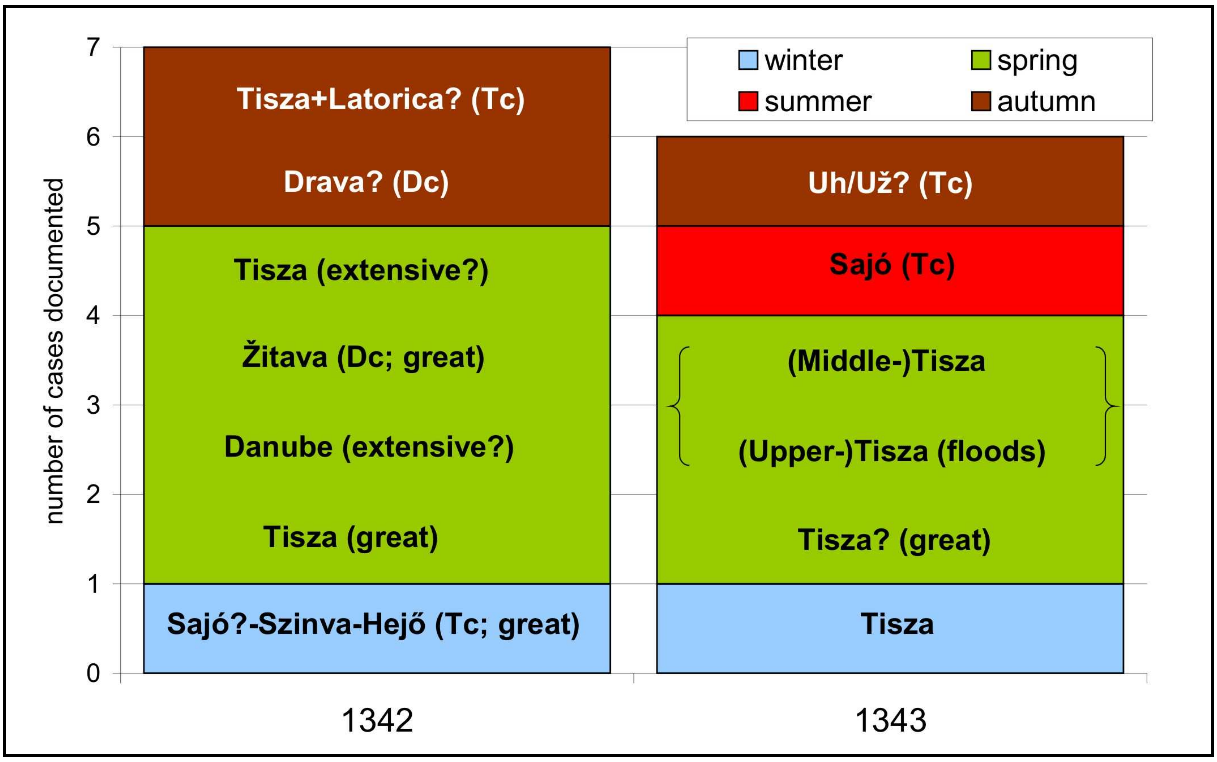


Fig. 6 Seasonal distribution of 1342-1343 flood events according to rivers and catchments (Dc=Danube catchment, Tc=Tisza catchment). For locations and areas affected, see *Figs. 1-3* above

Typical common characteristics of the two years are the unusually great number of flood events, both separated and spreaded in space and time, and also the great importance of spring floods, in both years rather evenly distributed in time. Another similarity is that the flood events in most cases occurred on or in the closest vicinity of the two (or three: also accounting with the Drava river) major rivers of the Carpathian basin, and only in two-two cases medium- or small-size rivers/river catchments were affected (*Fig. 6*).

Comparing the two greatest flood years, apart from the clear difference concerning the catchment areas affected (1342: Danube and Tisza; 1343: only Tisza), an important other difference is that most of the floods reported in 1342 were marked as great or extensive in magnitude: it is true for all winter and spring floods detected in this year, either occurred on the Tisza or the Danube catchments. Whereas in 1342, both in case of the Danube (early April) and in case of the (Upper-)Tisza in early May, the extent water surfaces might suggest the existence of inland excess waters, only the word ’*inundatio*’ was used in 1343 in the flood cases mentioned related to the Tisza catchment. Nevertheless, in the number of flood events reported, in the eastern parts of the Carpathian basin, namely in the catchment area of the Tisza river, 1343 has at least the same or even more importance than the year of 1342.

CONCLUSIONS AND OUTLOOK

Prevailing wet character of weather can be detected in Central Europe in 1342, which on the one hand led to three devastating flood waves in 1342, and presumably also at least two in 1343. In the latter year not only in Central Europe, but reports are also available referring to northern Italy. Moreover, extraordinary cool and wet weather and floods resulted in need and hunger in the German territories and Austria in 1343 and 1344.

With reference to the Carpathian basin, no directly weather-related information is yet available concerning 1343. In 1342, most probably generally preavailing cool and maybe also wet late spring–summer conditions caused the presumably late grain harvest in West-Hungary. The mid-September snow report in present-day West-Slovakia provides us information for presumably extraordinary cold weather in early autumn of 1342, when in the same time flood was observed in the southwest, in the immediate vicinity of the Drava river. The great amount and magnitude of flood events might suggest a precipitation surplus in winter, spring and late-summer and autumn in 1342. Based on the large number of flood events, covering each season, wet character of 1343 can also be rendered.

1342 and 1343 are clearly the most important flood years reported in medieval Hungary. The seven flood events in 1342 are relatively evenly distributed between the two main catchment areas, all six flood reports refer only to the events occurred in northern, northeastern parts of the Tisza catchments. Most of the flood events in 1342 were either great in magnitude or could be connected to great extent of waters. Another speciality is that, similar to the Czech lands and Austria, the famous millennial 1342 summer flood event, causing great damages in West Central Europe, cannot be really detected in the Carpathian basin. In contrast, in 1343 floods were observed along the Tisza river and in the Tisza catchment in all four seasons. In 1342, both along the Danube and the Tisza rivers, at least concerning spring time, we presumably should count with great extension of inland excess waters, which waters perhaps still caused problems in 1343.

Among future tasks related to this subject, it could be important to find more parallels with the neighbouring areas and other parts of Europe. Concerning large-scale patterns, a complex analysis of these unique flood years on an European level (e.g. Mediterranean cyclonic activities included) might also be an interesting direction of research. Moreover, another relevant task could be to detect possible short- and medium-term economic and social effects of this anomaly in the Hungarian kingdom.

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GLOBAL WARMING INDUCED CHANGES IN THE MEANS AND EXTREMITIES OF TEMPERATURE AND PRECIPITATION IN HUNGARY

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Abstract

Regional climate changes are still one of the most difficult problems of the climate change issue. Results by three scientific approaches, the raw General Circulation Models (GCM), the mesoscale models, compiled from the *PRUDENCE* project, and an empirical method, called *Natural experiment* are compared. The latter approach provides estimations of the future changes based on regression coefficients between the local and global variables in the monotonously warming 1976-2007 period. The global model results comprise results of 9 AOGCMs, whereas in the PRUDENCE set of 5 model outputs are analysed. The listed results start with changes in the seasonal temperature and precipitation averages. Here the signs and the magnitudes are similar according to all approaches: Faster than global mean temperature increases in all seasons, with strongly decreasing precipitation in summer and autumn but increased amounts in winter and spring. There is also a fair agreement of the three approaches in the temperature extremes of the warm half-year in Hungary, with much less unequivocal picture in the frequency of frozen days in the cold half of the year. For precipitation, again, the summer maxima of diurnal totals behave similarly according to the three approaches in all regions of the country. Namely, they exhibit unequivocal increase, whereas no clear picture is seen for frequency of wet/dry days.

Key words: climate change, GCM; mesoscale modelling; statistical downscaling; Hungary

1. INTRODUCTION

Despite the recent significant improvement in regional climate modelling (RCM, see e.g. in Christensen et al., 2007), regional impacts of the ongoing and projected global climate change are more difficult to estimate than the global effects. Current global climate models still do not incorporate important scales of physical processes that are significant in formulating regional and local climate. Another problem for the impact community is the lack of comparison between the different regional scenarios prepared by different methodologies in the past.

Present GCMs are too coarse to yield regional details of climate change, especially in the case of the extremes. Combination of a GCM and a regional model may promise better results, but one should not forget the governing role of the applied mainframe GCM, which determines the boundary conditions for the regional model. This role is clearly demonstrated in Fig. 11.6 of the IPCC (2007) Scientific Report, where two different mainframe models (Hadley Centre of the British MetOffice and Max Planck Institute for Meteorology, Hamburg) led to different response of the same regional model (Rossby Centre, Stockholm).

Despite these shortcomings of the regional modeling the authors do not question that meso-scale modeling is the most perspective way to obtain valid and physically plausible projections of future climate states, especially if considering short life-time and extreme weather events. Moreover, we recommend a set of state of the art European model studies, including those by Csima G. and Horányi A. (2008); Szépszó G. and Horányi A. (2008) and Torma Cs. et al. (2008) presenting the newest generation of the RCMs run in Hungary. Besides these papers two further papers can be recommended from the same special issue, complied from the results of European PRUDENCE project by Bartholy J. et al. (2008) and Szépszó G. (2008). Some results of the latter study, provided by Szépszó G. (2008), will also be reflected here in our comparison.

The aim of the present paper is to compare selected scenarios with respect to four precipitation and temperature extremities. They are dry/wet days, precipitation, frost and heat-wave. The changes are investigated by three parallel methods:

- average changes in 9 coupled AOGCMs, directly derived from Tebaldi C. et al (2006);
- changes in 5 models of the PRUDENCE Project, provided by both B2 and A2 scenarios (Christensen J. H. – Christensen O. B. 2007), specially elaborated for Hungary;
- empirical linear trends in the monotonously warming 1976-2007 period.

The applied precipitation extreme indices (following Frich P. et al. (2002, later F02) are:

1. Maximum number of consecutive dry days (*dry days*, or CDD in F02).
2. Frequency of dry days (R < 0.1 mm or 1.0 mm)
3. Number of days with precipitation higher than 10 mm (*precip*≥ 10 or 20; R10, R20 in F02).

The applied indices to describe temperature-related extremes:

4. Total number of frost days, defined as the annual total number of days with absolute minimum temperature below 0 °C (*frost days*, or Fd in F02).

5. Heat wave duration index, defined as the maximum period of at least 5 consecutive days with maximum temperature higher by at least 5 °C than the climate normal for the same calendar day (*heat-waves*, or HWDI in F02).

6. Frequency of hot days (T_{max} > 30 °C).

Summary of the compared indices are displayed in *Table 1.*

Table 1. Model-related frequency (e.g. R > 0.1 mm) of the given event. *CDD* is for the maximum number of *c*onsecutive *d*ry *d*ays, *HWDI* means *h*eat *w*ave *d*uration *i*ndex, i.e. maximum number of consecutive days with $T_{max} \geq T_{norm}+5^oC$, where T_{norm} is the climate normal for the given calendar day

Model	*Wet (dry) days*	*Precipitation*	*Frost*	*Heat-wave*
GCM	CDD	R>10 mm	T_{min} < 0 °C	HWDI
PRUDENCE	R ≥ 0.1 mm	R>20 mm	T_{min} < 0 °C	T_{max} > 30 °C
Empirical	R ≥ 1.0 mm	R>20 mm	T_{min} < 0 °C	T_{max} > 30 °C

2. METHODS PROVIDING EXTREME INDEX SCENARIOS

2.1 General Circulation Models

In the recent IPCC (2007) Report (Meehl G. A. et al. 2007) displays maps of extreme indices with reference on Tebaldi C. et al. (2006). We simply downloaded four graphical maps of the indices from www.cgd.ucar.edu/ccr/publications/tebaldi-extremes.html. Three maps are as in Fig. 10.18-19 of the Report (i.e. those, normalized against standard deviations by the IPCC), but for precipitation we used R10 instead of the mean intensity. The models used by Tebaldi C. et al. (2006) are the DOE/NCAR Parallel Climate Model (PCM; Washington W. et al. 2000) and Coupled Climate System Model (CCSM3), the CCSR MIROC medium and high resolution models (Hasumi H. – Emori S. 2004), INM-CM3 (Diansky N. A. – Volodin E. M. 2002), CNRM-CM3,6 GFDL-CM2.0 and 2.1 (Delworth T. L. et al. 2002, Dixon K. W. et al. 2003) and MRI-CGCM2 (Yukimoto S. et al. 2001). The model grid resolutions vary from 5°×4° to 1.125°. Model simulations are used from the A1B (mid-range) SRES scenarios (Nakicenovic N. – Swart R. 2000). The projected and control periods are 2080-2099 and 1980-1999, respectively.

2.2 Mesoscale models

Results of two times 5 RCM experiments, carried out in the framework of PRUDENCE Project (Christensen et al., 2007), which provided both A2 and B2 runs for 2071-2100 are further analysed. These models are: HIRHAM (DMI), RegCM (ITCP), HadRM3P (HC), RCAO (SMHI), PROMES (UCM).

The main objective of the PRUDENCE project was to provide high resolution climate change scenarios for Europe at the end of the 21th century by dynamical downscaling of global climate simulations. A total of 9 RCMs were used at a spatial resolution of roughly 50 km x 50 km for the time windows 1961-1990 and 2071-2100. More than 30 experiments were conducted with respect to the A2 and B2 SRES emission scenarios. Further details concerning the experimental setup are given in Christensen J. H. and Christensen O. B. (2007).

2.3 Empirical regression

Linear trend estimations of the local extreme indices are performed for the 1976-2007 period which is monotonously warming at the Northern Hemisphere. We may call it “natural experiment”, hence these three decades are mainly driven by anthropogenic greenhouse gas forcing, similarly to that one should expect in the following decades, at least. 15 temperature stations and 58 precipitation stations of Hungary are used to estimate the trends (regression coefficients). Since the precipitation results were quite different in their signs and significance, the 58 stations were sorted into 6 groups, according to the administrative numbers to ensure regionality of this amalgamation. The derived trend values (^{o}C/yr) are then multiplied by 110 years, which is the span of the PRUDENCE results. (The GCM-based changes correspond to 100 years, see 2.1.) Before the extreme index calculations, the daily time series were homogenised with the MASHv3.01 procedure (Szentimrey T. 1999, 2006).

Before we provide the results of this comparison, we hereby include the results of the similar analysis for seasonal maxima and minima.

3. COMPARISON OF CHANGES IN THE LOCAL AVERAGES

In this Section some earlier results (Mika J. 1988, 2006) are compared to more recent approaches of the IPCC AR4 (2007) and the PRUDENCE results. In Table 2 there are the expected changes for 2030 in the order of the three above approaches. More specifically, the *first line (IPCC, 2007)* contains the GCM-based results from the maps published in the Report and the Supplementary Materials ti the Chapter 10. The number of available models is 22. The *second line (PRUDENCE)* contains mean regional estimates from 25 different experiments. The gridpoint distance of the RCMs is ca. 50 km, which is much better than the ca. 200 km in case of the given GCM-s. The third line averages two simple statistical approaches (Mika J. 1988, 2006) and three paleoclimate analogies, i.e. 6 thousand, 122 thousand and 4 million years BP, (Mika J. 1991), i.e. five calculations. In majority of the results, when the experiment or the analogy did not refer to exactly 1 K global change, linear interpolation of the results were performed to obtain the scenario for 2030, when 1 K global warming is expected in majority of the global expectations comparing to 1961-1990.

Temperature exhibits higher changes in Hungary than the global averages (Table 2), though the three approaches give different orders of the seasons in this respect. The annual totals of precipitation do not change substantially, but its values decrease with the global warming in summer and autumn, whereas increased precipitation is expected in winter and spring.

The coincidence among the above changes means, that considering the 25, 21 and 5 individual scientific approaches, the similarity of the changes of the methods concerning their sign and order of magnitude can be seen as robust consequences of the anthropogenic global warming at least for the annual and seasonal averages of temperature and precipitation.

Table 2 Changes of annual and seasonal means of temperature and precipitation in Hungary for 2030 compared to 1961-1990. The average changes represent 25, 21 and 5 approaches. The global mean change is ca. 1.0 K according to the IPCC (2007) A2 projections

A2 scenario	Global change = 1.0 K for 2030					
Approach	Temperature change (K)	Annual	DJF	MAM	JJA	SON
IPCC 2007	Mean	0.9	1.0		1.3	
PRUDENCE	Mean	1.4	1.3	1.1	1.7	1.5
EMPIRICAL	Mean	1.6	2.0		1.1	
A2 scenario	Global change = 1.0 K for 2030					
Approach	Precipitation change (%)	Annual	DJF	MAM	JJA	SON
IPCC 2007	Total	-0.7	1.9		-3.7	
PRUDENCE	Total	-0.3	9.0	0.9	-8.2	-1.9
EMPIRICAL	Total	-2.2	7.6		-19.7	

4. COMPARISON OF SELECTED WEATHER EXTREMES

Weather extremes are even more problematic components of the projected regional climate changes, since, as our analysis demonstrates below, for them no unequivocal similarity exists. The four different extreme events are briefly analised in the following pages, where the maps and figures are found. Here, as general experience, we can conclude that two global and the regional models give fairly similar results for Hungary, despite the fact that the former source is used in average of the 9 models, whereas the PRUDENCE set is analised model-by-model.

Contrary to the similarity of the behaviour in the two modeling approaches, the empirical analyses differ from the model results in some respects. Frequency of dry days clearly increases according to the modeling approaches, but no clear trends appear empirically. The more frequent occurrence of heavy precipitation seems to be a common feature of climate in all approaches. Frequency of frost days should decrease according to both modeling tools, but the empirical analysis, again, does not support this consequence. For the hot extremes, however, all the three approaches give substantial increase of such days or events.

To assess significance of the empirical trends, one should know that only the frequency trends of hot days are significant at the 95 % level for all the 15 stations, compared to the inter-annual variability, with respect to the t-test. Contrary to this, frost days did not show significant trend in any station. Precipitation and extremity (R>20 mm/day) trends were also rare, 10 and 26 %, respectively. This is why we applied the sub-regional averages.

In the case of the diverging results, we need further investigations to explore the origin of these differences. One reason may be the remaining inhomogeneity in the diurnal series. Another reason for the deviations may be that statistical extrapolation of the trends presumes that the established relations remain unchanged in the future. However, the different forcing factors of various time periods may cause different regional changes. Hence, the results of the various approaches should ideally be intercompared for identical time periods.

4.1 Precipitation existence

Frequency of dry days increases in both modeling approaches. In the "natural experiment", the results are less unequivocal and just in 10 % of the stations significant. In 3 regions the wet days became more frequent, in 2 regions less frequent and 1 region showed no trend.

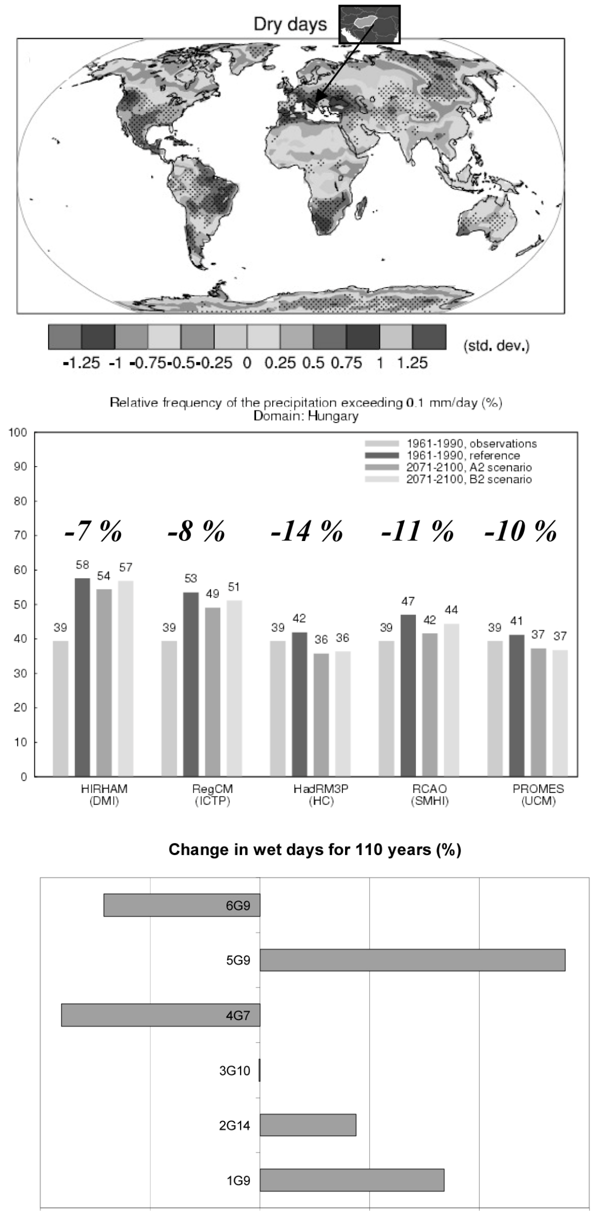

Fig. 1 Changes in the precipitation frequency, based on annual maxima of dry days in 9 GCMs for 2080-2099 vs. 1980-1999 (upper panel), frequency of wet days (R ≥ 0.1 mm/day) in coupled meso-scale PRUDENCE simulations for 2071-2100 vs. 1961-1990 (middle); and of R ≥ 1.0 mm/day for 110 years extrapolated from the trend analysis of 1976-2007 (lower)

4.2 Precipitation extremes

Frequency of heavy precipitation substantially increases according to all approaches. The empirical trends, significant in 26 % of the stations, yield even stronger increase than meso-scale modeling. In both cases there are strong inter-model and inter-region differences, respectively. The R>10 mm threshold and weaker GCM resolution mean clear but smaller changes.

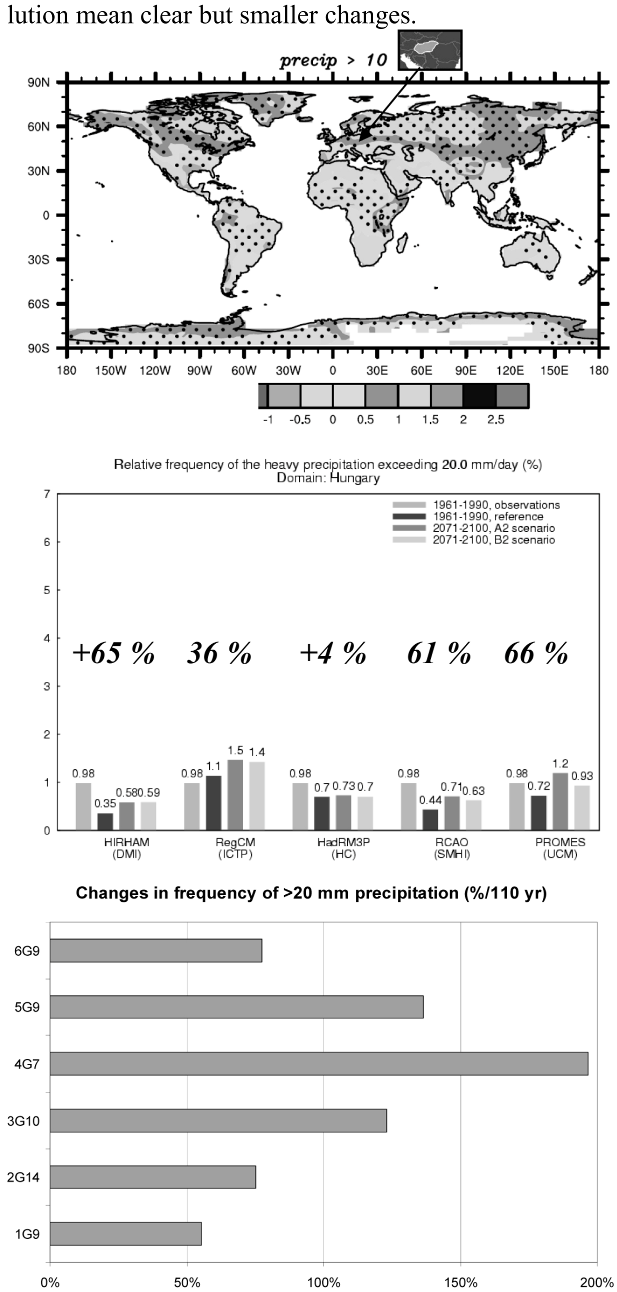

Fig. 2 Same as Fig. 1, but for the frequency of heavy precipitation, based on R>10 mm/day threshold (upper) and on R>20 mm/day threshold (middle and lower)

4.3 Low temperature extremes

Frequency of frost days substantially decreases according to both model approaches. But, 7 of the 15 stations involved into the trend analysis, however, indicate increase of the frost day frequency. But, none of the changes are significant at any individual station!

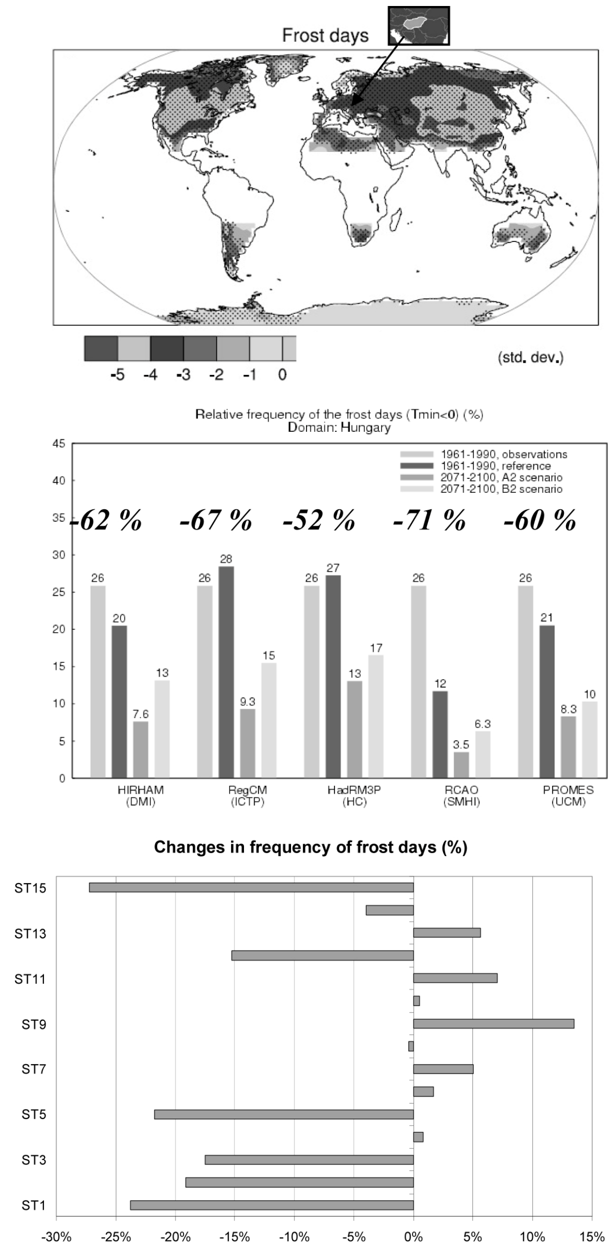

Fig. 3 Same as Fig. 1, but for changes in the number of frost (Tmin <0 °C) days (all panels)

4.4 High temperature extremes

Frequency of heat waves or hot days increases dramatically by all methods. The empirical approach gives even stronger changes than the PRUDENCE models. The GCM experiments yield very strong changes, indicating that not resolved meso-scale processes do not strongly contribute to the positive temperature anomalies.

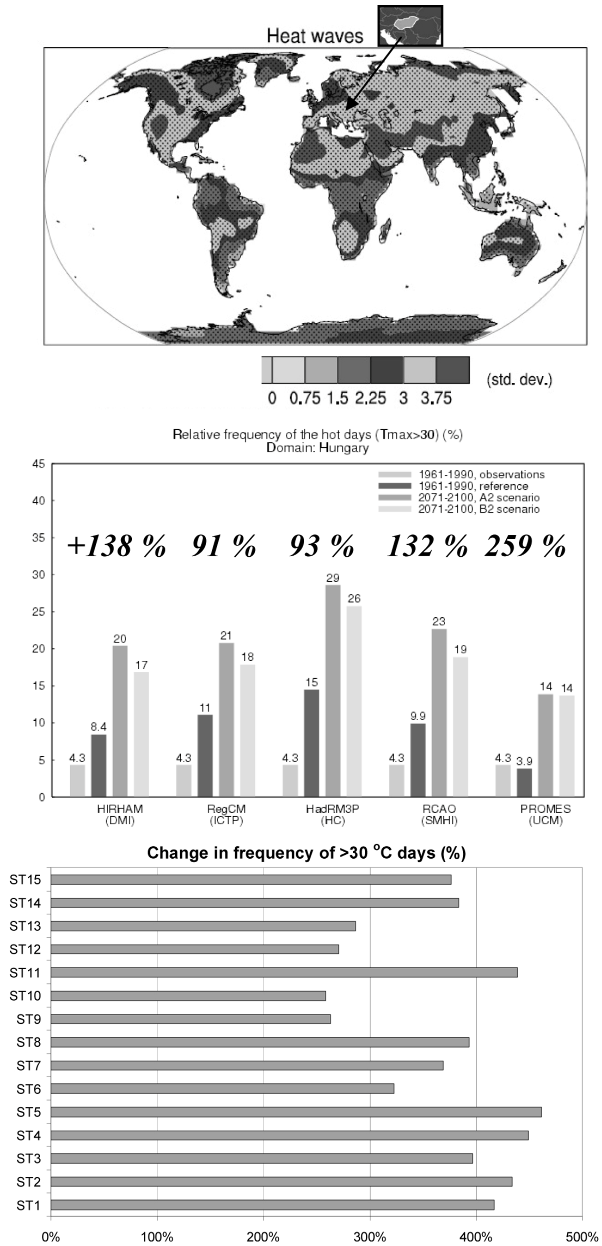

Fig. 4 Same as Fig. 1, but for changes in frequency of heat-waves based on frequency of the events when at least 5 consecutive days with T_{max} higher than the climate normal of the same day by at least 5 °C (upper); on frequency of hot days (T_{max}>30 °C) (middle and lower).

5 DISCUSSION

Changes in seasonal averages and in daily extremities of temperature and precipitation were analised parallel to the past and future global warming tendencies in three different methodologies. The changes in the seasonal and annual averages behave similarly according to these approaches. This means faster than global mean temperature increases in all seasons, with strongly decreasing precipitation in summer and autumn, but with increased amounts in winter and spring.

There is also a fair agreement among the approaches in the frequency of high temperature extremes and in the maxima of diurnal precipitation totals in all regions of the country. For these regional changes one may conclude that even if the applied individual methodologies are not absolutely exact (see below), the similarity of the results is convincing.

No ideal coincidence is established, however, in frequency of the frozen days and in frequency of the wet days. The two modeling approaches indicate decrease in both variables, but the empirical analysis yields cracked spatial picture with areas of both increasing and decreasing frequencies within the country.

In these two cases one should analise the shortcomings of the approaches before the particular conclusion. The shortcomings of the *GCM modeling* approaches are the coarse resolution with the lack of significant physical processes, especially of those driving the occurrence of the extremes. For the *RCM modeling*, the still insufficient (ca. 50 km) grid resolution should be mentioned, which is bounded by single mainframe models, not reflecting the full variability of the projections at the boundary of the imbedded model. The *Natural Experiment* empirical approach is based on observed data which are homogenised on monthly basis, hence one may not be sure that the inhomogeneities of the observations, that may be enhanced in extreme circumstances, did not influence the observed trend too strongly. In case of all investigations based on past data, one may also doubt that the difference in the causes among the two time sequences did not affect the result also in case of the diurnal extremes.

At present, the authors have no definite answer on the question if one should believe the majority of the results, i.e. one should accept that both the wet and the frozen days become less frequent with the global warming. A better strategy is to develop for all the approaches. This means that a new post-AR4 generation of the GCMs will gradually be available. The RCMs are even now much better resolved even in Hungary (their validation is already presented in the papers published in 2008, as referred in Section 1. Finally, the homogeneity of the diurnal series should specially be checked for the behaviour of the extremities.

Before these steps one can only make a practical, but not a scientific conclusion about the sign of the changes in case of these extremities.

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