2 Climate of Hungary

Abstract

The climate of the Carpathian Basin reflects the combined characteristics of the neighbouring regions. Despite of the small area and the modest orographic differences of the country, the climate elements (e.g. solar radiation, temperature or precipitation conditions) have distinctive spatial and temporal characters. The result of climatic measurements and the differences in the values will be described in this chapter. Besides, the agro-economical (e.g. drought hazard) and environmental resource potential of the climate (e.g. wind energy utilization) will be introduced. The latest will be described in detail (e.g. recreational potentials and skiing, are limited in natural conditions), as well as the renewable energy sources. Based on estimations, the potential amount of solar radiation (72 PJ,), wind energy (46 PJ), geothermal energy (50 PJ) and biomass (120 PJ) is far higher than the actual usage of these energy resources, which altogether is lower than 10 PJ, if the biomass usage (ca. 52 PJ) is not accounted. In this chapter, the special climate characters of the cities will be analysed too. Slightly detailed description is provided on the potentials (mountainous medical locations) and hazards of the climate (e.g. rainstorm hazard, heat stress, increasing extremities). The past and future climate changes of the Basin are also analysed.

2.1 Factors Influencing the Climate of the Carpathian Basin, the Climate Type

The climatic features of the Carpathian Basin are primarily defined by its location, which influences the angle of the incoming solar radiation. The country is situated between 45°45′N and 48°35′N latitudes, and between 16°5′E and 22°58′E longitudes. It is situated in between different climatic zones; therefore, the climate is mainly characterized by the features of the humid oceanic climate slightly varying temperatures and by the features of the less humid continental climate with more extreme temperatures. The annual mean temperature is about 2.5 °C higher than the typical value at this latitude, due to the influences (e.g. currents) of the Atlantic Ocean and the Mediterranean Sea that cause positive temperature anomaly in the Carpathian Basin.

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The climate is transitional, whose actual character is defined by the interactions of four major pressure systems ("action centres") and the resulting strongly variable surface pressure pattern (Péczely 2002):

– Temperate maritime air masses ("Iceland low"), which transport mild air in winter, and cool but humid air in summer;
– The temperate air masses of continental origin ("Siberian high"), which cause dry and very cold weather in winter and can cause critical air pollution in spite of the northerly and easterly winds (since they can strongly hinder the ventilation of the basin in the time of their winter activity;
– Subtropical air masses of oceanic origin ("Azores high"), which are active throughout the year, and transporting humid air with southerly and westerly airflow;
– The subtropical air masses of continental origin, carrying heat in the summer with southerly airflows ("Persian trough").

In the summer half-year, 60–70 % of the air masses arriving have oceanic origin, while continental air masses are prevailing in the winter half-year. In addition to these major impacts, Hungary is also influenced by the Mediterranean effect, prevailing primarily in periods of quiet autumn rains and in the early winter snowfalls (MET2 2009).

According to the Trewartha climate classification system, which is one of the most common classifications, the climate of Hungary is a (humid) subtype of the continental climate with long-warm season and a significant temperature fluctuation. Its main feature is the four distinct seasons, which sometimes take on an extreme character. The summer is long, it lasts for at least 3 months, its mean temperature is above 18 °C, and the daily maximum is frequently above 35 °C in the middle of the summer. The winter temperature is instable, colder and milder periods alternate; however, the number of months with a mean temperature below 0 °C is not more than three. The amount of total precipitation significantly differs in Hungary, but still satisfies the water demand of the society (see Chap. 3).

Apart from the transitional character, the other key feature of the climate is its basin character. Firstly, the disadvantages of the closed basin have to be highlighted, as the significant temperature variation, or the low wind energy (and to a smaller extent, the basin character can also influence the amount of precipitation). The irradiation conditions are more advantageous, especially for the agriculture. Among the disadvantageous consequences, the negative human health effect of the increased winter air pollution has to be mentioned.

Even the slight topographic differences can cause significant local variations in the climate; e.g., in the winter half-year, the total amount of sunshine duration is 50 % higher in the mountainous areas because of the cleaner air. More than a half of the country is a lowland plain area, with an elevation less than 200 m above sea level; thus, there are no significant orographically influenced regional differences in the climate.

On the basis of the global climate classification systems (e.g. Köppen, Trewartha), regional climate differences within the country cannot be identified due to the size of the country. Therefore, a different local-scale classification system has to be applied to reveal the regional differences. Bacsó (1959) made an attempt at it, and some preliminary attempts are also described in the climate atlas of Kakas (1960). The regional climate classification was developed on the basis of Péczely's (1979) water and heat availability categories. Based on these categories, 12 regions were defined which are characterized as wet or dry from the point of view of water supply and as warm or cool from the point of heat supply.

2.2 Spatial and Temporal Characteristics of the Main Climatic Parameters

In this chapter, the spatial features and interrelations of the sunshine duration, temperature, precipitation and wind conditions are introduced, which define several site conditions important for the society (see Sect. 2.3.).

2.2.1 Regional Differences in Sunshine Duration

Although the amount of solar radiation is reduced by several factors, (e.g. half of it is absorbed or reflected by the clouds), a rather large amount of energy still reaches the surface. Bartholy (2000) calculated that the annual surface radiation balance of an area of 20 km^2 equals to the yearly energy consumption of capital city, Budapest (about 10^{11} MJ). The spatial distribution of sunshine shows that its value is higher by 10–15 % in the central part of the Great Hungarian Plain than that in the northern or western near-border areas (Fig. 2.1; MNA 1989; MT 2002; OMSZ 2003). The highest values in the central part of the Great Hungarian Plain can exceed 5000 MJ, while 500 MJ lower values are typical in the western and north-eastern border regions. The amount of energy in the summer months is 5–6 times greater than that in the winter months. The highest values can be measured in July and not in June, because of the much smaller cloud cover of the former.

The duration of sunshine varies between 1800 and 2200 h in the Carpathian Basin (Fig. 2.2). The highest values occur in the southern part of Hungary; however, they still do not reach the half of the potential latitudinal values. The relief can significantly diversify the spatial pattern; e.g., during winter periods, when the mountains emerge from the cold, foggy air that covers the basin, higher temperatures and higher sunshine duration are measured in the mountains than in the lowlands.

2.2.2 Spatial Distribution of Air Temperature

The air temperature is primarily influenced by the cyclones and anticyclones of the major pressure systems described earlier, but secondarily, it is

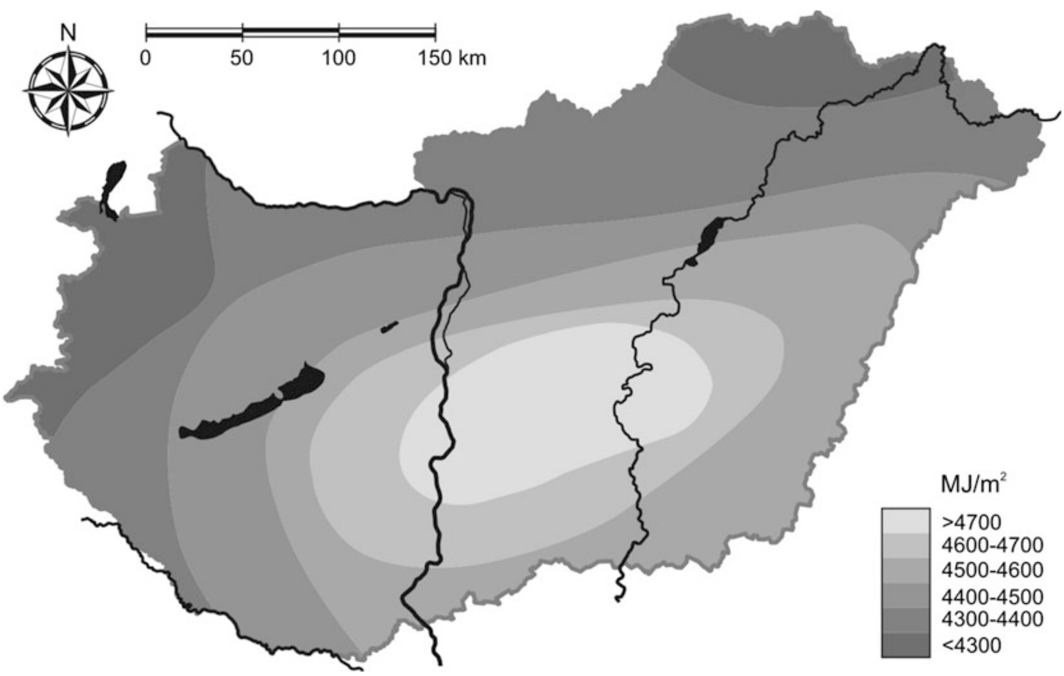

Fig. 2.1 The spatial distribution of the yearly amount of global radiation (MT 2002)

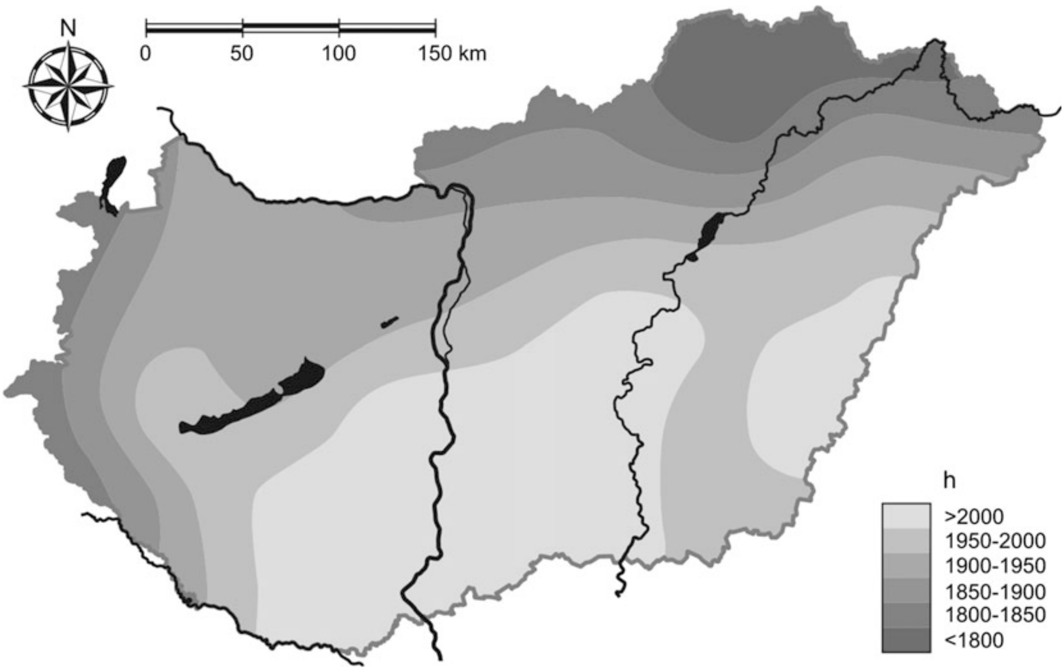

Fig. 2.2 The total annual sunshine duration (after OMSZ 2003)

influenced by topography too. On the western part of the country and in the hilly regions, lower annual mean temperature (8–11 °C) values are characteristic, while on the majority of the Great Hungarian Plain, the annual mean temperature is higher than 10 °C (Fig. 2.3). The slope aspect also influences the temperature; generally, the southern slopes of the mountains are much warmer than the northern ones. The highest annual mean temperatures are typical in the south-south-eastern part of the Great Hungarian Plain. The observed maximum annual mean temperature (13.3 °C) was measured in the downtown of Szeged (SE Hungary), and in this year, 12.7 °C was measured also in the neighbouring settlements. The absolute maximum temperature (41.9 °C) was recorded in Kiskunhalas on 20 July 2007, while the absolute minimum (–35 °C) was recorded in Miskolc on 16 February 1940 (MET3 2009). The average annual temperature fluctuation is over 20 °C, and the absolute annual temperature fluctuation exceeds the 65 °C in the whole country (MT 2002), which shows the continental character of the climate. Based on the 30-year average of the 1961–1990 periods, the mean temperature in January is between −1.5 and 3.5°C in the country, while in July, it is between 19 and 21 °C.

The yearly temperature pattern is defined by the large-scale climatic factors (e.g. global radiation), while the daily patterns are defined by local environmental factors (e.g. relief, cloud cover; MET2 2009). Between the northern and southern parts of the country, only a slight temperature difference can be observed because of the size of the country. The 3 °C annual mean temperature difference results in the 6–9 days' advance of the phenological phases in agriculture in the southern areas. The effect of height differences of the hilly regions can be estimated with more difficulties because of the local influencing factors, but according to the estimates, it is lower than 0.65 °C/100 m.

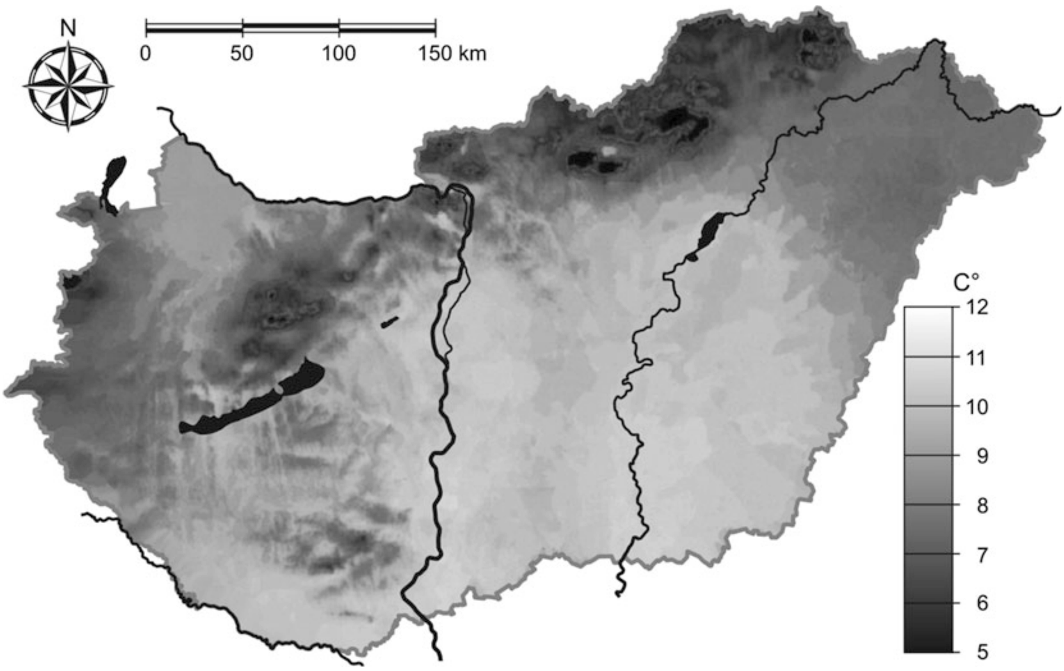

Fig. 2.3 The average annual mean temperature in Hungary between 1901 and 2000 (after MET3 2009)

2.2.3 Spatial Differences in Precipitation

The 600-mm annual precipitation in the centre part of the basin generally fulfils the water demands, as in average, the evaporation rate is 89 % of the total precipitation, though the evaporation can be estimated with errors (MT 2002). In general, the amount of precipitation decreases from the west towards the east (with the increasing continental character), and it increases with the increase in the height above sea level (by 15–35 mm/100 m; OMSZ 2003). The precipitation seems to be sufficient; however, its spatial and temporal distribution and its extremes can cause problems.

Based on the 30-year average of the 1961–1990 period, the precipitation amount varies mostly between 500 and 800 mm: the centre part of the Great Hungarian Plain is the most arid, while the south-western part of the country, the foothills of the Alps, and the higher regions of the mountains are the most humid (Fig. 2.4). The precipitation exceeds 800 mm on 3 % of the area (and exceeds 700 mm on 14 %), and it is lower than 500 mm in 2 % (but it is lower than 550 mm in 27 %; Lovász and Majoros 1994). The recorded lowest annual precipitation (203 mm) occurred in 2000 in Szeged.

The precipitation amount usually exceeds the evaporation (400-600 mm) in the whole country (Weidinger and Mészáros 2000). The total amount of yearly evaporation is influenced by not just the precipitation, but also by the soil moisture (Ács et al. 2007); thus, it is the greatest in Western Transdanubia. However, the potential evaporation is much higher than the precipitation in the summer half-year; thus, it sometimes reaches the 250–300 mm in the centre part of the Great Hungarian Plain, which means 250–300 mm water shortage. In periods of lower precipitation, lower air humidity or higher temperatures, water shortage (drought) can be evolved, which often appear in the central areas of the Great Hungarian Plain. Drought has several different types, depending on the point of view of the study: thus, meteorological or atmospheric (the precipitation is lower than

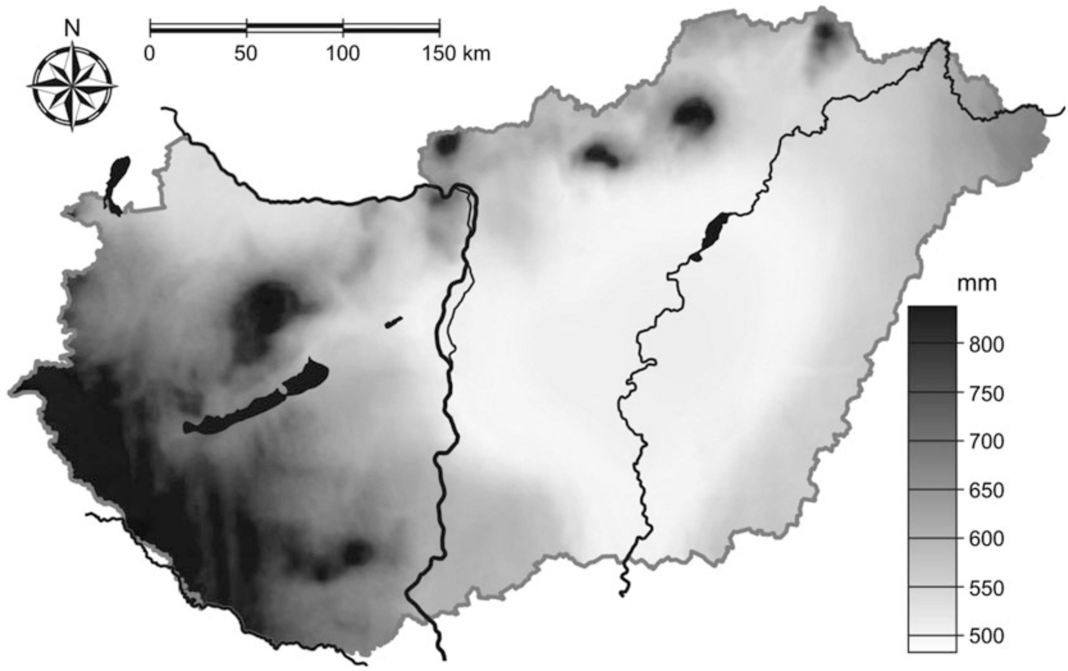

Fig. 2.4 Spatial distribution of the mean annual precipitation between 1960 and 1990 (after OMSZ 2003)

usual, while the temperature is high), hydrological (low level of groundwater and rivers), pedological (water shortage hinders the vegetation) and agricultural drought can be distinguished (Mezősi 2008).

Drought is one of the most serious environmental challenges in Hungary, caused by several factors. The amount and distribution of precipitation (in the growing season) is a major factor, but the evaporation, which mainly depends on temperature, the fertile layer and the physical character of the soil, is also important. From the agricultural point of view, these factors can hardly be modified. The evolution of droughts also depends on land use (its water demand), the selection of culture and the moisture saving cultivation methods; thus, the intensity of drought can be artificially influenced by several ways.

In Hungary, the most commonly used index to describe drought is the Pálfai Drought Index (PAI; Pálfai 2002), since the data of the widely used Palmer Drought Severity Index are not available (Horváth et al. 2001). The PAI is suitable to describe the yearly changes of drought rate, and it integrates the April–August air temperatures and the monthly precipitation values with different weighting (summer month have the highest weights); moreover, correction factors estimate the heat periods and dry periods, and the changes of the groundwater are also used for the calculation. The typical values are between 6 and 12 (°C/100 mm) in Hungary. The areas with a value of 5–6 are mildly, while the areas with values over 10 are greatly affected by drought (Fig. 2.5).

The spatial pattern of drought occurrence shows high variability. Most part of the country is affected by mild drought that can occur in every third year on the centre part of the Great Hungarian Plain. Heavy drought occurred only in the centre part of the Great Hungarian Plain in the past 100 years, with a return period of 20–50 years, while it occurs every 50–100 years in its peripheral regions (Pálfai 2002). Serious drought events were documented as also in the previous centuries: it was well documented in 1794 and 1863, and during the period of 1779–1800, altogether 11 unusually dry years

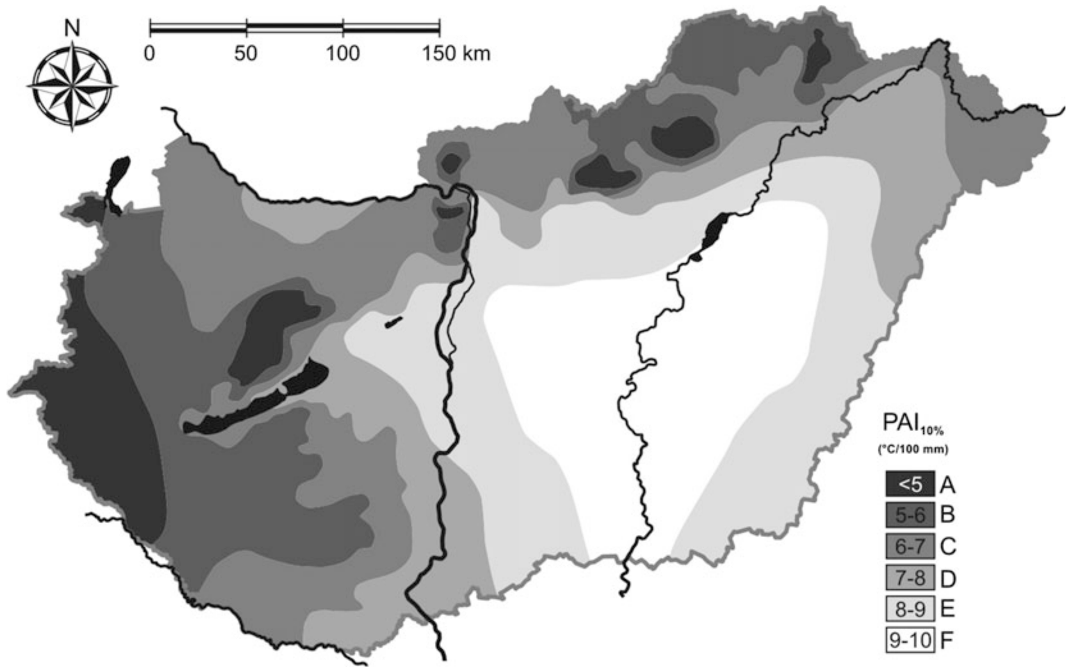

Fig. 2.5 Drought map of Hungary (after Pálfai 2004) **a** no drought hazard, **b** low hazard, **c** moderate hazard, **d** medium hazard, **e** serious hazard, **f** extreme drought hazard

appeared. Every drought events have unique characteristics that make any future predictions related to the hazard difficult, despite the long-term data sets, besides it would require a precise, long-term weather forecast, which is not available at the moment.

The temporal changes in precipitation distribution in Hungary have well distinguishable characters: the larger proportion of the yearly precipitation occurs in the summer half-year, and the yearly precipitation has two peak periods. The first precipitation maximum occurs in May–June, which is connected to the activity of the Atlantic air masses. (This early summer precipitation maximum was formerly called as the "European monsoon", although incorrectly.) The second maximum in autumn (September–October) is caused by the influence of the Mediterranean air masses. The minimum precipitation occurs in the middle of winter (December–January), when the anticyclones cause cold and dry weather. The annual precipitation amount has decreased in the past decades (MT 2002). The significantly recorded 100-mm decrease in the Danube-Tisza Interfluve during the past 100 years is particularly alarming (Kertész and Mika 1999). The observed decrease mainly affects the spring period; however, its spatial distribution is diverse.

The extreme values of precipitation demonstrate the extremities of the climate. In some years, more than 50-day-long dry period was recorded without any precipitation in Great Hungarian Plain: it had not rained for 52 days in Gyula in 1897. On the other hand, an annual amount of over 1000 mm is not rare in the western part of Hungary. High intensity storms can also cause serious damages, as it was recorded several times in the past decade, causing floods and flash floods (e.g. in 2010), soil erosion and accumulation (e.g. at Mátrakeresztes, Bükkzsérc, Mád, Gönc, Szabó 2001), or landslides. The precipitation is much more unpredictable than the temperatures, especially in the central part of the Great Hungarian Plain, where the yearly variability is significant.

The efficiency of the agriculture depends more on the amount of precipitation (and its distribution) than on the fertility of the soil. Thus, for example, the more humid environment compensates the lower fertility of soils in the Little Hungarian Plain compared to the Great Hungarian Plain. The precipitation difference is 200 mm in the growing season and the typical precipitation amount is 400–500 mm in West Transdanubia and North Hungary, while it is under 300 mm in the centre part of the Great Hungarian Plain; in addition, its distribution is more favourable in the western and northern parts of the country (Botos and Varga-Haszonits 1974).

2.2.4 Wind Conditions

The wind conditions are basically defined by cyclones and anticyclones arriving in the Carpathian Basin. They can be modified by the topography on a regional scale in the cases of winds under 100 m absolute height (e.g. orography is likely to cause the variety of wind conditions in the North Hungarian Mountains). At a few kilometres height, western winds are dominant. The main wind direction is NW and N; thus, winds arrive through the Devín (Dévény) Gate reach the line of the Tisza River, while the NE and N winds are typical on the eastern part of Hungary, which winds are often the source of the intense cold convections in winter (Fig. 2.6). The typical temporal pattern of the wind direction is that east of the Tisza, the NW winter winds change to NE during the summer half-year (Tar 2007; the wind directions and velocity are based on the map made by Dobosi and Felméry in 1971). The complexity of the wind directions is caused by the circulation phases and the topographic conditions (Péczely 2002). The distribution of the near-surface directions is not constant either, and the assessment of measurement results is not simple because the relative frequency of wind directions is small (max. 27 % in the eight-directional breakdown). Moreover, a similar amount of winds proceed in the main directions, as in the opposite directions (e.g. 25 % of winds is NE and 22 % SW at Nyíregyháza).

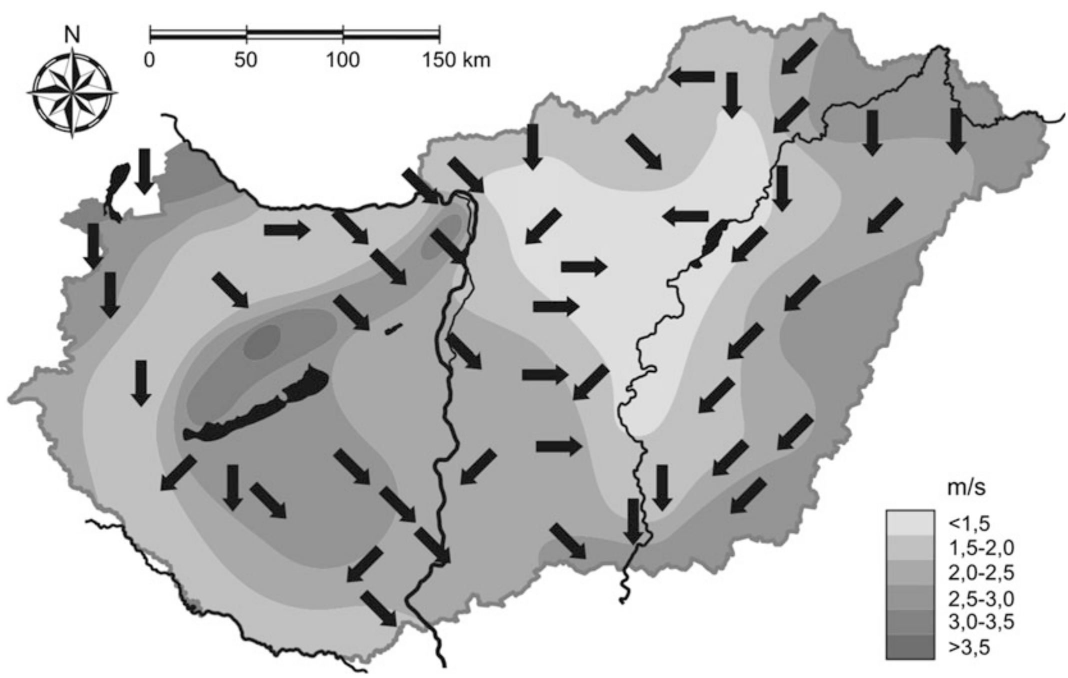

Fig. 2.6 Prevailing wind directions and average wind speed in the summer period (after Bartholy and Weidinger 2000)

The direction and velocity of the near-surface airflow reflects the orographic influence. The annual average wind velocity is 2–4 m/s. The area of the mountains, and especially their southern parts, and the western and eastern peripheries of the country are characterized by average wind speeds over 3 m/s. Thus, the Devín (Dévény) Gate and the southern slopes of the Transdanubian Mts. and the North Hungarian Mts. can be taken into consideration from the point of view of wind energy (OMSZ 2009). The territorial differences are similar according to the values calculated by the WAsP model, indicating below 150 W/m^2 wind energy in average, and it exceeds the 200 W/m^2 only in the above-mentioned regions (Radics 2004).

2.3 Social Aspects of Climate

The socio-economic activities are sensitive to climate changes to different extents. Agriculture, building industry and energy production are the most affected economic sectors by climate change. Conversely, the important question is that how these sectors influence the climate (Mezősi 2008). From climate sensitivity point of view, the agriculture and its productivity are affected by several climatic parameters, e.g. the rate and distribution of precipitation and temperature, and their extremities having diverse effects in different phenological phases. The natural resources and their conditions, such as the wind or solar energy, are also important for the society. The effect of climate change, e.g. growing temperatures and increasing frequency of extremes (rainstorms or heavy rains), and climatic hazards, on these resources and their utilization, has to be considered. From this point of view, the optimal extent of adaptation to the short-term projections is a key question.

In the followings, three regional and national issues will be discussed as examples within the complex system of relationships. Afterwards, (further) features and hazards related to the climate and its changes will be introduced, which are recommended to take into consideration during geographical and environmental assessments.

2.3.1 Number of Snow-Covered Days: Potentials for Skiing

The number of snow-covered days is the highest in the Mátra Mts. (the observed maximum of 154 days occurred in the winter of 1943/44). Therefore, the question is whether the natural conditions are appropriate for skiing in Hungary? If we consider only the number of snow-covered days, the answer may be positive, since the average 70–100 snow-covered days of the mountains can be sufficient (Fig. 2.7). However, other natural factors make skiing possibilities questionable: for example, the average natural snow-covered depth is only 30–35 cm, which is insufficient for skiing, especially if the high variability of snow depth is also considered (there were winters, e.g. 2006/2007, when practically no snow cover occurred in the mountains). Considering the tendency of climate change, the increase in winter precipitation and temperatures (Weidinger 2000), the potentials of winter sports are more uncertain because of the decreasing snow cover. Furthermore, the precipitation increases with the increasing elevation in the winter which is only half or third of the summer values. Of course, more favourable topographic features would result in a better situation; however, the system can be sustained with appropriate maintenance and artificial snow-making equipment and with preparations for the variable winter climate. (It is also has to be considered that the artificial snow may degrade the vegetation and the soil on the slopes.)

2.3.2 Potentials to Utilize Renewable Climatic Energy Resources

According to the Hungarian Academy of Science Subcommittee on Renewable Energy (2006), the theoretical value of renewable energy sources is 2500 PJ/year; however, the exploitable quantity is significantly smaller, if we take into consideration the aspects of technology, economy and the expected future potentials. The realistic value

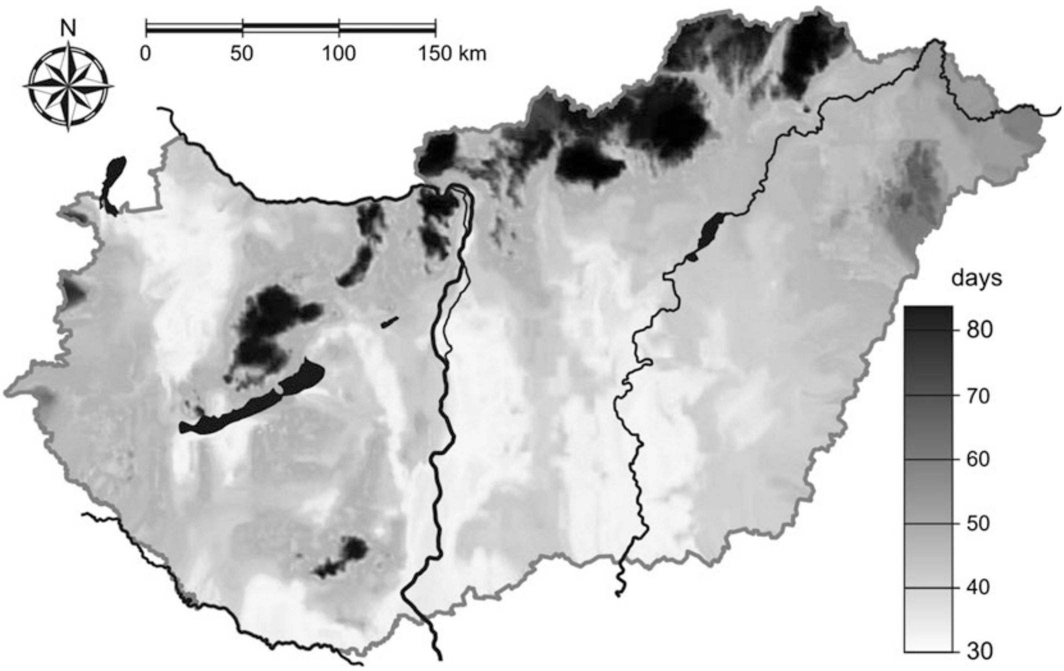

Fig. 2.7 The number of snow-covered days (after OMSZ 2003)

Table 2.1 The renewable energy sources in Hungary (based on http://ec.europa.eu/eurostat/data/database 2011)

	PJ/year energy				
	Biomass	Geothermal	Wind	Water	Solar
Potentially utilizable	120	50	46	0.9	72
Utilized at present	52.2	4.8	2.7	0.8	0.3

PJ petajoule = 10^{15} J; 1 J = approx. 0.239 cal or approx. 2.7 E–7 kWh

of the useable energy potential is estimated at 100–1200 PJ/year (GKM 2007), but only part of this is used in reality (Table 2.1). This potential can be understand by comparing it to the annual energy consumption of the country, which is approx. 1000 PJ. The wind and the solar energy are the most important among the climatic energy resources. The earlier data showed a very low proportion of wind energy in energy production; however, it has grown tenfold in the past years (Table 2.1). The same tendency characterizes the (solar collector and photovoltaic) use of solar energy. Considering the present situation, even reaching of the 5 % of the potentials already would show progress into the right direction.

According to Major (in Dobi 2006), the potential of solar energy is 140 W/m^2, the wind energy is 5–11 W/m^2, the geothermic energy is 0.09 W/m^2, and the kinetic energy of rivers is 8×10^{-5} W/m^2 in Hungary, while the estimated yearly energy consumption is about 1 million TJ (= 10^{12} J), which means a 0.5 W/m^2 energy density. In spite of the fact that this value is much lower than the surface density of solar and wind energy, the conclusion that these could easily cover the energy consumption of the country is not realistic. (Today, the EU recommendation of a 10 % share of the renewable energy out of the total energy production seems realistic).

Table 2.2 Daily average solar radiation realized on a horizontal surface in Hungary (after Energy Centre 2006)

Month	Average solar radiation ($kWh/m^2/d$)	Total solar radiation ($kWh/m^2/month$)
January	0.776	24
February	1.468	41
March	2.733	85
April	4.130	124
May	5.171	160
June	5.750	172
July	5.807	180
August	4.988	155
September	3.820	115
October	2.184	68
November	0.826	25
December	0.533	17
annual total	**3.200**	**1166**

2.3.2.1 Solar Energy Capacity

The solar energy potential of Hungary is above the European average, since half of the potential solar radiation reaches the surface. This provides 1300 kWh/m^2 (Energy Centre 2006) annually (Table 2.2.), and the regional differences are only 6–8 %. The present-day solar collector technology could be replaced by solar power plants, which are more economical; however, the price of the present two technologies differs considerably. Certain surveys estimate the solar energy potential (taking into consideration also the ecological limits) to be 400 PJ/year (Vajda 2001).

2.3.2.2 Wind Power Capacity

Experiments on non-traditional utilization of wind power date back to more than 50 years. The measurements of wind velocity were carried out for meteorological and aviation purposes at that time, not for estimating the power of the wind. At the beginning of the 1990s, the Hungarian Electricity Company (MVM) calculated wind power at 10 points in Hungary. (The data could be used only with limitations, as the measurements were carried out near ground level.) According to these measurements, wind power reaches 120 W/m^2 at three places: Little Hungarian Plain, Komárom County, and on the Foothills of the Mátra Mts. (Energy Centre 2006). In the Carpathian Basin, the frequency of wind velocity over 3–4 m/s, which is enough to start a wind generator, is 56–70 %. (The strongest wind gusts could be several times stronger, since a 44 m/s wind velocity was recorded in Szarvas in 1988; however, their occurrence is low.) The operational energy of wind is proportional with the cube of wind velocity. A wind of 20 km/h can produce eight times more energy than a 10 km/h wind (Bartholy 2000). Thus, the achievable annual wind power is 1.0 TWh for Hungary, meaning an energy source of 3–4 PJ/year according to the realistic estimations, although some optimistic estimates calculate this value to be 7 PJ/year (Fig. 2.8; Vajda 2001). According to Hunyár et al. (2006), these calculations significantly underestimate the wind energy potential of Hungary, because according to them, the annual wind energy potential is 40–90 TWh, depending on the wind turbine heights. In fact, the useable wind energy is restricted by several environmental, legal, technological and economic factors. For example, it is practical to have a medium voltage cable within a 10 km distance, and it is useful if an energy storage system is available.

Wind energy utilization can trigger significant investments (in case, a state subsidy and legally guaranteed purchase of energy by the state also included). For example, companies submitted draft contracts with valid environmental permission for 1500 MW wind turbine capacity until the end of 2005, equal to the capacity of the Paks Nuclear Power Plant (Csoknyainé 2006). However, only 20 % of these proposals acquired construction permits. Although wind energy is one of the cleanest energy sources, there are several environmental problems; e.g., the operation of the wind turbines creates noise, vibration and shadow flicker; nevertheless, these can be handled.

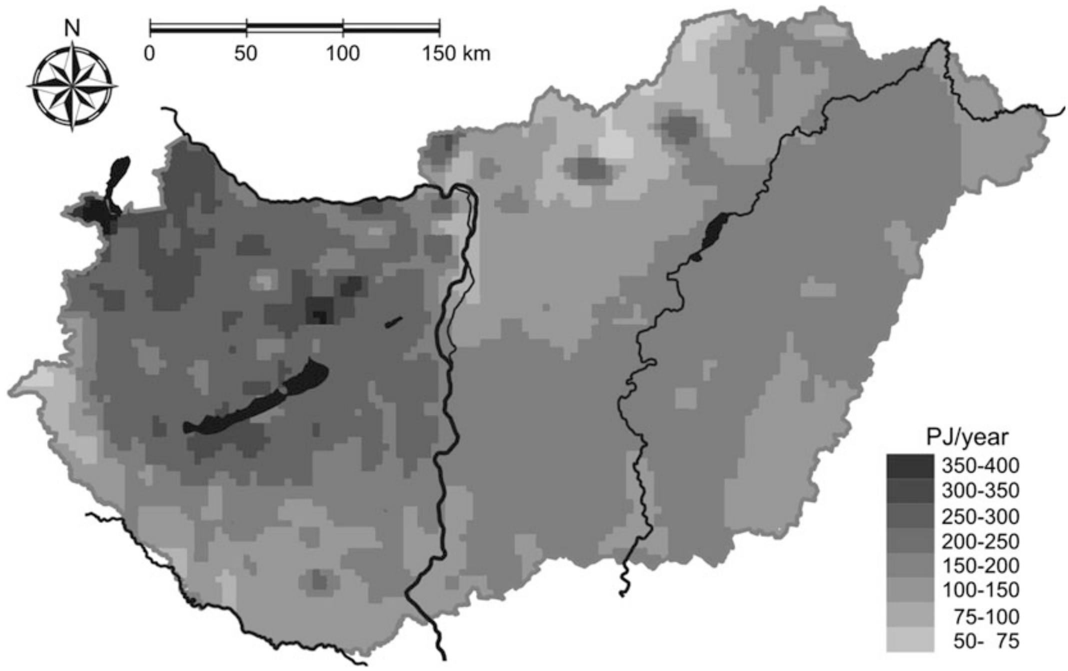

Fig. 2.8 Wind energy potential (PJ/year) at 75 m height (after Szépszó et al. 2006)

2.3.3 Special Climatic Features of Cities

Larger cities can significantly modify the environmental conditions, e.g. vegetation and soil settings, or water regime (Mezősi 2007), and the climatic conditions are especially sensitive to human impacts. In general, this influence is measurable in towns with a population of more than 50 thousand, and the rate of the effects is increasing with the city size. (However, some environmental changes are already detected in the cases of smaller settlements with only a few thousand inhabitants.) A specific, so-called urban climate develops in cities, which can be characterized by well-distinguished parameters (Table 2.3), as higher temperature emerging from the different energy balance of urban and natural surfaces, which is called "urban heat island" (Unger 2007).

2.3.4 Further Climatic Capabilities and Hazards

(A) *Capabilities*

The conditions for climatic health resorts, which have had spectacular success in the past century abroad, are not ideal in Hungary. (The "Luftkurorts" in Austria are used and assessed similar to the places with medicinal water in Hungary.) Such climatic health resorts are situated along seasides (to cure skin and respiratory problems) or in high mountains (to cure cordial and respiratory illnesses). The main advantages of climatic health resorts are the even temperature, the clean air and the decrease in partial pressure of oxygen (Rákóczi et al. 2002). According to the Hungarian regulations, those places could be qualified as a health resort, which has a natural healing factor (e.g. climate and

Table 2.3 Some characteristic features of the urban climate (after Sukkopp and Wittig 1993; Mezősi 2007)

Factor	Difference between the countryside and the urban areas (%)	Explanation
Global radiation	−20	Shade effect
Precipitation	+10	More pollution
Air humidity	−60 to −30	Lack of vegetation and natural evaporator surfaces
Wind velocity	−25	Near-surface friction caused by the strong segmentation of the surface
Annual mean temperature	+0.5 to 1.0	Anthropogenic impact
Minimum temperature	+1 to 3 °C	A maximum value of +10 °C may occur in urban heat islands
Aerosol	+1000	Industry, households and traffic
SO_2 (μg/m^3)	+1000	Industry and households
CO_2	+1000	Households and traffic
Dust (mg/m^2/d)	+600	Traffic and industry

water). To utilize these, an institutional background is also necessary. The climatic health resort status can be awarded for 20 years by the OGYFI (National Health Resorts and Spa Directorate General) based on the opinion of the OMSZ (Hungarian Meteorological Service) and the approval of the relevant ministries. The potentials are the most advantageous in the Kőszeg and Sopron Mts., which have a subalpine character, and in the Mátra Mts., where this type of treatment has long tradition at Kékestető. The air of several caves provides favourable conditions for medical purposes (Bálint and Bender 1995), which is beneficial not only because of the low levels of pollution and dust, but also because of the high calcium and magnesium content (e.g. Tapolca and Jósvafő caves).

(B) *Hazards*

The following sections outline natural hazards having climatic components and having continuously increasing effects because of the increasing human use of the environment. From this point of view, the question of whether the rainstorms or foggy days are becoming more frequent, or whether the air quality is worsening is important.

(a) Rainstorm hazard
Rainstorms usually occur in Hungary 20–33 times in the summer period, on average. A problem with rainstorms is the insufficient forecast system, in spite of the lightning register operated by the OMSZ since 1998, and nowadays, it is possible to follow lightning and rainstorms on the Internet. The pattern and frequency of lightning and rainstorms (Fig. 2.9) provide information about their propagation, and the released energy can also be calculated. Nowadays, the improving forecast system can reduce this type of hazard.

(b) Heat stress
Because of the increasingly warming summers, many people sense the increasing heat stress affecting their bodies. To make this perception measurable and comparable, a heat stress definition was developed. The value of heat stress is calculated on the basis of temperature and air humidity; however,

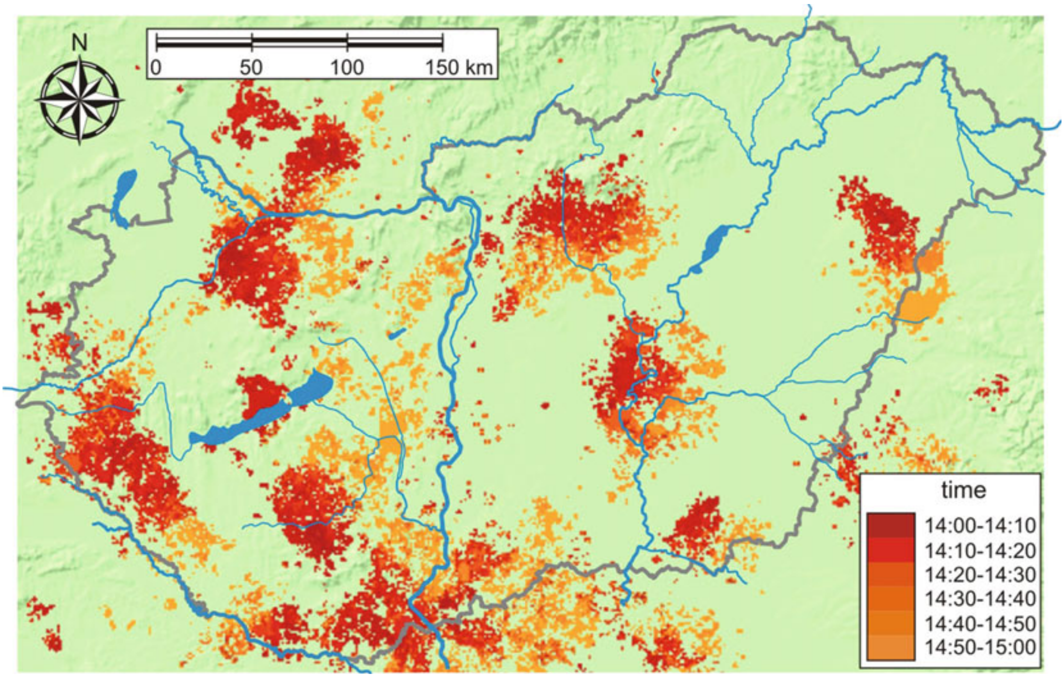

Fig. 2.9 Hourly lightning strike map of Hungary, between 14.00 and 15.00 o'clock on 26 June 2009 (after OMSZ database)

temperature fluctuation and the extreme values are not integrated into the calculation despite of their significant effect on human comfort (Fig. 2.10; Gulyás et al. 2004).

(c) Increasing climate extremes
Everyday experience is that the frequency and rate of climate extremes, the so-called climate catastrophes, are progressively increasing. The environmental consequences of extreme climate events are becoming more frequent and affecting larger territories (Szabó 2001). The climate extreme indices related to temperature show an increasing tendency and/or a decreasing recurrence interval (Bartholy and Pongrácz 2005). The amount of annual precipitation in Hungary has been decreasing for about a hundred years; however, the frequency of extreme precipitation events has increased, e.g. intensive precipitation events occurred in 1998–2002 and in 2010, causing high and long floods on rivers. In addition, the number of days with more than 20 mm rainfall has significantly increased in the past 25 years. The growth of the total duration of the heat waves and dry periods was measured too (Pongrácz and Bartholy 2006).
The increasing extremities can be detected also in the case of the solar radiation intensity. It has different values during the day because of the changes of the angle of incidence. The very high UV radiation values (over 8.0) are dangerous, because the UV (ultra violet) radiation is the harmful component of solar radiation, and may cause skin cancer. The observed maximum value of UV-B radiation (9.4) in Hungary was measured at Kékestető (Mátra Mts.). Figure 2.11 shows a series of maps about the daily changes in the intensity of UV-B radiation. (An OMSZ recommendation on the duration of sunbathing could also be found on the original maps.)
Extreme temperature values also show high variability. The yearly maximum temperatures are generally 33–36 °C (at 200 m asl),

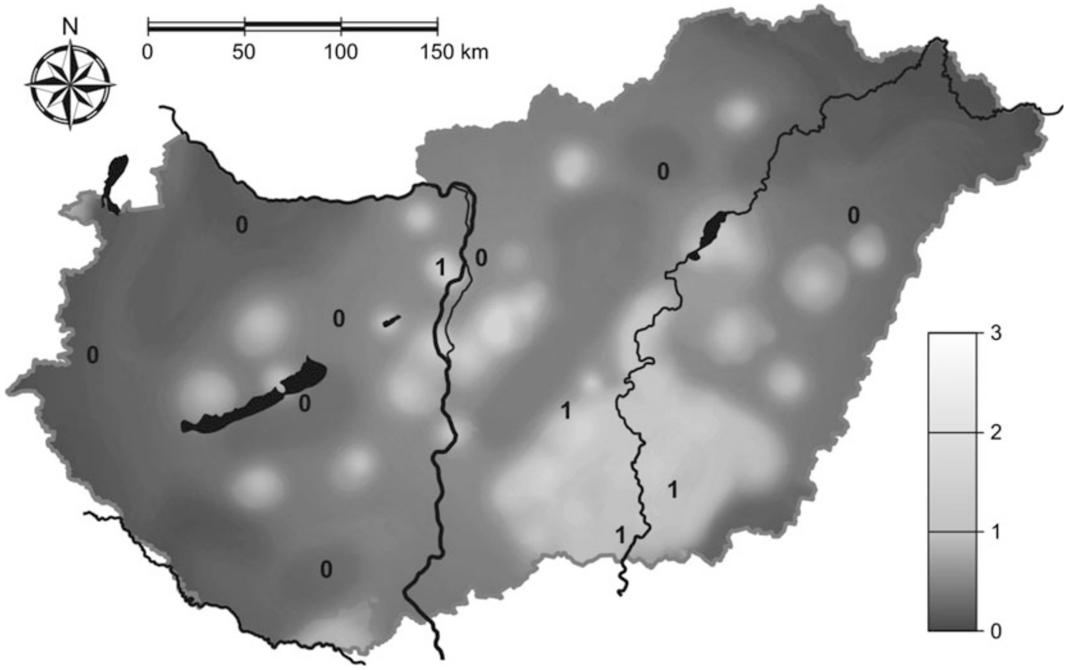

Fig. 2.10 Heat stress map of Hungary on 1 August 2009 (after www.idokep.hu). The higher values refer to higher heat stress

while the minimum ones are usually between −16 and −19 °C. The observed absolute maximum temperature on the lowland regions is 39–41 °C, and the minimum is between −25 and −30 °C in the majority of the territory of the country. Extreme heat (above 30 °C) can occur in the whole country, even in the Kékes peak (Mátra Mts.), whereas extreme cold frequently occurs in the deeper parts of the Great Hungarian Plain and in the narrow, closed valleys in the mountains (Péczely 1979). The greatest absolute fluctuation of the temperature is 76.9 °C.

Climate projections for the twenty-first century, based on regional climate model simulations, show an increase in the frequency of extreme values (MET9 2010). These models project the changes of extreme climate indices, e.g. number of summer days (T_{max} > 25 °C), hot days (T_{max} > 30 °C), extremely hot days (T_{max} > 35 °C), winter days (T_{max} < 0 °C) and extremely cold days (T_{max} < –10 °C). At the end of the twentieth century, extremely hot days (T_{max} > 35 °C) were not common, occurred only on 10 % of the territory of the country; however, in the first half of the twenty-first century, they could occur every year at any time in the period from May to September (MET9 2010). A similar tendency can be projected in the case of precipitation: the daily precipitation intensity index will increase; thus, the amount of average precipitation on one rainy day will increase in the future. The increase is about 10 % in Hungary; however, it is only significant in the southern area of the Great Hungarian Plain.

(d) Further hazards

Among the climatic hazards, the susceptibility to fog formation and frost poses serious risks. Fog develops when the near-surface water vapour condensates (when the air temperature drops to the dew point, or when the water vapour content increases in the air and becomes saturated because of

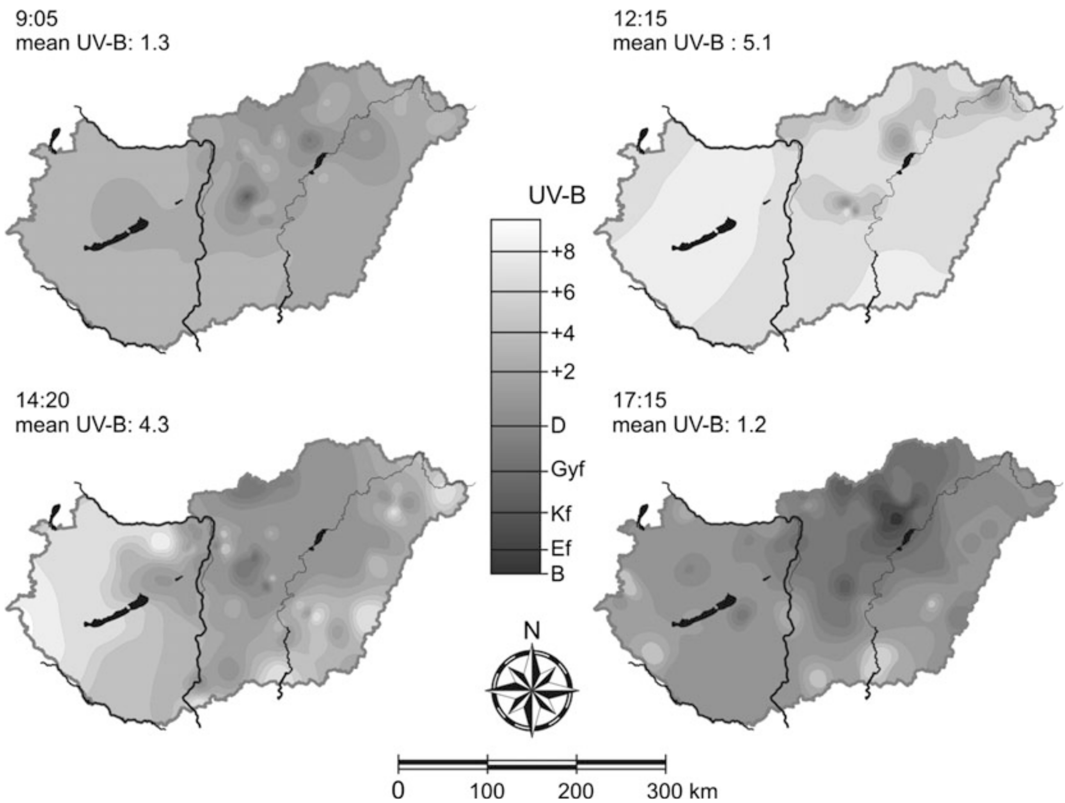

Fig. 2.11 UV radiation values on a summer day (2 August 2009, after www. met.hu) *B* cloudy, *Ef* strongly clouded, *Kf* moderately clouded, *Gyf* lightly clouded, *D* clear sky

evaporation). The fog has several different classifications to assess and evaluate its origin and location. These classification schemes can be based on, e.g., the processes that are involved in creating fogs, the position of the fog or the horizontal visibility. Undoubtedly, one of the most critical consequences is the strong reduction in horizontal visibility for traffic; thus, sometimes, only 10–30 m is the visibility distance of the fog which is very thick (in case of radiation fogs formed near surface). The winter is the typical period of fog formation, and the periods of fog event can contribute to worsening air quality because of the decreased ventilation. Because of the deteriorating air quality and the accumulation of air pollutants caused by the fog, several larger cities had to inform (Budapest 2008, 2010; Pécs 2010) and then alarm (Miskolc 2010) the population about smog alerts.

The frost is especially harmful for the vegetation, because the water in the plants freezes; thus, the plant cells can get damaged and the leaves die (the expression "black frost" comes from this). Several other environmental hazards in connection with frost are known; for example, roads and wires can get damaged (Pinczés 1994).

2.4 Past and Future of the Climate

The climate change in geological times has been summarized in Sects. 1.1.3 and 1.8, while its changes in the past nearly 10 thousand years are described in Sect. 1.9. Even in historic times, significant social effects could be attributed to the ecological changes caused by the altered climate. For example, in the second–fourth centuries, a great migration started because of the cold and dry climate periods in Central Asia, because the deteriorating climate triggered limited ecological potential. Other approaches connect the migration waves to the warming and aridification of the climate in the sixth–seventh centuries, which also meant ecological limitations for the nomadic tribes practicing animal husbandry (e.g. grazing).

The short (hundred years) climate changes could be explained by the changing intensity of solar insolation. Lean and Rind (1998) reconstructed the changes of sunshine intensity until 1600, and they found that the minimum intensity had taken place between 1600 and 1800, when it decreased by 0.24 %. This corresponds to the time of the latest climate deterioration, the Little Ice Age and its continental, European maximum. It meant annual mean temperature decrease by 0.5 °C in the northern hemisphere. The Little Ice Age also corresponds to a period of low solar irradiance, which has been known for a long time: Wolf, Sporer and Maunder Minimum-like events have been recorded since the thirteenth century. During the Sporer Minimum (1402–1516) sunspots were not recorded for more than one hundred years, and during the Maunder Minimum (1645–1715), only a dozen were recorded in a 70-year period. The results of the analysis of alpine glaciers for the last cooling period also show an agreement with these observations (Jörin et al. 2006).

It is difficult to describe the climate deterioration of the Little Ice Age in the Carpathian Basin, because of the lack of data. Based on the information collected by Réthly (1962, 1970, 1998) Rácz (2008) reconstructed the climate deterioration during the Little Ice Age (between the end of the sixteenth and the end of the eighteenth centuries). Similar to other European countries, the winter and spring months became colder (March had more of a winter character), and the Junes were more humid being more similar to the spring months. These statements were also supported by various chronicles, manorial records and dendrological data (Grynaeus et al. 1994). Several analyses also draw the attention to the fact that the climatic features between 700 and 1200 AD triggered dynamic transformations in agriculture all over Europe.

The climate change of the last century was characterized by warming since the last third of the nineteenth century until the 1940s. The 1940s were especially humid, and a cooling was detected, possibly induced by volcanic activities. After this short period, the warming has been intensified due to the rapidly increasing anthropogenic influences since the 1970s. The recorded temperature fluctuation did not exceed 1 °C in the period (MT 2002).

To assess the future climate change, various climate model projections and uncertainties should be considered. Since the climate projection scenarios of the models cannot be confirmed, they are not considered as scientifically justified by several researchers. However, some main tendencies still can be outlined, owing to the more and more accurate data and information, which are appropriate to serve as a base for a "relevant" strategy of the adaptation to climate change. The climate change estimations are hindered by the fact that the natural and social factors are connected, and some factors are more easily projected than others.

The annual mean temperature will increase by 0.5 °C until the end of the twenty-first century in the northern hemisphere, if the composition of the atmosphere remains constant. However, the temperature may increase by 1.5–4.0 °C if the present economic activity maintained (ICCP 2007). It is difficult to draw definite conclusions for Hungary, because of the contradictory climate tendencies of different projections even for such a small area. Nevertheless, in longer timescale, a warming by 0.5–0.7 °C could be expected. The climate simulations project a climate alteration towards the eastern Mediterranean climate, and the anthropogenic influence is regarded as the primary cause. It is more difficult to project the changes in the amount of spatial and temporal distribution of precipitation. Some climate simulations project decreasing autumn–winter precipitation (MT 2002), whereas other models show an increase during the winters (Bartholy and Mika 2005) and autumns (Láng

2006). These differences have different effects on surface water regime and flood hazard. In general, the possible increase in evaporation due to the higher temperatures will be accompanied by the decreasing precipitation, leading to the moisture loss of soils, to limited water availability for the vegetation and to a decrease in groundwater level. There are some areas where the land use will be significantly modified in the future, because of the decreasing amount of precipitation and higher temperatures. For example, some researchers found that the Danube-Tisza Interfluve will face with water shortage periods and aridification. All climate models project an increasing frequency and intensity of extreme events causing significant difficulties in the water supply and water management. Also, the researchers highlight that a significant and extensive reduction in air pollution and the adaptation to the changing ecological conditions may considerably decrease the damages caused by climate change.

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