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A brief history of aerosol research in Hungary

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Abstract—The aim of this paper is to summarize the history of Hungarian research carried out during the last forty years to study the atmospheric aerosol. This period can be divided in three parts. In the first part (between 1960 and 1980) the water soluble inorganic ions were investigated to understand the role of aerosol particles in the cloud formation The studies showed that water soluble particles are composed mainly of ammonium sulfate and about the half of the mass of this compound can be identified in the size range of particles with a diameter below 0.2 μm. The sampling program done over the remote ocean indicated that sulfate particles give the major part of the number of aerosol particles even under oceanic conditions, far from the continents. Sulfur budget calculations made it evident that sulfate particles in the continental air are of anthropogenic origin. This meant that human activities control in a great measure the formation of cloud condensation nuclei. Research in the second part (between 1981 and 1995) was devoted to the study of elemental composition of aerosol particles including some toxic metals like lead, zinc and vanadium. Since about 1995, in the third part, one of our main aims has been the investigation of organic species in the atmospheric aerosol. These studies demonstrated that an important fraction of organic matter consists of macromolecules like humic substances in the soils. A non negligible part of these macromolecules are soluble in water. The second goal after 1995 has been to study the effects of the optical properties of aerosol particles on the solar radiation transfer for understanding the role of aerosol particles in visibility control and climatic variation.

Key-words: atmospheric aerosol composition, cloud condensation nuclei, light extinction, Hungary.

1. Introduction: the beginnings

The existence of aerosol particles in the air was first demonstrated by *Coulier* (1875) and *Aitken* (1880) in the second half of the nineteenth century. Their expansion chamber experiences showed that water droplets formed on "dust" particles served as condensation nuclei. They also demonstrated that dust particles could be eliminated from the air by several subsequent expansions. Thus, Aitken noted that "if there were no dust in the air there would be no fogs, no clouds, no mist and probably no rain". On the other hand at the beginning of the twentieth century *Mie* (1908) further developed the earlier proposition of Lord Raleigh according to which the particles in the air are optically active, mainly those having a size comparable with the wavelength of the solar radiation. The concept that the Earth's atmosphere constitutes a huge colloidal system was introduced by *Schmauss* and *Wigand* in 1929. *Junge* (1952) was the first to demonstrate that particles in different size domains investigated by different aims and methods have a continuous size distribution.

Until the fifties the chemical composition of atmospheric particles remained practically unknown, in spite of the fact that, beside dust of continental origin, the presence of sea salt particles were already indirectly indicated by fog and frost analyses as well as by their effect on visibility. Another broad class of particles, which can be observed even in naked eye was named "combustion particles", or simply "smoke". In the fifties some important new results were obtained. Thus, the classical measurements of *Junge* (1963) made it clear that a major part of water soluble particles with a radius between 0.1 and 1.0 μm consisted of sulfuric acid and ammonium sulfate formed in the air by chemical reactions followed by condensation. On the other hand, his results also indicated that near the seas in the radius range above 1.0 μm water soluble particles were composed of sea salt (mostly sodium and chloride ions) in agreement with the results of pioneering aircraft flights of *Woodcock* (1953) carried out under oceanic conditions.

At that time, owing to research in cloud physics, it was already evident that only a fraction of aerosol particles serves as condensation nuclei in natural clouds. This idea was based on the fact that the number of cloud droplets was found to be smaller than the concentration of particles measured by expansion chambers (*Mason*, 1957). On the basis of his observation Junge proposed that this active fraction is in the radius range of 0.1–1.0 μm where ammonium sulfate particles are predominant. This proposition was in disagreement with the general earlier belief that sea salt particles serve as active condensation nuclei, called later cloud condensation nuclei (CCN) by *Twomey* (1959).

This was briefly the situation in 1960 when Hungarian aerosol research started. Our first goal was to check whether sea salt particles have an important effects on cloud and precipitation formation over Central Europe and, generally speaking, what kind of water soluble particles do exist in the air above our country. The second direction was to determine the concentration and deposition of different metals. Finally, the role of aerosol particles in the control of radiation transfer was also investigated. The aim of this paper is to summarize the main results of Hungarian investigation made in this field between 1960 and 2000.

2. The water soluble inorganic fraction

The first research goal was to clarify the role of chloride particles in cloud formation over Hungary. On the surface, the sampling was carried out by an impactor, while aloft small slides, exposed from a light aircraft, were used to capture the particles. In both cases the particles were collected on a gelatin surface sensitized by silver nitrate. The surface measurements in suburban Budapest (see *Fig. 1*) and aircraft flights indicated that the concentration of chloride particles is higher in air masses of maritime origin as expected. The concentrations increased generally with height (*Mészáros*, 1963) in agreement with earlier observations of *Byers et al.* (1957) made over North America. It was also found that the number of chloride particles is too low to be important in cloud formation. There was an indication that even the number of all particles with a diameter above 0.2 μm was not sufficient. This was later proved by capturing particles by membrane filters below freshly formed small cumulus clouds with parallel droplet samplings above the cloud base (*A. Mészáros*, 1969). The results of this program are summarized in *Table 1*.

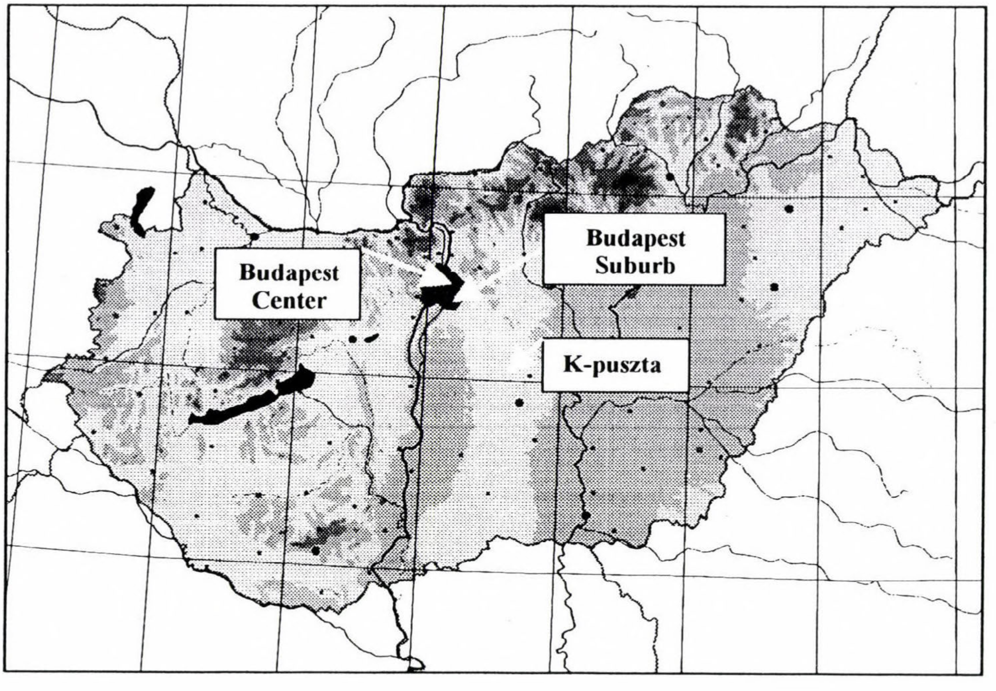

Fig. 1. Aerosol sampling sites referred in the text.

Table 1. Comparison of below-cloud aerosol particle concentration (N, with d > 0.2 μm) and cloud droplet number (n) above the base of freshly formed cumuli in different days (N°).

N° →	1	2	3	4	5
N (cm^{-3})	330	350	300	220	500
n (cm^{-3})	2300	1080	1660	1100	2300
N/n (%)	14	32	18	20	22

Data tabulated clearly show that the concentration of particles in the size range above 0.2 μm is much lower than that of droplet concentration. It is interesting to note that similar results were obtained by *Hidy et al.* (1970) over Northeastern Colorado. Thus, one concluded that particles smaller than the above size give a major part of CCN. According to thermodynamic calculations small particles can serve as CCN only if they are soluble in water. However, at that time the chemical composition of small particles was an open question. For this reason we sampled the particles by a cascade impactor of four stages backed up by suitable filters. The samples were analyzed with nephelometric and colorimetric chemical methods. This program indicated (*Mészáros*, 1968) that the fraction of water soluble substances increases with decreasing diameter and soluble aerosol material in the size range below 0.2 μm is composed mostly of sulfate and ammonium ions, while the quantity of nitrate and chloride ions is lower and in many cases it can practically be neglected[1]. It was also found that the half of the mass of ammonium and sulfate ions is in this size range (see *Table 2*). This involved that on number basis the great majority of ammonium sulfate particles has a very small size.

Table 2. Size distribution of various ions in percentage of their total mass (*Mészáros*, 1968). Note that *d* is the particle diameter.

Size range	Ammonium	Sulfate	Chloride
d > 2 μm	8	12	33
2 > d > 0.2 μm	45	45	49
d < 0.2 μm	47	43	18

[1] The origin of chloride ions in the size range of d<0.2 μm is not clear. It is assumed, however, that they are of anthropogenic origin.

Thus, it was concluded that CCN consist of ammonium sulfate particles with diameter below 0.2 μm. The same conclusion was drown by *Twomey* (1968) by measuring the size and volatility of CCN. Research in Hungary also demonstrated that sulfate particles in summer daylight form by photochemical reactions (*Mészáros,* 1973), while in winter some other processes also play a part. Although there are other possibilities (formation in liquid water), we found later that in night mainly during the winter half-year sulfate ions come into being on the surface of elemental carbon particles (*Mészáros* and *Mészáros*, 1988).

The conclusion that CCN are composed of ammonium sulfate was widely accepted in the literature. The work of many other scientists pointed into this direction. Thus, on the basis of research done in the U.S.A. in this field (e.g., *Dinger et al.*, 1970; *Hudson*, 1991) one proposed without doubt that CCN are composed of sulfates. At the beginning of seventies the first aerosol measurements were made in the air over remote oceans. Hungarian samplings were carried out on board a Soviet research vessel by means of membrane filters. The samples obtained were evaluated on the basis of particle morphology by an electron microscope. The results showed (*A. Mészáros* and *Vissy*, 1973) that particles identified are composed mainly of ammonium sulfate in the size range of fine particles (d<1 μm), while coarse aerosol (with particle diameter above 1 μm) consisted of sea salt particles (*Fig. 2*). This means that in the control of the composition of fine background aerosol sulfate particles play an essential role.

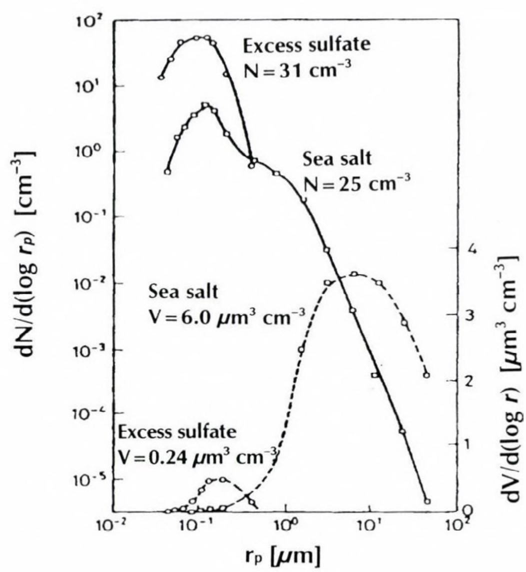

Fig. 2. Number (N) and volume (V) size distributions of sea salt and excess sulfate in the air over the oceans (r_p denotes the radius of aerosol particles).

Atmospheric sulfur budget calculations indicated that sulfate particles in oceanic air form by the gas-to-particle conversion of dimethyl sulfide emitted by the oceanic biota. On the other hand the precursor gas of continental sulfate particles is predominantly sulfur dioxide emitted because of the combustion of fossil fuels by man (see e.g., *Langner* and *Rodhe*, 1991). In other words CCN over the continents are of anthropogenic origin. This conclusion involves indirectly the following interesting question (*Mészáros*, 1992): what particles did serve as CCN before the industrial revolution, and what was the structure of continental clouds some hundred years ago? Since there were clouds and precipitation even at that time, we may ask: on what kind of particles formed cloud droplets before human influences over the continents? Are there water soluble fine particles other than sulfate which serve as CCN even now? These questions obviously involve that further research is needed in this field. Since the water soluble fraction of inorganic substances in the aerosol is well known, we concluded that we have to look for organic water soluble species. However, before discussing this problem let us summarize the results of Hungarian research aimed to study the elemental composition and mass balance of atmospheric aerosol particles which preceded in time the measurements of organic compounds.

3. Elemental composition: metals in the atmosphere

Beside condensation, the study of the atmospheric aerosol is important for the chemistry of other media of our environment. This is caused by the fact that, by means of dry and wet deposition, different elements in the aerosol are deposited onto the hydrosphere, pedosphere and biosphere. For this reason the investigation of these deposition processes is also of interest for solving many environmental problems, including anthropogenic effects on biogeochemical cycles of aerosol components. Thus, beside sulfur, nitrogen and chlorine in water soluble form, in the eighties the main aim of our research was to study the atmospheric concentration and deposition of different metals and metalloids in the air. For this purpose aerosol particles were captured under different conditions on Nuclepore filters and the elemental composition was determined by nuclear methods (PIXE: *P*article *I*nduced *X*-ray *E*mission). At the same time precipitation water, collected at several sites in Hungary, was analyzed by the ICP emission analysis (*I*nductively *C*oupled *P*lasma). In some cases aerosol samplings with a Berner-type cascade impactor (analyses by atomic absorption spectrometry) was also made to gain further insight into the size distribution of the elements.

The concentration of some selected elements under different environmental conditions (see Fig. 1) are summarized in *Table 3*. In parenthesis the enrichments factors relative to aluminum are also given.

Table 3. Concentration and enrichment factor (in parenthesis) of some selected elements under different conditions in Hungary. Concentrations are expressed in ng m^{-3} (*Molnár et al.*, 1993).

Sampling site →	City center	Suburb	Background
Al	274 (1)	290 (1)	131 (1)
Mn	13.4 (5.9)	13.4 (5.6)	3.4 (3.1)
Pb	203 (2710)	82.3 (2950)	10.4 (824)
V	6.1 (28.5)	4.4 (19.4)	2.0 (19.3)
Cu	21.5 (158)	11.5 (79.9)	4.4 (68.0)

One can see from data tabulated that the concentrations decreases from city center to background as expected. The ratio of city (Budapest) concentration to the value measured at K-puszta site (background) is high in particular for lead and in a lesser way for copper. This is mainly due to traffic density and coal combustion, respectively. The man-made origin is also proved by the high values of the enrichment factor. Vanadium is a notorious pollutant of oil combustion. Its concentration decreases from city to background but its enrichment is smaller than for copper. It is interesting that even aluminum and manganese, considered of crustal origin, show a similar trend than elements of mostly anthropogenic origin. In spite of this result we used aluminum to calculate the enrichment factors for obtaining values generally published in literature.

To gain further insight into the properties of different elements, their size distribution was also studied on the basis of samplings carried out in Veszprém (*Mészáros et al.*, 1997), which is a relatively clean university town in western Hungary (see Fig. 1). This is proved by the fact that concentrations measured in this town are only slightly different from those obtained at K-puszta station. The size distribution of four elements according to sampling in eight size ranges is represented in *Fig. 3* (note that the size spectrum for copper is not given, which is very similar to that of vanadium). It follows from these spectra that different elements can have different size distributions which is obviously caused by formation and dynamic processes. Thus, manganese of soil origin has a maximum in the size range of particles having a diameter above 1 μm (coarse particles). The main maximum of aluminum also can be found in this size interval. However, a smaller peak also exists in the smaller size range indicating some other, but less important sources. Lead has an unimodal distribution which is probably caused either by the condensation of lead containing species on particles with diameter above 0.25 μm during their emission, or by the particle coagulation. Contrary to this, a non-negligible fraction of vanadium (and copper) consists of particles smaller than 0.125 μm indicating fresh aerosol.

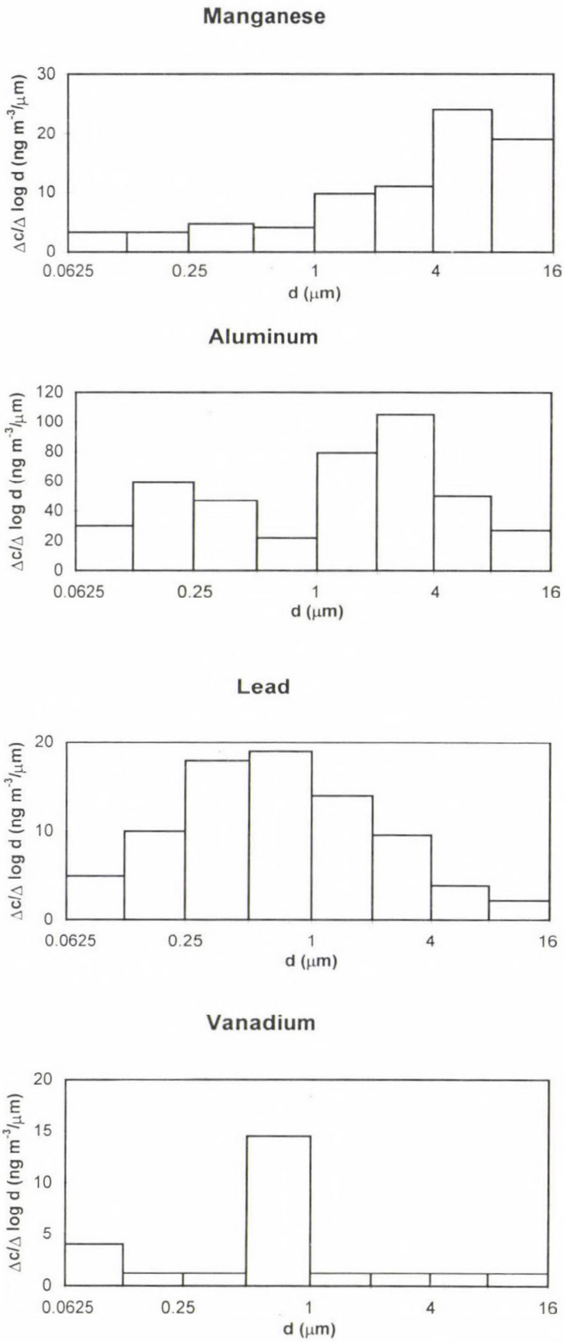

Fig. 3. Size distribution of the mass (c) of manganese, aluminum, lead and vanadium containing particles in Veszprém air. (Note that *d* is the particle diameter.)

These results make it obvious that the size distributions must be taken into account when we calculate the dry deposition and health effects of different metals (*Molnár et al.*, 1995). However, the comparison of the values calculated with the wet depositions shows that wet deposition plays a more important role in the self-cleaning of the atmosphere as does dry deposition.

Hungarian elemental aerosol data was also elaborated according to the direction of air trajectories. This work showed (*Koltay*, 1994), among other things, that in the cases of north-west trajectories the non-crustal Mn/V ratios were close to the value found in western Europe (about 2). However, for the air arriving from the north-eastern sector, the corresponding value is as large as 8.3 indicating the effect of coal burning and industrial activity. This study clearly indicates the importance of elemental ratios in the study of the origin of air pollution.

4. Mass balance calculated in 1990

In 1990 we believed that we have sufficient amount of data to try to calculate the mass balance of atmospheric aerosol particles. This means that the mass of different compounds calculated on the basis of inorganic ion and PIXE measurements is summed up and the results are compared with the total mass measured directly by weighing aerosol filters before and after the sampling. The input data for this calculation based on PIXE and wet chemistry analyses are given in *Table 4* (*Mészáros,* 1991). The table contains the fourteen most frequent elements found in the Hungarian aerosol. It can be seen that the first six elements as well as magnesium in the last row have an enrichment near one (within a factor of about two). Consequently they are considered as mineral dust components. The rest of elements are characterized by an enrichment factor much higher than 1. It is high in particular for sulfur and nitrogen: these elements are obviously of non-crustal origin. It is to be noted that the relatively high sodium concentration/enrichment is due to the fact that in the Hungarian Great Plain the soils contain much more sodium carbonate than the "average" soils used in the calculation.

Data in Table 4 shows that the concentration of sulfur as well as ammonium- and nitrate nitrogen is very important. Except some nitrate, these species can be found in the fine particles (see later), together with elemental carbon. On the other hand the level of sodium, silicon, aluminum and calcium is also significant, especially in the summer half-year (see *Borbély-Kiss et al.*, 1991). These elements constitute the soil derived aerosol particles.

On the basis of these data the main compound in the aerosol was estimated as listed in *Table 5*. For constructing the table the main composition of

Hungarian soils was also taken into consideration. According to this first approximation sodium carbonate is an important component in the coarse size range. This is partly caused by the water content of its crystals. On the other hand in the fine size range the composition is controlled by ammonium sulfate. This involves that oxygen is a major element in the aerosol over Hungary.

Table 4. Elemental composition of atmospheric aerosol particles under background conditions in Hungary measured by PIXE and wet chemistry (denoted by an asterisk) methods. *Ef* is the enrichment factor relative to titanium (it is equal to one if the element is of soil origin)

Element	Concentration (ng m^{-3})	Ef
Si	945	0.4
Al	340	0.6
Ca	495	2.6
Fe	324	1.1
K	265	2.1
Mn	12.8	2.7
S	1778	1507
Cl	22.1	31
Pb	24.8	457
Zn	29.9	106
NH_4-N*	1268	
NO_3-N*	352	6568
Na*	2880	18.9
Mg*	250	2.2

We have to emphasize, however, that Table 5 is based on elements and ions tabulated in Table 4. This means that aerosol particles may contain other substances which were not identified. This possibility is supported by the fact that that the total mass concentration of aerosol particles, measured by direct weighing in 1988, is 54 μg m^{-3} on an average. By comparing this latter value with the total concentration in Table 5, we can conclude that the compounds tabulated constitute only 64 % of the total mass. In other words this means that there is an important unidentified fraction. It was obvious to suppose again (see Section 2 of this paper) that this fraction consists of organic materials. For this reason in the second half of nineties our main aim has been to look for organic matter in the aerosol.

Table 5. Mass of different species in atmospheric aerosol particles over Hungary. Note: elemental carbon was measured by means of an optical method (*Heintzenberg* and *Mészáros*, 1985).

Size	Compound	Concentration (ng m^{-3})
Coarse	$KAlSi_3O_8$	1889
	$NaAlSi_3O_8$	1166
	$Al(OH)_3$	225
	$Na_2CO_3.10H_2O$	17271
	$FeCO_3$	705
	$CaCO_3$	1238
	$MgSO_4.7H_2O$*	2563
	Subtotal	**25057**
Fine	NH_4NO_3	2012
	$(NH_4)_2SO_4$	4381
	H_2SO_4	2130
	Elemental carbon	810
	Subtotal	**9333**
Coarse + Fine	**Total**	**34390**

*Mg was considered as $MgSO_4$ since water soluble magnesium was identified

5. *Organic compounds*

The philosophy of our research aiming to study the organic substances is as follows. It is well known that in the U.S.A. several series of measurements have been carried out to identify organic species. In these programs organic solvents were used to dissolve organic compounds from aerosol samples. The results of these studies show that only a small fraction of organic compounds can be identified individually in this way (see e.g., *Rogge et al.*, 1993). For this reason our aim has been to characterize the group of organic compounds with special emphasis on water soluble fraction. In the atmosphere the main solvent is water, and one of the main questions is whether particles are water soluble or not. Thus, the goal of our program has been to look for water soluble organic substances. We hoped that in this way we can explain in a more deeper manner the nature of CCN as outlined in Section 2 of this paper.

Briefly, the atmospheric particles were captured in this case by high volume samplers and an impactor of two stages backed-up by suitable filters. The samples were analyzed by different up-to date chemical methods like capillary electrophoresis, gas chromatography-mass spectrometry, high performance liquid chromatography etc. Total, elemental and organic carbon was measured by the evolved gas analysis. In the last years for particle sampling and characterization an *e*lectric *l*ow *p*ressure *i*mpactor (ELPI) was applied (*Laitinen et al.*, 1996). In this device particles are electrically charged before entering the impactor. According to their inertia the charged particles impact onto metal foils to create electric signals which are in real-time counted, while samples can be subsequently analyzed. All the samplings were carried out under background conditions at K-puszta site.

The first result of this program is that total carbon concentration in the fine particle size range is comparable or higher than sulfate ion concentration. The majority of total carbon consists of organic carbon, while the mass of elemental carbon is relatively low. The organic carbon concentration can be as high as 10 $\mu g\ m^{-3}$ which is sufficient to explain the missing mass in the fine size range (see Table 5), mainly if we recalculate the mass of carbon as an element into the mass of carbon compounds by using the conversion factor of 1.8 we found (*Kiss et al.,* 2000).

The second interesting finding is that at least the half of the mass of organic carbon is soluble in water (*Zappoli et al.*, 1999; *Kiss et al.*, 2000). Further, there is some indication that this water soluble fraction is composed of macromolecular species which behave very similarly as humic acids in the soils[2]. This idea was based on the laboratory comparison of UV spectra, electropherograms and thermal behavior of humic acid standards to those of aerosol samples. The pyrolysis of aerosol samples also indicates that macromolecules in the fine size range are composed of polysaccharides, lignins, proteins and lipids very similarly to major soil compounds (*Gelencsér et al.*, 2000). This possibility was first demonstrated by *Mukai* and *Ambe* (1986), but these Japanese workers found humic substances in a much lower concentration. Moreover, macromolecular substances in aerosol samples were identified in street dust by *Havers et al.* (1998) in Germany. Finally, *Likens et al.* (1983) showed that in precipitation water a major part of dissolved carbon is in macromolecular form. This finding is interesting in particular if we consider that practically no humic substances are found in the coarse particle size range which excludes the possibility that these substances in the air originate from the mechanical disintegration of soils. Since such molecules cannot be formed in the air by chemical reactions, *Gelencsér* (2001) supposes that macromolecules are released from the soils in gaseous form and condensed in the air by homogeneous or heterogeneous nucleation.

Unfortunately the size distribution of water soluble organics (or humic acid-like substances) is not yet known. However, our measurements made by

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[2] The concentration of different carboxylic acids in aerosol phase was found to be rather low in Hungary, although in clean air in the Swiss Alps their role is more important (*Sárvári et al.*, 1999).

ELPI show that organic carbon and sulfate ions have very different size distributions (*Fig. 4*). While sulfate ions are accumulated in the size range of 0.25–1.0 μm, an important part of the *mass* of organic carbon particles have diameters below 0.06 μm. This means that on *number* basis the majority of aerosol particles consists of organics in agreement with the finding of *Novakov* and *Penner* (1993). If these small organic carbon particles are soluble in water, one can assume that they can serve as CCN. By accepting this hypothesis we can conclude that an important part of CCN under continental conditions (at least in Europe) is independent of, or only indirectly related (through agriculture) to human activities. It goes without saying that this conclusion should be verified by further research. Anyway, fog studies in Po Valley, Italy, demonstrate (*Facchini et al.*, 1999) that polar water soluble organic species (giving the majority of total organic mass) can be found mostly in droplet phase, while insoluble carbon is detected preferentially in interstitial particles.

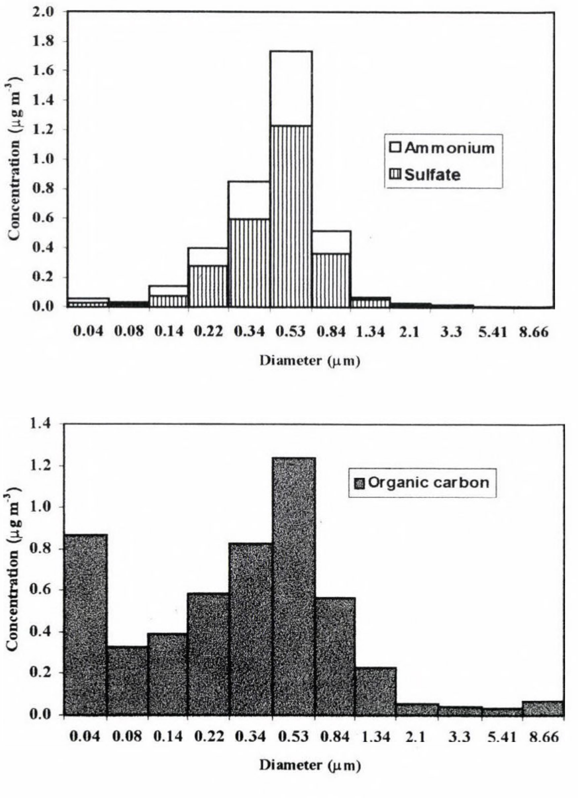

Fig. 4. Size distribution of ammonium sulfate and organic carbon particles.

An other interesting fact emerging from the figure is that ammonium sulfate particles detected in 1995–1996 have larger sizes than they had thirty years ago (see Table 2; *Mészáros*, 1968) when sulfate concentrations were higher than today. If we do not consider differences in sampling methods, one can speculate that temporal variations in sulfate concentrations and size distributions are the result of the decrease of sulfur dioxide emissions in Hungary and generally speaking in Europe (*Mylona*, 1996). Higher emission rates resulted not only in higher sulfate concentrations, but also in smaller particles due to the continuous aerosol formation by gas-to-particle conversion. This involves that the relative importance of sulfate ions in condensation processes *versus* the effects of organic carbon was higher some decades ago than presently.

6. Optical properties and chemical composition

Aerosol particles in the air scatter and absorb solar radiation. This aerosol extinction is important not only in the regulation of visibility, but also in the control of solar radiation transfer. Since solar radiation transfer determines the radiation budget, changes in aerosol characteristics contribute to climatic variations (*Charlson et al.*, 1991). For this reason, parallel with chemical measurements, optical properties of fine aerosol are also monitored at K-puszta station. The scattering and absorption coefficients are observed by an integrating nephelometer (working at 535 nm) and a particle soot absorption photometer (550 nm), respectively. The aim of the program is to look for correlation between these optical parameters averaged for 12 or 24 hours and the chemical composition. It should be noted that the values of the scattering coefficient varies typically between 50 and 100 Mm^{-1}, while the range of the absorption coefficient is generally 5–10 Mm^{-1}. This means that the extinction of solar radiation by aerosol particles is controlled by light scattering.

The first evaluation of data showed that in winter the scattering coefficient correlates significantly with sulfate concentration and the absorption coefficient is determined by elemental carbon. In summer the situation is more complicated: the correlation between the sulfate concentration and scattering is weaker (*Mészáros et al.*, 1998). A more detailed analysis of data revealed that the summer situation can be interpreted if the concentration of organic compounds is also considered (*Molnár et al.*, 1999). That is, in summer daylight the correlation between sulfate and scattering coefficient is significant only when the weather is characterized by the passage of cold fronts with relatively low temperature, more or less cloudy sky and temporary precipitation. In these cases the correlation coefficient between sulfate and scattering is 0.96, while the corresponding figure for ammonium is 0.95. On the other hand, during hot and stable weather with sunshine, weak wind speeds and high ozone concentrations, both scattering and absorption coefficients correlate well with organic species. *Table 6* gives the correlation coefficients for this type of weather period. We note that, considering the number of cases, the relationship is significant at a probability level of 0.1% if the correlation coefficient is equal to or larger than 0.80.

It would be very interesting to know what the difference is between the organic species occurred during these two weather types. One possibility is that in these two weather periods the size distribution of organic particles is different. One can speculate for example that in the case of the first weather period the aerosol contains organic particles with an average size below the optically active size range. An other explanation can be the different chemical composition in the bulk organic fraction. Anyway, the interpretation of the data needs further, more detailed investigation.

Table 6. Correlation coefficients between the concentration of carbonaceous particles and optical properties. WS denotes the water soluble fraction.
Note that oxalate constitutes the most important carboxylic acid in aerosol phase.

Species →	**Oxalate**	**Total carbon**	**WS carbon**
Scattering	0.85	0.80	0.80
Absorption	0.84	0.96	0.88

On the basis of this study one can conclude that in certain situations the organic species play an important role in the control of the optical properties of the aerosol. Under other conditions their role is secondary in comparison with that of sulfate particles. Thus, the chemical properties controlling the optical parameters can change significantly from day to day. This conclusion rises the question how we can apply aerosol composition averaged for large time and spatial scales for understanding the behavior of the aerosol optics and radiation transfer in the air in a deeper way.

7. Conclusions

On the basis of the above discussion one can conclude that Hungarian aerosol research has contributed to the formulation of the following conclusions:

- Under continental conditions sea salt particles do not play a role in the control of the formation of clouds and precipitation.

- Both in the air over the oceans and continents ammonium sulfate is the most essential water soluble inorganic compound in the atmospheric aerosol. Considering their size and number these particles constitute an important part of cloud condensation nuclei.
- Taking into account that under continental conditions sulfate particles are presently of anthropogenic origin, in the past, before the industrial revolution, other aerosol type took part in the cloud formation. This fraction is consisted with a high probability of organic substances of biogenic origin.
- The deposition of different toxic elements, mainly in the wet deposition, supplies an non-negligible material flux into continental ecosystems.
- The mass balance of aerosol particles is improved considerably if organic substances are also considered. These macromolecular substances are partly water soluble and contribute to the control of cloud formation and solar radiation transfer in the atmosphere.
- In spite of the great progress in atmospheric aerosol research, world-wide and in Hungary further research is needed, mainly in the field of organic particles, to elucidate in a deeper way the role of aerosol particles in the control of environmental processes including weather and climate.

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Estimation of hourly temperature for the application of agrometeorological models

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Abstract—The importance of agrometeorological models and their application to improve cultivation techniques are growing day after day. This is mainly due to the need of an integrated agriculture, in which expensive and polluting input has to be substituted by more sustainable agronomic practices. Unfortunately, weather data used as input for these models are not always available, so methods to estimate the missing data have high importance. Starting from these considerations, some models to calculate hourly temperature from maximum and minimum daily values were used to simulate thermal pattern during seven different years (from 1994 to 2000). The obtained results were first compared with the measured values of hourly temperature to control the accuracy of the models. Then, calculated temperatures were used as input of an agrometeorological model simulating the development of *Plasmopara viticola* on grapevine (*Vitis vinifera*). Simulations, using measured and predicted temperatures, were compared to evaluate the possibility of applying temperature models to generate input data of biological systems. The Parton model showed the higher accuracy, while the Ephrath, Wcalc and Goudriaan models presented a decreasing precision in the simulation of thermal pattern. However, all the methods allowed a good substitution of measured temperatures for the application of agrometeorological models.

Key-words: generation of weather data, epidemiological models, sine-exponential models, deviance indexes.

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1. Introduction

Temperature and other weather variables obviously have a very important effect on many physiological processes taking place in plants. Often temperature is one of the critical variables that drive biological systems, affecting crop growth and development, disease and insect attacks. Consequently thermal pattern has fundamental importance in model simulation, representing the main driving variable (*Benincasa et al.,* 1991). Usually, the available temperature data consist of daily average or daily maximum and minimum values. This is particularly true for historical climatic series, marginal areas and developing countries, where economical limitations obstacle the diffusion of automatic weather stations. However extreme values offer a good representation of the average meteorological conditions and probably they are sufficient in some situations, such as bioclimatic characterisation (*Orlandini et al.,* 2000). In biological models, however, the use of daily average or maximum and minimum values can cause deviations. In fact many biological processes, such as photosynthesis, respiration, transpiration and disease infection respond continually to weather variables (*Bjorkman*, 1979), so that daily totals or means of the required weather data are not sufficient (*Eprath et al.,* 1996). For many models and applications it is then crucial to obtain an approximation of hourly temperature, starting from daily maximum and minimum values. These considerations have stimulated the development of algorithms that allow to calculate hourly temperature from daily extreme data generating the driving variables to be used as input of many agrometeorological models (*Friend,* 1996).

The two most frequently used techniques for simulating the shape of daily curves of air temperature are the empirical and the energy budget model (*Parton* and *Logan,* 1981). The application of the latter is generally difficult because energy budget models require extensive computer time and data input (i.e., solar radiation, wind-speed, dew point). Empirical models draw the shape of the diurnal temperature curve in a variety of ways, varying from simple curve-fitting models based upon sine-exponential curves (*Parton* and *Logan,* 1981; *Wilkerson et al.,* 1983; *Eprath et al.,* 1996) to more sophisticated techniques utilising Fourier analysis (*Carson* and *Moses*, 1963). It is not easy to represent the shape of daily temperature by few terms of a Fourier series, since many of the observed diurnal temperature curves are a combination of periodic sine and exponential decay curves (*Reicosky et al.,* 1989). Whereas sine-exponential models require only daily maximum and minimum temperatures, julian day and latitude to calculate hourly temperature.

The purpose of this work was to investigate the accuracy of several methods for calculating hourly air temperature from daily maximum and minimum values, collected in Chianti area (Tuscany, central Italy). Methods were selected from the literature on the basis of their simplicity, in terms of the number of input data and procedures of computing, so to allow a wide range of possible applications. The accuracy of models was studied first comparing model predictions with real hourly values of temperature collected in seven subsequent years (from 1994 to 2000) and then using predicted values as input of the agrometeorological model PLASMO (*Orlandini* and *Rosa,* 1997), simulating the development of *Plasmopara viticola* on grapevine (*Vitis vinifera*).

2. *Material and methods*

2.1 Data collection

Weather data were measured at the Mondeggi farm station (latitude 43°42'N, longitude 11°20'E), with 1 hour interval, for the period going from April to August, during seven years (from 1994 to 2000). In particular, temperature data were collected using a thermistor (Vaisala HMP 35A, Helsinki, Finland) with an accuracy of ±0.2°C at +25°C. Thermistor was placed, at the height of 2 m, in a shaded and ventilated chamber to prevent direct solar radiation from influencing the readings. All data were logged directly in digital format, using a data-logger (Delta-T, Cambridge, England) placed in the station. Maximum and minimum daily values were used to apply for the temperature models, while hourly values were used to analyse model performance. Complete data sets of measured weather parameters were applied to run PLASMO model. It is based on temperature, relative humidity, rainfall and leaf wetness hourly values, to simulate the attack degree in percentage terms (ratio between infected and total leaf area) of grapevine downy mildew.

Temperature data collected during 1994 were used to calibrate the models by reducing the values of the average deviation of simulated from measured temperatures.

2.2 Temperature models

Four different methods were selected to calculate hourly temperature according to their limited input request and simplicity of computing. The chosen models were: Parton, described by *Parton* and *Logan* (1981); Wcalc, described by *Wilkerson et al.* (1983); Ephrath, described by *Eprath et al.* (1996); Goudriaan, described by *Goudriaan* and *van Laar* (1994). For the detailed mathematical description of the model equations it is possible to refer to the original papers. A general overview of model structure is only presented (*Table 1*).

Table 1. Main characteristics of temperature models.
Legend: Smh = time of maximum solar height; p and c = tuning parameters

Model	Function for daytime temperature	Function for night-time temperature	Time of maximum temperature (Local Time)	Time of minimum temperature (Local Time)	Number of parameters
Ephrat	Sinusoidal	Exponential	Smh + p	Sunrise	3
Parton	Sinusoidal	Exponential	Smh + p	Sunrise + c	1
Goudriaan	Sinusoidal	Exponential	13:30	Sunrise	3
Wcalc	Sinusoidal	Linear	14:00	Sunrise+2 hours	0

All models have some common assumptions: maximum temperature happens during daytime, before sunset; minimum temperature happens about at sunrise; the time of minimum and maximum temperature are fixed; daily minimum and maximum air temperature are the main input; Julian Day and latitude are used to calculate sunrise and sunset times from standard meteorological equations.

All methods selected are empirical and they describe the shape of the daytime temperature curve by a sinusoidal equation (*Fig. 1*). Three models use an exponential decay curve for calculating night-time hourly temperature, while Wcalc uses a linear equation. Ephrat and Parton models fix the time of maximum temperature adding to the time of maximum solar height (12:00) as a parameter. That parameter represents the delay in the maximum air temperature with respect to the time of maximum solar height, caused by heat storage in the atmosphere and in the surface layers of the soil (*Ephrath et al.*, 1996). The other models fix the time of maximum temperature at 13:30 (Goudriaan) and at 14:00 (Wcalc). The time of minimum temperature is fixed at sunrise in Ephrath and Goudriaan models, at sunrise plus a parameter in Parton and at sunrise plus 2 hours in Wcalc. Several tuning parameters are included in the models allowing a better fitting of simulations to different situations.

All models were implemented in computer programs using Fortran 32 language.

2.3 Analysis of model performance

To test the performance of the models two different analyses were carried out. First, in order to evaluate the accuracy of models describing the hourly trend of thermal pattern, temperatures measured at hourly intervals were compared to the calculated values.

Second, the possibility of using calculated data as input of agrometeorological models was assessed, by using predicted hourly temperatures as input data for a model simulating the development of grapevine downy mildew. The results of simulations were then compared with those obtained by using measured hourly temperature as input. The "goodness of fit" of each model was then evaluated by applying several statistical indices (*Mayer* and *Butler,* 1993).

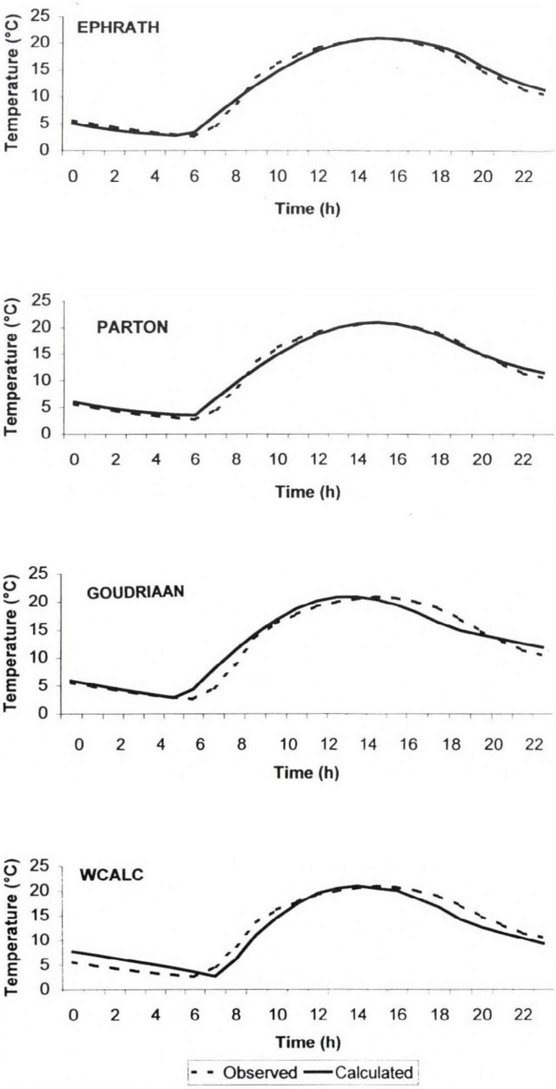

Fig. 1. Comparison of observed and calculated hourly courses of temperature for a typical day.

Mean bias error (MBE) and mean bias percent error (MB%E) allow to evaluate the average deviation calculated from measured values. A negative result of MBE and MB%E indicates that, generally, the model overestimates temperature with respect to the observed one.

Mean absolute error (MAE) and mean absolute percent error (MA%E) were used to evaluate the variation of simulated data around the observed patterns. Low values of MAE and MA%E indicate a low deviation of simulated values with respect to the measured values and so a higher accuracy of model.

$$MBE = \frac{\left(\sum_{i=1}^{n}(T_m - T_c)\right)}{n}, \tag{1}$$

$$MB\%E = 100\,\frac{\left(\sum_{i=1}^{n}\left(\frac{T_m - T_c}{T_m}\right)\right)}{n}, \tag{2}$$

$$MAE = \frac{\left(\sum_{i=1}^{n}|T_m - T_c|\right)}{n} \quad \text{and} \tag{3}$$

$$MA\%E = 100\,\frac{\left(\sum_{i=1}^{n}\left(\frac{|T_m - T_c|}{|T_m|}\right)\right)}{n}, \tag{4}$$

where n is the number of observations, $T_{m,i}$ is the i*th* measured value and $T_{c,i}$ is the i*th* calculated value.

3. Results and discussion

The values of MAE and MA%E indicated that Parton and Ephrath models had a lower deviation of simulated temperatures with respect to the measured values. In particular, Parton model showed the lowest MAE, while Ephrath the lowest MA%E (*Table 2*). The bigger accuracy of Parton and Ephrath models with respect to the others models was probably due to the higher number of tuning parameters allowing a better calibration of models to the observed temperature pattern.

In particular, analysing the influence of each parameter, it was possible to point out the importance of parameter for fixing the time of maximum temperature with regard to the time of maximum solar height. As matter of fact, Goudriaan model had only a parameter for determining night-time temperature and it showed almost the same error as for Wcalc model which did not have any parameters. On the other hand, the other two models included parameters both for the night-time and the time of maximum temperature position obtaining the best estimation.

Table 2. Statistical measures of model performance.
Legend: MAE = mean absolute error; MA%E = mean absolute percent error; MBE = mean bias error; MB%E = mean bias percent error

Model	MAE (°C)	MA%E	MBE (°C)	MB%E
Ephrath	1.11	8.33	-0.38	-1.58
Parton	1.10	8.79	-0.45	-2.50
Goudriaan	1.64	11.49	-0.20	-1.37
Wcalc	1.60	11.55	0.51	1.72

These considerations were confirmed by the decade analysis of error trend (*Fig. 2*). Parton and Ephrat presented the same level of error, that was quite stable enough during the whole vegetative season. Wcalc and Goudriaan model errors were observed at a higher level, particularly during the warmer months of the year, when the hourly trend is strongly affected by the delay of maximum temperature. Considering the decade trend of MA%E (*Fig. 3*) it was possible to point out, that during the spring the relative errors of all the models were higher, probably because of the lower levels of air temperature and the high weather variability. This variability maybe caused an alteration of normal sinusoidal daytime trend of temperature increasing the error of model result.

The values of MBE and MB%E indicated that, on average, Wcalc model underestimated the observed temperature, while the other models overestimated the real thermal pattern (Table 2). Moreover, Parton model showed a higher value of bias percent error with respect to Ephrath. As it is possible to emphasize from *Fig. 4,* this difference was mainly due to the higher underestimation of night-time temperatures of Ephrath model, that compensated for daytime overestimation reducing the daily amount of MB%E.

The purpose of this work was also to investigate the possibility of using calculated temperatures, instead of measured values, as input in simulation models. For this aim PLASMO simulations, performed with calculated and measured temperature values, were compared.

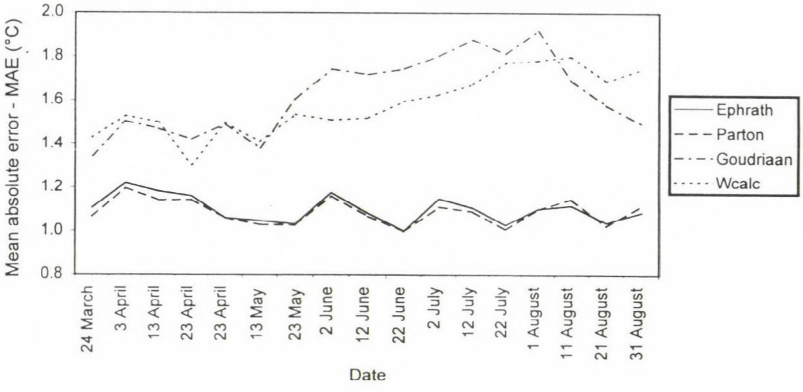

Fig. 2. Analysis of decade value of MAE.

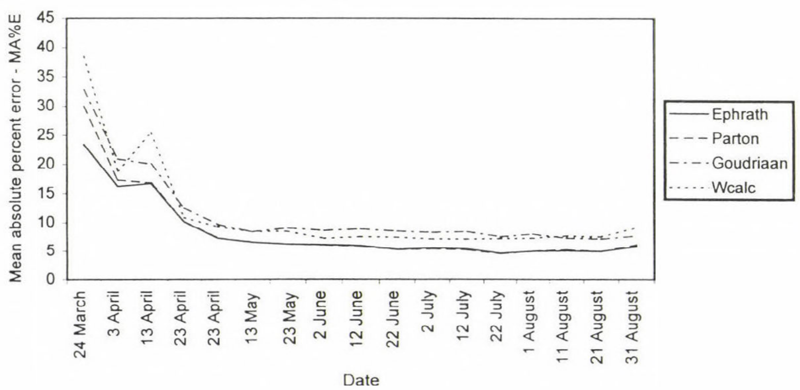

Fig. 3. Analysis of decade value of MA%E.

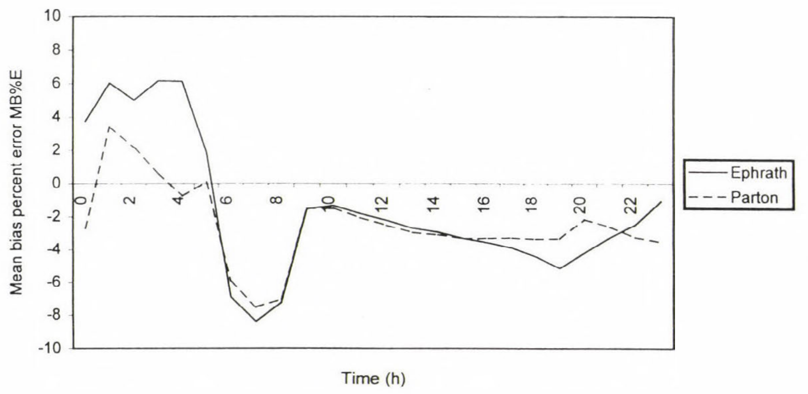

Fig. 4. Analysis of hourly curve of MB%E for Ephrath and Parton models.

The analysis of the PLASMO simulations was first carried out calculating the values of statistical indices of deviance (MAE, MA%E, MBE, MB%E) and then comparing the attack degree simulated by the model at three different periods of the year, using predicted and measured hourly temperature series of input data. The number of infections reported during the season was not analysed, because it is not a function of temperature but affected by relative humidity, leaf wetness and rainfall.

For all the models low average errors were observed, but Ephrath showed the best mean value for the whole analysed period (*Table 3*). This consideration was in agreement with the accuracy of model with respect to the measured temperature (Table 2).

Table 3. Average deviance of PLASMO simulation performed with calculated temperature with respect to simulation performed with measured values of air temperature. *Legend:* MAE = mean absolute error; MA%E = mean absolute percent error; MBE = mean bias error; MB%E = mean bias percent error

Model	MAE (°C)	MA%E	MBE (°C)	MB%E
Ephrath	0.24	13.28	-0.04	-3.45
Parton	0.32	13.43	-0.27	-9.72
Goudriaan	0.42	19.12	0.08	-3.19
Wcalc	0.42	16.30	-0.13	-7.05

During four of the six considered years the attack degree of *Plasmopara viticola* was very low (*Table 4*) and this had probably influenced the percentage errors, increasing their values. The level of MBE and MB%E indicated that Goudriaan model had a little trend to underestimate attack degree, while the other models overestimated the intensity of pathogen infection during the season (Table 3).

Table 4 presents the attack degree simulated by all the models at three different days of the six considered years using temperature measured or calculated. The differences between the attack degrees were very low for all models. Moreover, the differences showed an increasing trend from the beginning to the end of the season. Ephrath showed the lowest differences confirming its accuracy in simulating the hourly temperature.

Table 4. Attack degree values (%) simulated by PLASMO model using calculated and measured temperatures at three different days of the year

	1995			1996		
	June 30	July 31	August 31	June 30	July 31	August 31
Measured	0.49	3.80	29.72	0.47	0.49	1.20
Ephrath	0.49	3.44	30.47	0.47	0.60	1.67
Parton	0.50	3.97	31.72	0.48	0.55	1.67
Goudriaan	0.49	3.03	28.41	0.47	0.59	1.62
Wcalc	0.48	4.08	32.72	0.46	0.47	1.33

	1997			1998		
	June 30	July 31	August 31	June 30	July 31	August 31
Measured	0.58	1.05	5.71	0.97	3.94	6.01
Ephrath	0.57	0.93	5.07	1.38	1.57	6.81
Parton	0.57	1.04	5.81	1.41	3.39	6.01
Goudriaan	0.57	0.86	4.66	1.45	3.70	6.74
Wcalc	0.57	0.90	5.11	1.19	2.43	4.39

	1999			2000		
	June 30	July 31	August 31	June 30	July 31	August 31
Measured	0.27	1.94	1.88	1.95	5.09	20.70
Ephrath	0.29	2.38	2.31	1.91	5.04	20.21
Parton	0.30	2.55	2.48	2.07	5.89	22.75
Goudriaan	0.30	2.73	2.65	1.75	4.27	17.38
Wcalc	0.31	2.94	2.86	1.85	4.95	20.69

4. Conclusions

This study referred to select and calibrate some models to estimate hourly air temperature using daily data for Chianti zone. The models showed a different accuracy in simulation of diurnal thermal pattern with respect to the observed data. A particular attention must be devoted to calibration of models, also considering that the same parameters should be modified during the season to take into account for the variation of solar radiation regime, as affecting the pattern of hourly temperature. With this aim, also the area of model formulation and calibration represents a fundamental element for the successful application of the model in different areas and periods of the year.

The use of calculated temperature as input data in a model for grapevine downy mildew allowed a good simulation of pathogen infection, with low deviance from the results obtained by using measured temperature values. However this assumption can not be considered true for every agrometeorological model, also depending by model sensibility to the specific weather parameter (*Cappugi,* 2000).

The always growing importance of agrometeorological models and decision support systems in modern agriculture demands the study of methods for the estimation of other weather and agrometeorological variables, such as relative humidity and leaf wetness. This will increase the possibility of application of these important instruments, also in areas, where economical or technical problems may reduce the diffusion of weather stations.

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Analysis of drought severity using PDSI and SPI indices

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Abstract–The Great Hungarian Plain, which is the most important agricultural area of the country, is often stricken by drought. Dry years were particularly frequent in the last fifth of the 20th century. Tendencies of seasonal and annual precipitation totals during the 20th century were analysed using data series of monthly precipitation amounts from 14 Hungarian observing stations. Efficiencies of PDSI and SPI were investigated focusing the examples of unusual large changes in water supply anomalies between November 1999 and October 2000.

Our results show that precipitation has clearly decreased during the 20th century, particularly in early spring and early autumn. The decrease of annual totals is significant at the 0.95 level in all parts of Hungary. Frequency of severe drought events has markedly increased, although very wet periods also occurred in the recent years. PDSI and SPI are widely applied tools to characterise natural water supply. The various indices have different advantages and disadvantages. For example, while SPI for 6 months seems to be the best indicator of natural water supply for an average plant, SPI for 3 months is the better tool for sensitive, shallow-rooted plants.

Key-words: precipitation trend, water supply anomalies, drought, drought indices, Hungary.

1. Introduction

Drought is a recurrent phenomenon in Hungary causing frequent and substantial damages in the agricultural production. As high as 36% of the overall agricultural loss originates from drought, followed by hail, floods and frosts in the order of mean rates (*Dunay* and *Czakó*, 1987). Albeit drought has never been rare in the past, the period from 1983 to 1995 was exceptionally dry. In this 13 years the drought was chronic with relatively short interruptions of wetter subperiods, and 8 of the 13 years were extremely dry. This long series of dry years is unique in the 20th century in the Carpathian Basin, and only the period from 1943–1952 (*Gunst*, 1993) was accompanied by similarly frequent disastrous drought events. In the late 90's some very wet years followed, but the growing season of 2000 was extraordinarily dry again.

Hungary is situated in Central Europe, close to the 47°N geographical latitude, in the Carpathian Basin. The climate of Hungary is strongly influenced by the circulation patterns carrying maritime, continental or Mediterranean air masses, and the basic features originated from the macrosynoptic effects are modified by the topography of the basin and some other local factors. In most part of the country the climate is continental with semiarid features, since it can be characterized by 450–600 mm annual precipitation and 800–1000 mm year^{-1} potential evapotranspiration (PE). One fifth of the country in the Southwest and the mountainous regions in the North part are slightly wetter, with 600–800 mm typical yearly sum for both precipitation and PE. The wettest month of the year is June (60–90 mm), and the lowest monthly values are measured between January and March (25–40 mm) on average. However, the Great Hungarian Plain, which is the most important agricultural area of the country, particularly often suffers from insufficient water supply during the summer months. Frequent occurrence of water shortage in summer can be explained by the higher PE and in connection with it the increased water demand of plants under sunny and warm weather conditions, as well as the very large variability of precipitation amounts. While, on the one hand, cloudbursts with 50–100 mm precipitation may cause local floods, and monthly precipitation sum can sometimes exceed 200 mm, on the other hand, months without any precipitation and 3 month periods with below 100 mm total may occur at any time of the year. The importance of sufficient plant water supply is the highest in the growing season (April–September), and unfortunately, the highest variation of precipitation amount is detected in the same part of the year.

Numerous appropriate methods are known for characterizing different levels of water supply, especially drought events. The Palmer Drought Severity Index (PDSI) developed by *Palmer* (1965) is one of the most popular drought indices nowadays (*Briffa et al.*, 1994; *Scian* and *Donnari*, 1997; *Cook et al.*, 1999, etc.). However, some limitations of the PDSI have been recognized (e.g., *Alley*, 1984; *Kogan*, 1995; *Guttman*, 1998), and now the Standardized Precipitation Index (SPI) developed at the Colorado State University in the 90's is the mostly recommended drought index by many researchers (*McKee et al.*, 1995; *Edwards* and *McKee*, 1997; *Guttman*, 1998; *Hayes et al.*, 1999). Attempts of introducing some other drought indices are also promising (*Byun* and *Wilhite*, 1999), but these are beyond the scope of this study. Persistent lack of precipitation in 2000 in Hungary, following an unusual wet period, provides a good opportunity to investigate the efficiencies of PDSI and SPI, and describe the characteristics of a considerably rapid development of a severe summer drought as well.

Systematic changes of monthly, seasonal and annual precipitation totals, as well as efficiencies of PDSI and SPI are discussed in the following sections.

2. Data and methods

2.1 Data

Daily precipitation and monthly temperature data from 6 meteorological observing stations covering the period January 1901–October 2000, monthly precipitation and temperature data from further 8 meteorological observing stations (January 1901–December 1998) as well as county-averages of monthly precipitation for each Hungarian county (November 1999–October 2000) are used in our work. *Table 1* shows the list of the observing stations, their geographical coordinates and some further information related to the used data series. Spatial averages were used in the evaluation of precipitation tendencies, therefore, observing stations are sorted into 3 regions: four stations are sorted into the northern region (N) and five-five stations to the western (W) and southeastern regions (SE).

Table 1. List of the observing stations where the used data series are originated from

Observing stations	**Geographical coordinates**		**Elevation (m)**	**Daily precipitation data**	**Region**
Sopron	16°36'E	47°41'N	240		W
Szombathely	16°36'E	47°15'N	218	+	W
Keszthely	17°14'E	46°44'N	115		W
Mosonmagyaróvár	17°16'E	47°23'N	122	+	W
Pécs	18°14'E	46°00'N	140	+	W
Budapest	19°02'E	47°31'N	120	+	N
Miskolc	20°46'E	48°07'N	133		N
Debrecen	21°37'E	47°33'N	120	+	N
Nyíregyháza	21°41'E	47°59'N	105		N
Baja	19°11'E	46°11'N	113		SE
Kecskemét	19°46'E	46°54'N	114		SE
Szeged	20°09'E	46°15'N	80	+	SE
Szarvas	20°33'E	46°52'N	83		SE
Túrkeve	20°45'E	47°06'N	87		SE

2.2 Trend analysis

Systematic changes in monthly, seasonal and annual precipitation amounts of the 20th century are analyzed using linear regression technique (based on calculation of least square deviations), supplying with the construction of confidence interval of trend values, as well as applying Mann-Kendall test. These methods are widely used in the analysis of precipitation trends. The regression line fitting method was applied e.g., by *Curtis et al.* (1998), *Akinremi et al.* (1999), *Stafford et al.* (2000); the Mann-Kendall test was applied by *Schönwiese et al.* (1994), *Lettenmaier et al.* (1994), *Rodrigo et al.* (2000), etc.; and both the regression line fitting and the Mann-Kendall test were used by *Brunetti et al.* (2000). Application of other methods also occurs: *Zhang et al.* (2000) use an improved version of the regression line fitting, where, applying a red noise model, the serial autocorrelation in the precipitation series is taken into account; *De Luís et al.* (2000) chose the Spearman's test, which is also a highly recommended method (*Sneyers*, 1992). We have experienced that the results of significance investigations coming from traditional regression analysis are very close to the results of Mann-Kendall test, so application of further methods would likely not lead to essentially different results than those come from the mentioned two techniques. In this paper only trends showing statistical significance at the 0.95 level applying either best linear fitting or Mann-Kendall test are selected as significant.

2.3 Drought indices

PDSI for the investigated period was calculated relying on *Palmer* (1965). The values of this drought index tend to show the departure of water supply from the climatic normal for a date (usually at the end of a specified month). Calculation of the PDSI requires meteorological and soil information, namely values of precipitation amounts, PE and field capacity, as well as the climatic normal values of precipitation and PE. Taking into account that PE depends mostly on temperature in Hungary, and temperature data are available in much higher number and accuracy than measured PE data, the Thornthwaite method was applied to approach PE. At the calculation of climatic normals the 1901–1980 period was specified to be the reference period. Derivation method of the PDSI is recursive, thus monthly PDSI values are sensitive not only to the same month's meteorological conditions, but also to precipitation amounts and temperature values of the previous 6–9 months. While a positive PDSI shows surplus, negative values show shortage of the contemporary water supply. A PDSI value between –2 and –3 means moderate drought, a PDSI of between –3 and –4 means severe drought, and a PDSI of less than –4 indicates extreme drought.

Calculation of SPI is simpler, and it does not need data beyond monthly precipitation amounts. The source data series is required to be at least 30 year long. At first a gamma distribution is fitted to the source data, then the gamma distribution is converted into standard normal distribution. In this way a particular monthly precipitation amount is coupled with the value of the standard normal distribution having the same probability function value as the precipitation amount has in the source data set. The respective value of the standard normal distribution is the SPI. This method is also applied for precipitation totals of longer than 1 month periods, so one may use 1-month SPI, 2-month SPI, 3-month SPI, and so on. The usual length of the period applied is between 1 and 12 months. Hereafter a number after "SPI" marks the length of the time window, for instance SPI-6 denotes the standard precipitation index for six months.

Owing to the derivation method, the same SPI for different locations or different seasons means the same deviation relative to the climatic normal of the precipitation amounts. So, an SPI value less than –1 occurs 16 times in one hundred years, an SPI of less than –1.5 occurs 6.7 times and an SPI of less than –2 occurs 2.3 times in 100 years, on average. Therefore periods having SPI between –1 and –1.5 are moderately dry, periods having SPI between –1.5 and –2 are severely dry, and SPI values below –2 indicate extremely dry condition.

3. Tendencies of monthly, seasonal and annual precipitation amounts in the 20th century

Fig. 1 shows the long term changes of annual precipitation totals during the period 1901–1998 in Hungary. It seems that fluctuations are rather similar in the different regions, and the W region is the wettest throughout the century. While the earliest part of the investigated period was the wettest in W, in the other two regions the most precipitation fell around 1940. The sign of the mean (linear) change is negative in the whole country: –7.7 mm decade^{-1} in SE, –9.2 mm decade^{-1} in N, and –11.0 mm decade^{-1} in W. All these rates are statistically significant at the 0.95 level.

Rates of systematic changes were not uniform in various periods of the year. *Fig. 2* illustrates the mean rates for the individual months. Although the absolute values are very different, all the monthly trends have negative sign with the only exception of June. While there is hardly any systematic change from May to August, 3–4% per decade decrease has been taken place in the precipitation amounts of early spring and early autumn subperiods.

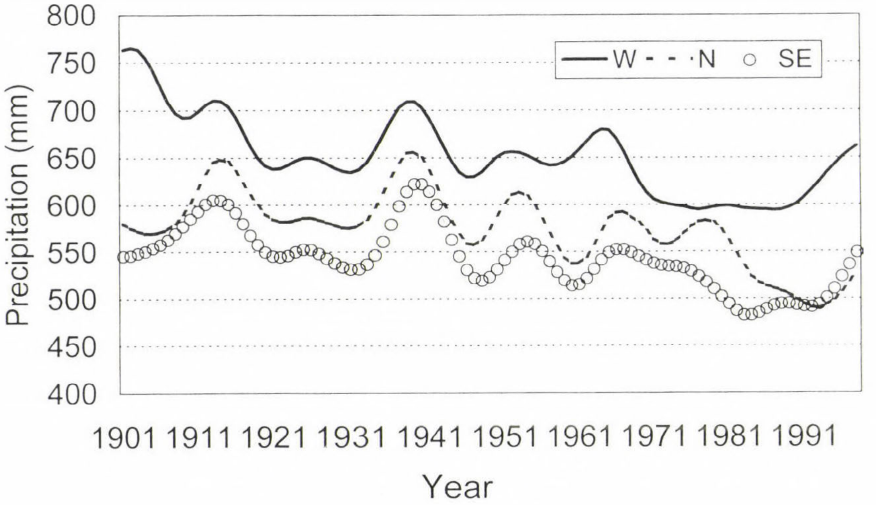

Fig. 1. Annual precipitation totals in the 20th century, over different regions of Hungary. Values are smoothed with a 15-point Gaussian filter.

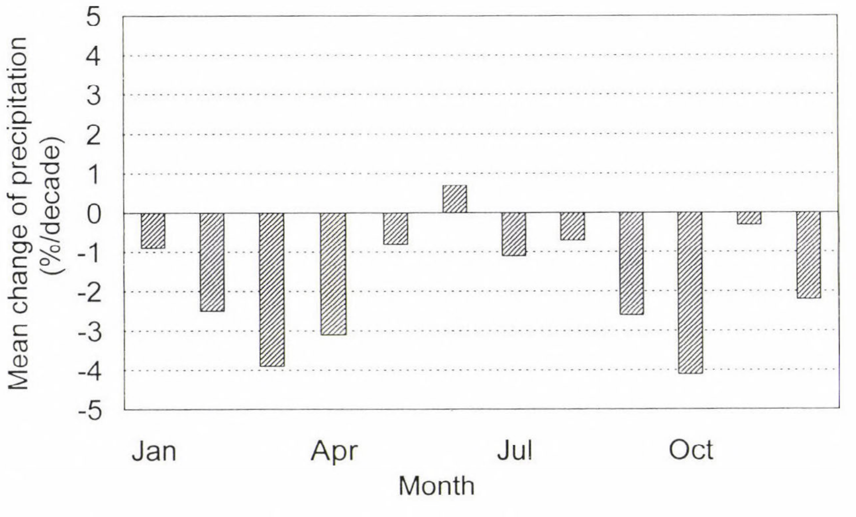

Fig. 2. Mean changes of monthly precipitation amounts in % per decade unit, countrywide averages. (100% = mean value for the 1901–98 period.)

Table 2 presents mean annual changes of precipitation amounts for 1-month and 3-month subperiods. Statistically significant trend values are marked with bold characters. Since the shorter the period, the higher the variance relative to the average systematic change, trends for individual months are not significant—except for countrywide average precipitation amounts in March (despite of the slightly higher decreasing rate in April and October, the signal-noise ratio is not so clear in any other case). Trends for precipitation totals of 3-month periods are generally not significant either, however, the majority of the trends in Table 2 belonging to early or mid-spring is significant.

Table 2. Mean change of monthly, 3-month and annual precipitation amounts (mm decade^{-1}). Significant trends at the 0.95 level are marked with bold characters

Month	W	N	SE	Mean	3-month	W	N	SE	Mean
January	-0.8	-0.2	0.1	-0.3	DJF	**-3.4**	-2.1	-0.6	-2.0
February	-1.0	-0.6	-0.7	-0.8	JFM	**-3.1**	-2.3	-1.9	**-2.4**
March	-1.3	-1.4	-1.4	**-1.4**	FMA	**-4.1**	-2.7	**-3.8**	**-3.6**
April	-1.8	-0.6	-1.7	-1.5	MAM	**-3.9**	-2.3	**-3.6**	**-3.3**
May	-0.8	-0.2	-0.4	-0.5	AMJ	-1.5	-1.0	-1.8	-1.5
June	1.2	-0.1	0.3	0.5	MJJ	-1.1	-0.9	-0.1	-0.7
July	-1.5	-0.5	0.0	-0.7	JJA	-1.2	-1.1	0.4	-0.6
August	-0.9	-0.4	0.1	-0.4	JAS	-3.8	-2.1	-1.1	-2.4
September	-1.5	-1.1	-1.2	-1.3	ASO	-3.7	-3.6	-3.4	**-3.6**
October	-1.4	-2.1	-2.3	-1.9	SON	-2.6	-3.7	-3.9	-3.3
November	0.3	-0.5	-0.3	-0.2	OND	-2.6	**-3.8**	-2.8	-3.0
December	-1.5	-1.3	-0.2	-1.0	NDJ	-1.9	-2.0	-0.2	-1.3
Annual	**-11.0**	**-9.2**	**-7.7**	**-9.3**					

Fig. 3 shows the long term fluctuations of seasonal precipitation amounts. In accordance with Table 2, slight decreasing trends are visible here. Fig. 3 confirms that the highest amount of precipitation generally falls in summer in Hungary. Nevertheless, it also seems that long term fluctuations and regional differences are the highest in summer too. In the other seasons regional differences are relatively small both in the shapes of the fluctuations and in the absolute values of mean precipitation amounts.

Owing to the decreasing trends in precipitation amounts, frequency of drought events increased during the 20th century. Calculating mean frequencies of PDSI <-3 occurrences from five data series (Mosonmagyaróvár, Budapest, Debrecen, Pécs and Szeged), the results are 8% for the 1901–40 subperiod, 16% for 1941–80 and 24% for 1981–1998. *Szinell et al.* (1998) presented a detailed investigation of drought tendencies in Hungary for the period 1881–1995. According to that, frequency of drought has increased in all seasons. The alterations are mostly significan for moderate drought events, as well as for severe drought events in the eastern–northeastern parts of the country.

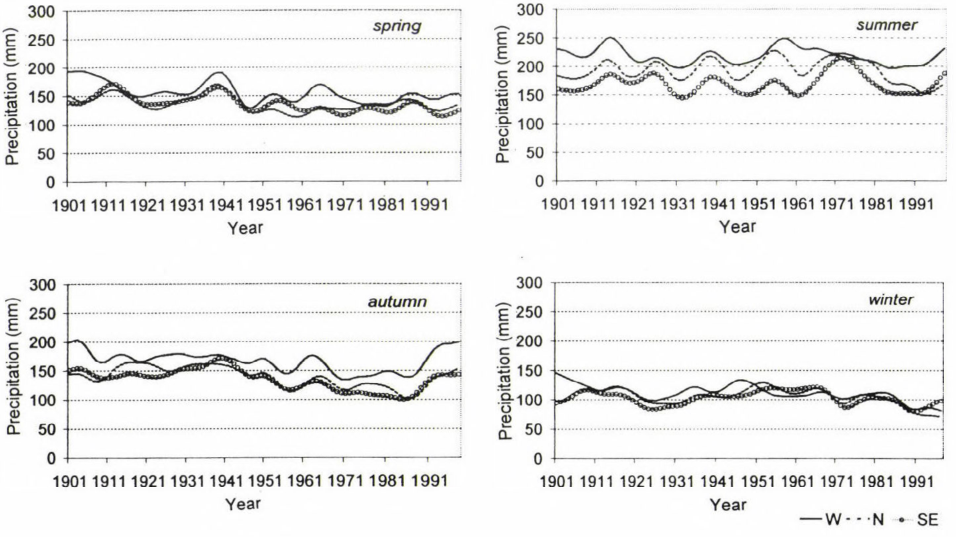

Fig. 3. The same as Fig. 1, but for seasonal precipitation amounts.

Since there are some evidences of a slight global warming in the 20th century (0.5–0.7°C, see *WMO*, 1999) it may be interesting to compare our results with the precipitation change scenario for Hungary referring to a slight global warming. Relying on some statistical connections between local temperature and meteorological variables for the hemispheric scale, some 10% decrease in annual precipitation amount is expected, however, decrease is predicted only for the summer half of the year (*Mika*, 1988; *Molnár* and *Mika*, 1997).

4. *Efficiencies of PDSI and SPI in evaluation of drought in 2000*

One of the curiosities of drought in 2000 in Hungary was that this event was preceded by an extraordinarily wet period, and there was hardly any transition stage between the two kind of extreme conditions in 1999 and 2000. The time period between September 1998 and December 1999 was unusually wet in the whole territory of Hungary. The precipitation surplus was the highest in the eastern half of the country, resulting the second wettest year of the 20th century in the Great Hungarian Plain. The area covered by inland waters reached 250 thousand ha in December 1999 and the following 1–2 months. Later on, wetness in the first third of 2000 was changeable. While in January and February the sum of precipitation was half of the climatological average, March and the first week of April was humid again.

The wet early spring was followed by a three months long dryness from April 11 until July 10, the lack of precipitation was rather uniform in the whole country. We note that according to averages of long time series, this 3-month part of the year should be one of the wettest in Hungary, and similar long lasting dry periods very rarely occur in this season. In the beginning the dry weather was favorable for the rapid withdrawal of inland waters. Although at the beginning of May the inland water coverage was still 40 thousand ha, at the same time a considerable large area has already been stricken by the gradually worsening water shortage. By the end of May the inland waters disappeared everywhere, and the moisture-shortage in the upper soil layer reached a severe degree in extensive parts of the country. Since the precipitation falling this time is very important for the plants grown here, the water shortage caused damages in agricultural production. The dry weather still continued in June and in the first third of July. The weather was almost steadily sunny, and daytime temperatures were well above the climatological average. These factors made the PE higher than average worsening the water shortage. As a result of this long lasting unusual weather, a disastrous drought developed in most part of Hungary.

The monthly precipitation amounts compared to the long term averages are shown in *Fig. 4*. In May the precipitation sum was less than half of the usual amount, and in June, which is the wettest month of the year in Hungary on average, the fall was even only the 28% of the climatic normal. The precipitation amounts fell between April 11 and July 10 in Szeged and Mosonmagyaróvár were the lowest ever occurred in the same period of the year in the 20th century. In Miskolc this period of 2000 was the second driest, in Budapest and Szombathely the third driest in the century.

A few weeks of humid weather followed in July, but August was again very dry, the precipitation amount in this month was only 30% of the long term average. The precipitation fell in July could moisten only the upper 20–40 cm layer of the soil, and in August it dried up quickly worsened by the extremely hot weather in the second half of August when the temperature often rose up to 35–40°C. We compared the precipitation amounts fell between May and August with those were measured in the same periods of other years of the 20th century. In Szeged and Budapest the summer of 2000 was the driest in this century, in Szeged 64 mm, in Budapest 79 mm precipitation fell during the four months. These amounts equal to the sum in one average summer month in Hungary. (In Szeged the new record is only 70% of the earlier measured record.) According to the precipitation fell from May to August, in Mosonmagyaróvár the second, in Miskolc the eighth, in Szombathely the twelfth, in Debrecen the nineteenth, in Pécs the twentieth driest year was the last year of the century. In September and October the dryness continued, but it was spatially not so uniform as before, and in accordance with the seasonal cycle of plants, it caused less harm in the agricultural production than during the previous months.

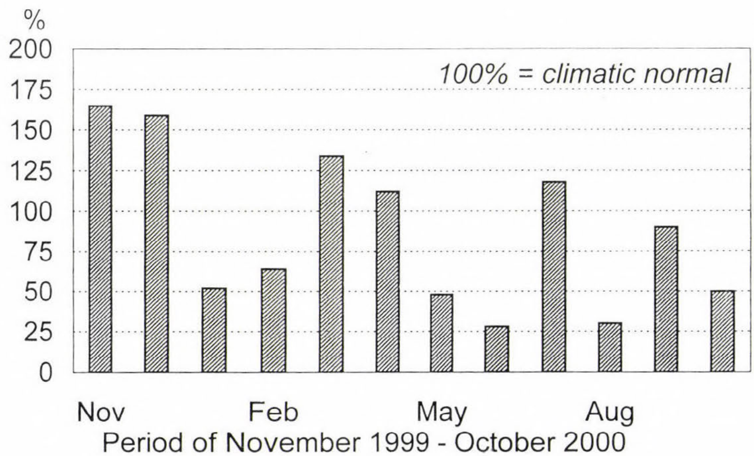

Fig. 4. Monthly precipitation amounts from November 1999 to October 2000, in percentage of climatological normal (1961–1990). Countrywide averages.

Considering that the starting and ending dates of dry periods may occur in any day of a month, drought indices based on merely monthly values of meteorological elements may be insufficient in some cases. For example, the first and very severe dry period leading to the drought focused in this paper lasted from April 7 to July 10, so it was longer than 3 months. As monthly precipitation amounts for April and July were above the normal, the same dryness seems to be substantially shorter relying on the monthly data, and the widely used index values are obviously affected by this shortcoming of the method. Notwithstanding, application of indices derived from monthly precipitation values is appropriate in many cases, especially for characterizing the natural condition in processes which are strongly depend on the long term departures of precipitation amounts.

Considering the different applications, different drought indices may provide the best estimation of a given drought. PDSI and SPI indices for the relevant period were calculated and compared to obtain a more detailed description about the unusually rapid development of drought in 2000. Values of PDSI from November 1999 to October 2000 can be seen in *Fig. 5* for various places of Hungary. In the end of 1999 the values were near normal in the northwestern counties, but extremely high in the Southeast. After December the curves for the southern places show some surprisingly sharp decrease of excess water. This region was very wet in November and December, but in January and February hardly any precipitation fell. In spring and summer the decrease of PDSI values continued throughout the country, but with a much smaller rate than in the beginning of the year in the Southeast. Around the end of the summer the values mostly fell below –3, and the lowest value in Szeged dropped below –5 in October. According to this, the drought was weak or moderate from May to July, but it became severe from the late summer in most part of Hungary.

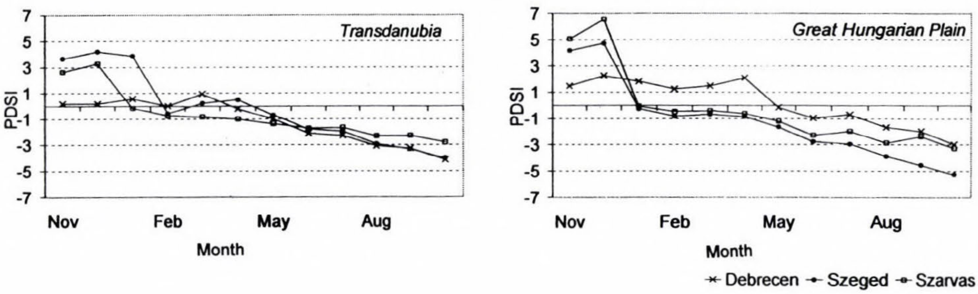

Fig. 5. Values of PDSI from November 1999 to October 2000.

SPI values were calculated for 3, 6 and 9 month periods, for the same locations as the PDSI. These SPI values are presented in *Fig. 6* for the same time period as in Fig. 5. In spring and in summer the prevailing tendency of SPIs is decreasing, similarly to the tendencies of PDSIs. Unusually large decline of SPI values occurred in the Southeast (Szarvas and Szeged) and in Budapest (central-North).

Calculating drought indices, it is obvious that the delay is shorter and the fluctuations are larger for the applications of relatively short time-windows. Among the illustrated indices, the SPI-3 is the most sensitive to the short term changes, and, consequently, it is the only index which indicates moderate water shortage even already early in the spring in some places. A few months later, in the beginning of the summer both SPI-3 and SPI-6 indicate drought of moderate to extreme levels in most part of the country. On the contrary, decrease of SPI-9 is rather slow, and indicates moderate drought late in the summer at first.

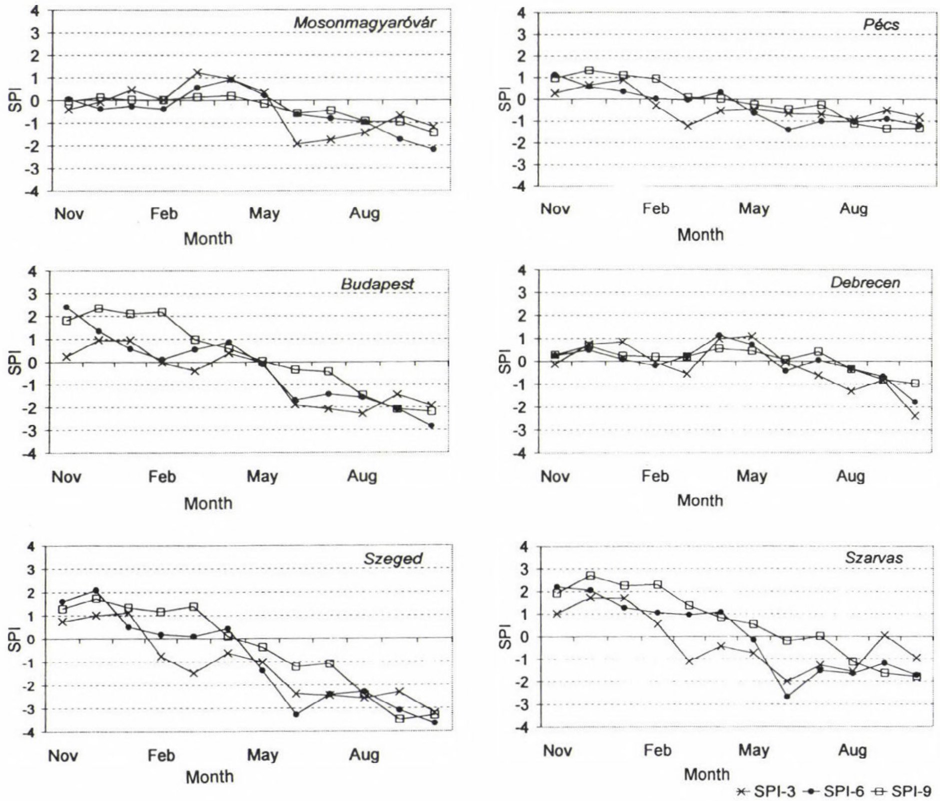

Fig. 6. Values of SPI-3, SPI-6 and SPI-9 from November 1999 to October 2000.

Relying on the presented results, one may conclude that SPI-3 is an appropriate tool for analyzing water supply of sensitive, shallow-rooted plants, since changes of SPI-3 tend to show the changes of moisture content in the upper soil layers in a rather reliable way. SPI-6 can be recommended also for application in the agricultural water management, but for plant species with moderate drought tolerance, since when values of SPI-6 are significantly low, soil must be heavily dried up due to the persistent shortage of precipitation.

SPI-9 and PDSI are not the best tools for indicating a rapid development of agricultural drought, since their persistence is higher than that of originates from the usual storage capacity of available moisture content in the root zone. However, SPI-9 seems to be the most suitable tool for indicating some hydrological conditions: where the water surplus caused extended inland waters in late 1999, values of SPI-9 remained high in the first quarter of the year 2000, and they were still not low late in the spring. The speed of the change in SPI-9 is comparable with the observed withdrawal of the inland waters. SPI-9 may also be appropriate for characterizing the water supply for deep-rooted plants and forests. We cannot state similar good characteristics about PDSI, since we do not know any natural process which would correspond both to the rapid fall after December and to the much slower changes afterwards. This shortcoming of PDSI is a close consequence of its distribution characteristics (*Guttman*, 1998) and known from earlier works (e.g., *Szalai* and *Szinell*, 2000). Limitations in use of PDSI are summarized by *Wilhite et al.* (2000), and similar results related to the effectiveness of PDSI and SPI were found by *Bussay et al.* (2001). SPI is also highly recommended in the two papers last mentioned. Nevertheless we note that use of PDSI also has some advantages: it is a well-known index, and its properties are analyzed in details. Its values are computed and archived over many regions of the world, and as it has only one type, values from any place of the world are comparable well. While application of PDSI seems to be fairly good to obtain a quick survey about changes of water supply, comparative application of SPIs using various time-windows is suggested for a thorough analysis.

5. Conclusions

Systematic changes in precipitation amounts during the 20th century, as well as efficiencies of PDSI and SPI in describing water supply anomalies were investigated using precipitation and temperature data series of observing stations in Hungary. Our main findings are summarized below:

- Annual precipitation amount significantly decreased during the 20th century in all parts of Hungary.
- Precipitation has decreased in all seasons. While the highest decrease rate detected in early and mid-spring, there was hardly any systematic change in early and mid-summer.
- Owing to the decreasing trend of precipitation, frequency of drought events has become higher.

- PDSI and SPI indices follow fairly well the anomalies of plant water supply.
- SPI-6 (SPI-3) is an appropriate tool to characterize water supply condition for plants having average (enhanced) sensitivity to water shortage.
- SPI-9 seems to be an effective tool to follow the slow hydrological processes due to precipitation anomalies.
- Main characteristics of PDSI are similar to those of SPI-6 concerning the time-characteristic of the processes described by them. However, some disadvantages of PDSI were revealed in this study.
- Summarizing our experiences, some kind of parallel use of SPIs applying different time-windows (e.g., SPI-3, SPI-6 and SPI-9 together) may be suggested for overall investigation of natural water supply.

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Selected characteristics of wind climate and the potential use of wind energy in Hungary. Part I

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Abstract—Several authors investigated Hungarian wind characteristics in the last few decades. For instance, *Tar* (1980, 1983) analyzed the entire country. The European Wind Atlas was published in 1989 in Ris , Denmark for the Commission of the European Communities. Shortly after the need of a similar publication for the non-EU member countries emerged and only eight years later just partly satisfied with the Wind Atlas for the Central European Countries (*ZAMG*, 1997). Responding partly for these initiatives, and partly perceiving the increased prosperity of renewable energy resources in this region, in the middle of the 90's a research program started to study and map the wind climate of Hungary to aid on wind energy usage. Within this project, supplementary wind characteristics have been calculated for 13 Hungarian climate stations. Wind measuring field experiments have been performed and analyzed to determine the possible wind energy resources of Hungary. Temporarily operating climate stations have been installed for automated data collection and quality control. Vertical extrapolation of wind potential and calculation of the Weibull parameters have been completed in order to compare available and extractable wind potential. Mean power outputs and errors of using different averaging periods have been estimated. Using the European Digital Terrain Model, the WAsP model have been adapted. Errors of the model have been analyzed by comparing complex (valley of Lake Akkajaure, Sweden) and simple (Hegyhátsál area, Hungary) terrains.

Key-words: renewable energy resources, wind energy, wind climate, statistical time series analysis, wind field modeling.

1. Introduction

Wind energy has been used for a very long time. During the last two millenniums, historical evidence provides information even from Persia, China, and Japan (*Gipe*, 1995). For hundreds of years, wind energy has been used to power different types of machinery. Later, windmill has been invented to produce an alternate resource. Windmills were utilized first in Denmark (*Hills*, 1994); Paul La Cour built the world's first wind turbine generating electricity in 1891. He was concerned with the storage of energy, and used the electricity from his wind turbines for electrolysis in order to produce hydrogen for the gas light in his school.

At the end of the 19th and beginning of the 20th century, more and more windmills were used to pump water in rural areas and ranches. In Hungary more than 800 windmills worked at that time (*Filep*, 1981). Many of these fell out of use in the 1930s and 1940s, when electricity began to be supplied to these areas. In the 1970s and 1980s, a renewed interest arose in wind technology with rising energy prices and international policy on reduction of emission, but these efforts have once again begun to fall along the wayside despite the potential capacity for development in this area.

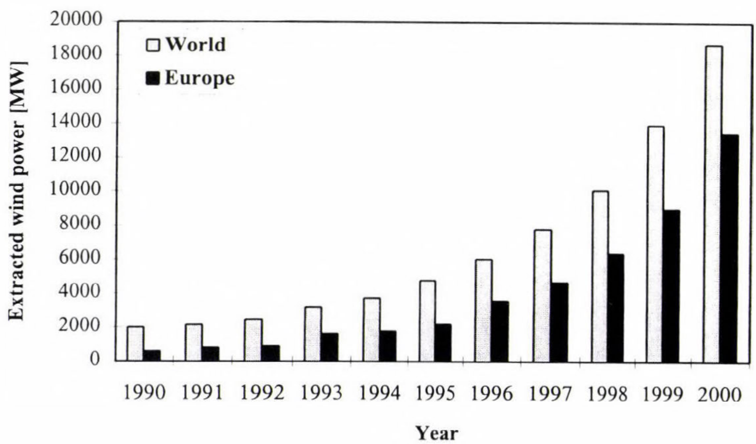

Fig. 1. Extracted wind power in the last decade in Europe and on the whole world (*Heier* and *Kleinkauf*, 2000).

In the last decade, wind energy usage shows definite increasing tendencies in Europe and on the whole world as well (*Fig. 1*). In the 1990–2000 period, the extracted wind power (in MW units) increased approximately twenty times in Europe and eight times in the world (*Heier* and *Kleinkauf*, 2000). Although Hungary is not among the countries having considerable wind power resources, because of the shortage in traditional fuel resources, the rising energy prices, and the unbalanced export-import ratio of energy supply it becomes necessary to consider and review the usage of our potential renewable energy resources. This was the main purpose of our research project started in 1995. In the first part of this paper we present some of our results on wind climatology and the application of wind energy. First, the main wind characteristics of 13 Hungarian climate stations are discussed. Then, results of two measuring field experiments are presented, comparing available and extractable wind power values. On the basis of the measured time series, errors coming from the different averaging periods are estimated. Finally, two case studies are presented. Namely, wind field simulations have been performed (using the Wind Atlas Analysis and Application Program — WAsP) for two different terrain types to validate the model and verify its adaptability.

2. Wind characteristics of selected stations in Hungary

In order to determine the potentials of wind energy usage in different regions of the country, several wind characteristics have been calculated based on a five year long (1968–1972) hourly time series for 13 meteorological stations in Hungary (*Kovács*, 1996). Wind direction data set is available for 16 sectors, and the accuracy of wind speed data is 0.1 m s^{-1}. Geographical locations and heights of the stations above the sea level are shown in *Fig. 2*. Also, the heights of instruments are indicated. Empirical and statistical data quality controls have been carried out on the raw time series. Because of the different heights of the measuring instruments, further correction was necessary. Wind data have been converted to the standard measuring height (10 m) in order to compare them. Since the necessary parameters for using wind profile equations were not available, only a semi-empirical formula (*Mezősi* and *Simon*, 1981) could be used:

$$v_h = v_{10}\left(0.223 + 0.656\ \lg\left(h + 4.75\right)\right), \tag{1}$$

where h indicates height, v_h and v_{10} indicate original and corrected wind speed values, respectively.

Using the transformed wind speed time series, comparative potential wind power study could be carried out for the country. Usually potential wind power is calculated in two different ways. If only wind speed values are known, the available wind power can be defined (*Justus*, 1985) as

$$P = \frac{1}{2}\rho v^3 C, \tag{2}$$

where C is the area of the wind turbine, ρ is the density of air, and v is the wind speed. To obtain extractable wind power (P^*), the left side of this Eq. (2) should be multiplied with the efficiency (E) of the wind turbine (*Justus*, 1986):

$$P^* = \frac{1}{2} E \rho v^3 C . \tag{3}$$

On the other hand, if Weibull parameters are available, potential wind power can be calculated using the gamma function (Γ) (*Troen* and *Petersen*, 1989):

$$P = \frac{1}{2} \rho A^3 \Gamma\left(1 + \frac{3}{k}\right), \tag{4}$$

where A and k are the Weibull parameters.

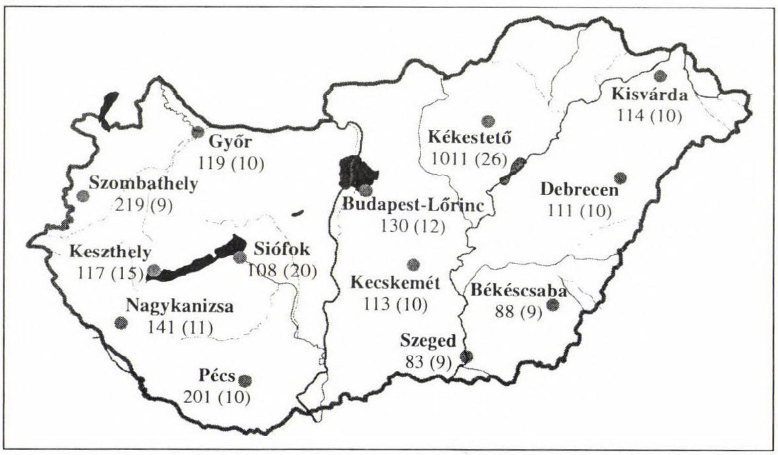

Fig. 2. Geographical locations of meteorological stations.
Height (m) of the station above the sea level and height (m) of the measuring instrument above the surface (in parentheses) are indicated.

In order to provide a better description of regional wind climates, several wind characteristics have been obtained and assembled to climate charts. For this purpose, first we determined seasonality of the wind speed frequencies, annual distribution of wind duration and wind power, monthly wind speed anomalies and their cubic anomalies, relative frequencies of wind speeds in the least windy and the windiest months. For all the 13 stations involved in this research, climatological and energetical diagrams have been assembled considering the structure of the European Wind Atlas (*Troen* and *Petersen*, 1989).

Fig. 3 presents one of the wind climate and energetic diagrams for the meteorological station of Budapest-Lőrinc. On all of these station charts, statistical parameters (at the top) and five diagrams with eleven different climate curves are given as it is detailed below.

(1) Average seasonal variation of wind speed:

a: average seasonal variation of measured wind speed ($m\ s^{-1}$) and
b: average seasonal variation of the cube of measured wind speed ($m^3\ s^{-3}$).

(2) Wind rose:

c: relative frequencies of wind directions (%),
d: contribution of each sector to total mean speed (%) and
e: contribution of each sector to the cube of total mean speed (%).

(3) Duration and power of wind:

f: duration of wind (hours) and
g: average annual potential power of wind ($kWh\ m^{-2}$).

(4) Relative frequencies of wind speeds:

h: relative frequencies for the least windy month,
i: relative frequencies for the windiest month.

(5) Monthly anomalies:

j: monthly average wind speed anomalies ($m\ s^{-1}$) and
k: anomalies of the cubes of monthly average wind speeds ($m^3\ s^{-3}$).

It is possible to estimate wind potentials of a given region, if potential wind power has been calculated using the Weibull parameters. Based on these results and suggestions of a comparative study on three empirical methods (*Poje* and *Civindi*, 1988), the *Justus* and *Amir Mikhail* (1976) empirical approach has been chosen. This methodology has been applied to extrapolate the Weibull parameters and potential wind power. On the basis of this method, Weibull parameters A and k at level z can be calculated as follows.

$$A(z) = A_a \left(\frac{z}{z_a} \right)^n , \tag{5}$$

$$k(z) = k_a \frac{1 - 0.088 \ln \frac{z_a}{10}}{1 - 0.088 \ln \frac{z}{10}} , \tag{6}$$

where A_a and k_a are parameters at the measuring level z_a and n can be determined as

$$n = \frac{0.37 - 0.088 \ln A_a}{1 - 0.088 \ln \frac{z_a}{10}}. \tag{7}$$

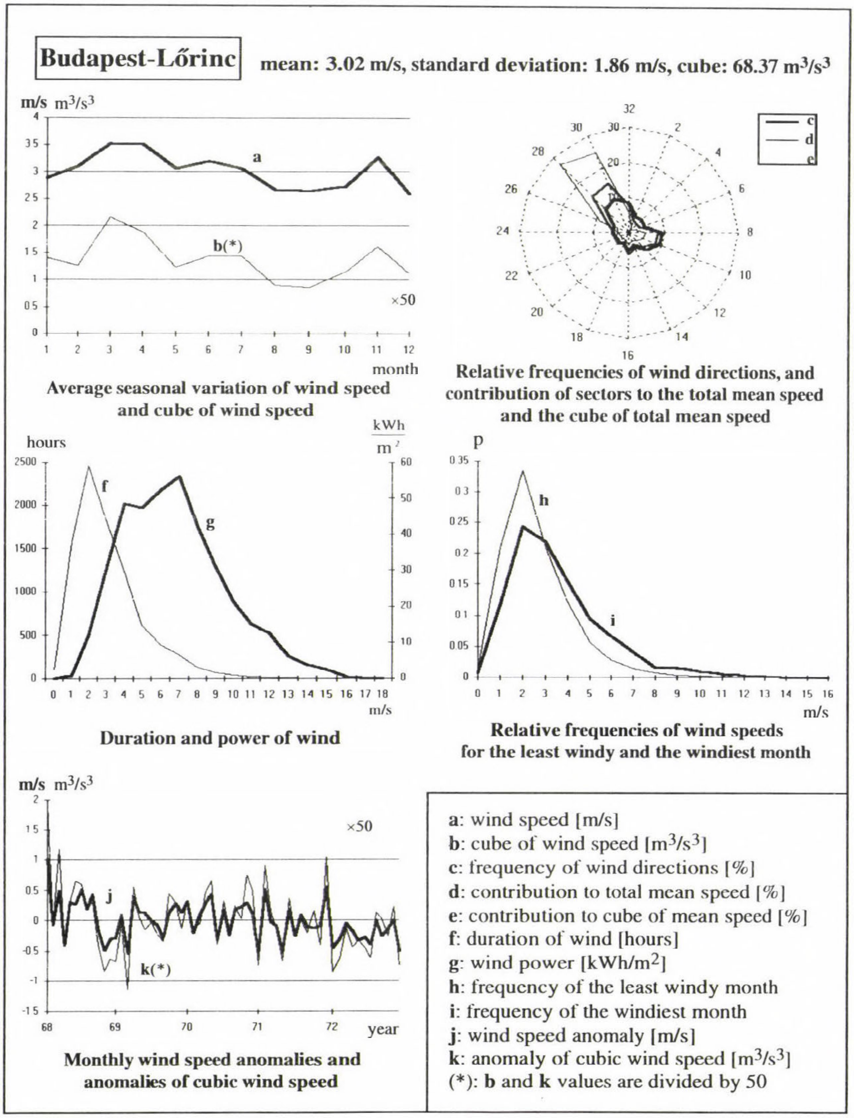

Fig. 3. Wind climatological and energetical diagram for Budapest-Lőrinc station.

For every station, extrapolation has been carried out for the 10 m level. *Table 1* summarizes the extrapolated values for all measuring sites. Both the A and k parameters show relatively small variability. The A parameter has a minimum in Kisvárda ($A=2.24$), and its maximum value occurs in Kékestető ($A=4.55$). From the literature (*Troen* and *Petersen*, 1989), values of A can reach even 8–10 at special seashore stations. The k parameter shows even smaller variability, values are usually between 1.06 and 1.82 m s^{-1}. Consequently, values of the potential wind power are low as well.

Table 1. Weibull parameters and potential wind power. P_1 denotes potential wind power calculated by the cube of averages (Eq. (2)) at 10 m height. P_2 and P_3 are potential wind power values based on Weibull distribution (Eq. (4)) at 10 m and 50 m heights, respectively. The marked (*) value is based on measurements at 26 m height.

	Stations	k ($m\ s^{-1}$)	c	P_1 ($W\ m^{-2}$)	P_2 ($W\ m^{-2}$)	P_3 ($W\ m^{-2}$)
1.	Békéscsaba	1.48	2.93	32.1	29.3	85.3
2.	Budapest	1.72	3.32	41.0	32.9	97.9
3.	Debrecen	1.52	3.32	45.0	40.2	113.5
4.	Győr	1.41	3.21	39.7	42.0	116.0
5.	Kecskemét	1.65	2.71	20.5	18.4	59.2
6.	Kékes	1.61	4.55	167.4*	93.9	273.8
7.	Keszthely	1.33	2.81	34.9	32.1	90.6
8.	Kisvárda	1.06	2.24	27.6	30.8	82.5
9.	Nagykanizsa	1.17	2.26	24.4	23.2	66.5
10.	Pécs	1.82	3.71	49.3	42.6	123.2
11.	Siófok	1.13	3.34	78.2	82.9	169.7
12.	Szeged	1.60	3.70	60.2	50.9	140.5
13.	Szombathely	1.23	4.49	193.6	158.4	350.9

Potential available wind power values have been calculated using the two above described methods. However, we applied extrapolations not only for 10 m but also 50 m above the ground level in sight of the possible siting of the small and large wind energy conversation systems. Selected results can be found in Table 1. Potential wind power P_1 has been calculated for 10 m using the definition of available wind power as shown in Eq. (2). Power values P_2 and P_3 have been determined at 10 m and 50 m, respectively, based on the Weibull parameters (Eq. (4)). Actual values of P_1, P_2, and P_3 demonstrate well the spatial variability of estimated wind powers in different regions of the country. Furthermore, the difference between P_3 and P_2 is convincing about the importance of the rotor axis height.

3. *Wind measuring field experiments, analysis of possible error sources*

Field experiments carried out in the last five years provided more detailed information of local wind climate which is essential for siting and installing wind power stations. Selected results of two wind measuring field experiments will be discussed. Wind measurements started in Budapest (270 m above the sea level, Szabadság hill, July–August 1995) and in a Hungarian village, Perbál (310 m above the sea level, near the Pilis mountain, September–October 1995). The first site is located on the hilly western side of Budapest, in a residential area with average density of family houses, surrounded by green patches (gardens, parks). The measuring instruments were set on the flat roof of a building (12 m above the ground). The other site (8 m above the ground) had more rural surroundings: outskirts of a small village (24 km from Budapest) and a crop field. For the experimental measurements sonic anemometers (GILL research sonic anemometer) were used since they are suitable for estimating available wind power.

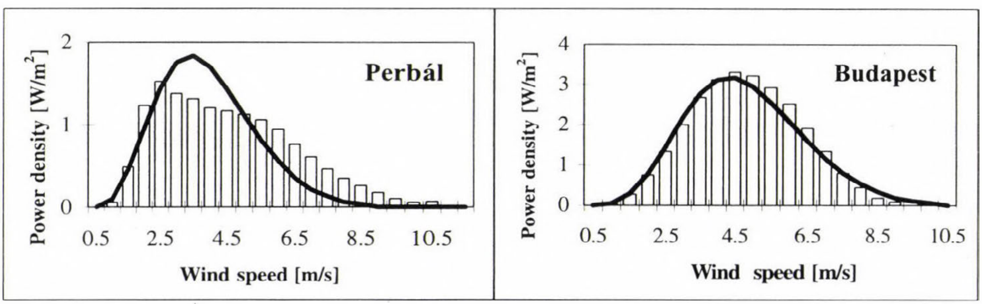

Fig. 4. Wind power density functions of field experiments. Bar values have been calculated using power density of empirical distribution, solid lines indicate estimation of power density based on Weibull distribution.

Wind density functions are good tools to analyze wind speed frequency distributions at a given site. *Fig. 4* compares wind power density functions for the two field experiments. Because of the different measuring conditions (agricultural fields/roof of a tall building), only distributions of wind speed frequencies could be analyzed and compared (*Vigh*, 1996), but not wind power values. Different measuring heights cause significant differences between power density values. In case of the residential area, the power density function has a sharp peak, and no significant differences appear between the estimated power density functions. In case of the rural region, which is a better environment for steady wind energy production, the errors of the estimations are larger.

Important characteristics of wind generators are the "cut-in" and "cut-off" wind speeds. These characteristics strongly depend on the type and power of the wind energy station. *Fig. 5* compares those parameters for micro (300 W) and small (11 kW) wind turbines using available (Eq. (2)) and extractable (Eq. (3)) wind power terms. Only the area under the available wind energy curves shows the effective power. Although, the power represented by the area between the two curves is present over the geographical terrain, it is not extractable with any generator. The figure illustrates well the importance of siting and selection of the appropriate wind turbine type.

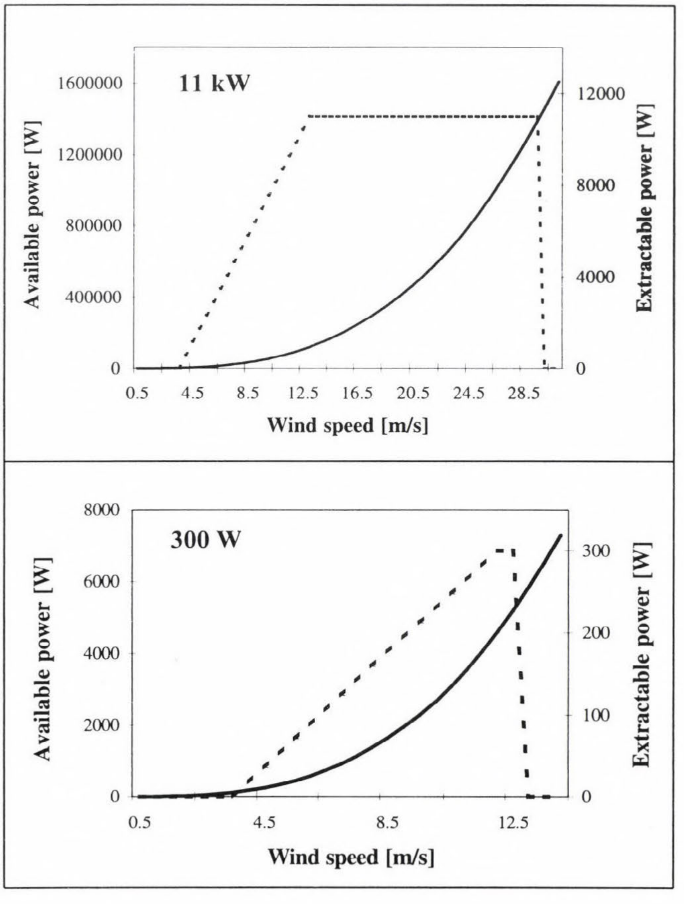

Fig. 5. Available (solid line) and extractable (dashed line) wind power curves for 11 kW and 300 W wind turbines, respectively.

Direct use of the measured wind speed data for wind resource calculations results in power estimations that are representative only for the actual position of the wind-measuring instruments. Characterization of available wind power of various sites of interest is via their average available wind power per unit area. Thus, an averaging process is included. The averaging period is a very important factor of determining the values of wind power (*Bartholy* and *Radics*, 1999). If only the mean speed is known and the mean available wind power is desired, then information about the *energy pattern factor* ($<V^3>/<V>^3$ ratio) is needed. *Fig. 6* gives information about this difference in case of Budapest and Perbál experiments. Note, that the stronger the wind the larger the error values. Therefore, to avoid very large estimation errors, the averaging period should be selected very carefully.

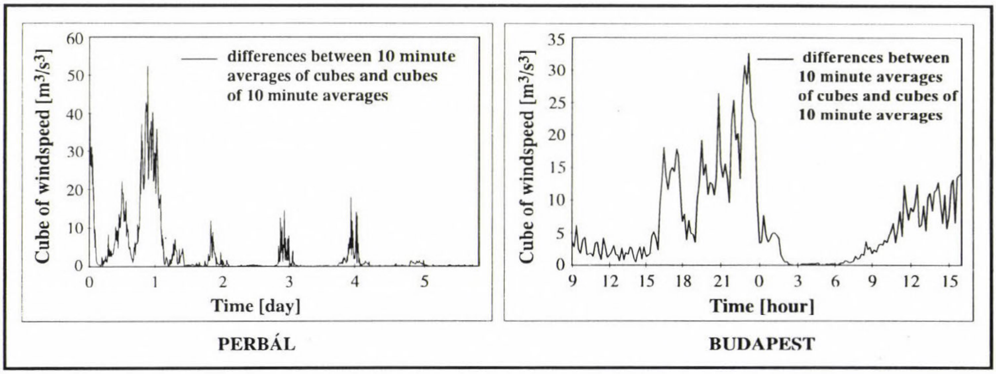

Fig. 6. Energy pattern factors of field experiments.

4. Wind field estimations with the WAsP model

In order to calculate and map the possibilities of potential wind energy usage in Hungary, several wind experiments and measured data series have been analyzed recently for selected subregions and the entire country (*Tar*, 1991; 2000). All of these studies used time series observed at the individual wind measuring stations. Before planning extractable wind power or siting wind power stations, it is necessary to know the spatially continuous wind fields, which can be obtained only by the use of wind models. Based on the recommendations of the European Wind Atlas (*Troen* and *Petersen*, 1989), among several appropriate models we chose the WAsP model (*Mortensen et al.*, 1993).

First we have analyzed the validity of the WAsP model over complex terrains. So, results of observations and model simulations have been compared in case of steep valley and hilly region. Wind data of the profile measurements in Hegyhátsál (Hungary) and from four Swedish stations (Suorva, Ritsem, Vietas, and Juobmotj kk) have been used to analyze and compare the wind climate of those different terrain types. For this purpose, WAsP model simulations have been run using different input data.

The WAsP model was developed at Ris National Laboratory, Roskilde, Denmark. It is a linear spectral model for near neutral boundary layer flow over complex terrain. The model can be used to analyze raw time series and to generate Wind Atlas data, which means that the wind observations have been cleaned from site specific conditions (roughness, shelter, topography). Also, it can be used to estimate the wind climate at any site using digitized topographical, roughness and shelter maps. Finally, it is possible to calculate total energy content of the mean wind, as well as the annual mean power production of a wind turbine, provided that the power curve of the turbine is available.

The WAsP model is based on the transformation of the frequency distributions of wind speed divided into twelve sectors (each of them represents 30 degrees). In order to clear the wind data from site-specific conditions, the model executes a so-called upward transformation, which calculates the geostrophic wind climate for a given region. Initially, three submodels (shelter model, orographic model, and roughness change model) are used to correct the sectorwise histograms of wind speed frequencies. The result is a corrected histogram that would be measured if the obstacles were taken away, the site was flat and the roughness values were low. After these calculations WAsP executes the so-called downward transformation. This process transforms the geostrophic wind distribution to a wind distribution at lower levels considering standard conditions.

The WAsP program allows to determine wind climate of any site during the measuring period if the site description and the Wind Atlas data set is available for the region. This application part of the model is an inverse of the analysis model, where input is the same as in case of calculating the Wind Atlas. In the application model the same submodels are used, however, the obstacle list, roughness description and orographic data are updated according to the new site.

4.1 WAsP simulations for mountainous terrain (case study for the valley of Lake Akkajaure)

First, we analyzed model simulation results for a mountainous terrain, for a steep valley. Since sufficiently long time series of any Hungarian site were not available, in the frame of the MOWIE project we run the model for a Swedish site. In order to test WasP, one needs at least two simultaneous measurements of wind speed and wind direction from two different measuring stations. Wind data observed at one of the sites are used as input of the model and the corresponding wind field for the other site is calculated. Model output can be directly compared to the measurements. Mean wind speeds for twelve sectors were calculated using the model at Suorva and Ritsem (*Bartholy* and *Radics*, 2000). These stations located in the valley of Lake Akkajaure in the Sjöfallets National Park at northern part of Sweden (*Fig. 7*). Wind fields have been simulated using two different sets of input data measured at 10 m height. Since the main purpose of this analysis is the validation of the model, longer time series were not required (Ritsem: 1981–1995, Suorva: 1995–1996). Nevertheless, estimation of extractable wind power applies decadal timescale. First, input data from Ritsem have been used to simulate wind speed and direction at Suorva. This has been followed by using wind data from Suorva as input data to simulate wind climate at Ritsem station.

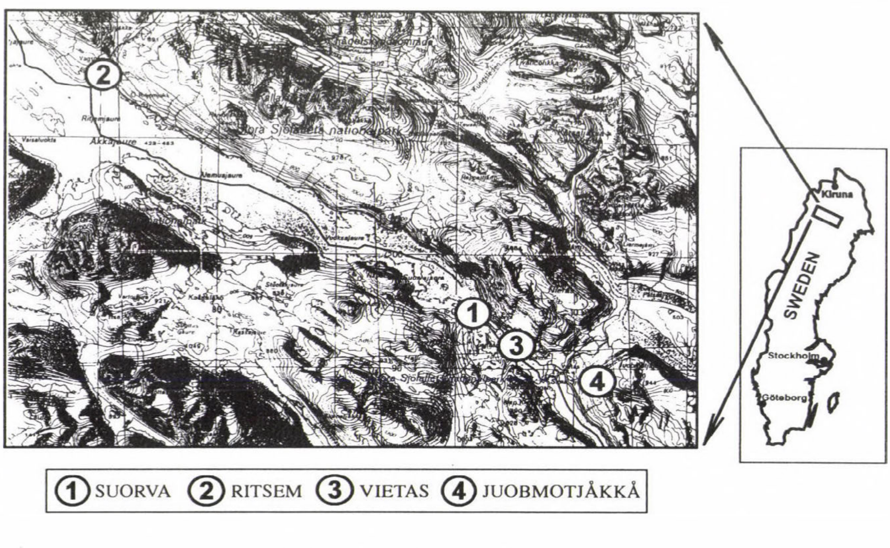

Fig. 7. Measurement stations in the valley of Lake Akkajaure in Sweden.

Topography has been included in WAsP as a height contour map using 100 m isolines. Because of model limitations, a 50 km × 50 km area has been used around the station. In this paper we selected the period between November 1 and May 30 every year assuming that the valley is covered by snow during this time (geographical location of the stations are at 67°N). Roughness-change lines have been determined by a mathematical routine. Roughness length has been defined as 0.8 m, 0.2 m, and 0.1 m for forests, closed shrublands and open shrublands, respectively. In case of grasslands, barren or sparsely vegetated areas, water bodies, ice and snow covered regions roughness length of 0.001 m has been chosen. There were no obstacles nearby the stations. After calculating the wind atlas data set from the input data, wind field of the given site has been computed by the WAsP model. In the following part of this chapter, simulations will be described separately and then compared.

Measured wind data set of Ritsem has been applied to model wind climate at Suorva for twelve sectors. Simulated mean wind speeds are shown in *Fig. 8* and compared to measured values. The mean wind speed is plotted as a function of the wind direction of the individual sector (spanning over 30 degrees). Simulated mean wind speed is 3.96 m s^{-1}, while the mean wind speed calculated from the observations at Suorva is 6.31 m s^{-1}. So the model significantly underestimates (by 37%) the mean wind speed. In general, values of simulated mean wind speed are too low and differences are very large in the case of northerly, north-westerly and westerly winds. Neither the maximum nor the minimum of the simulated wind are in the same sector as those of the measured wind.

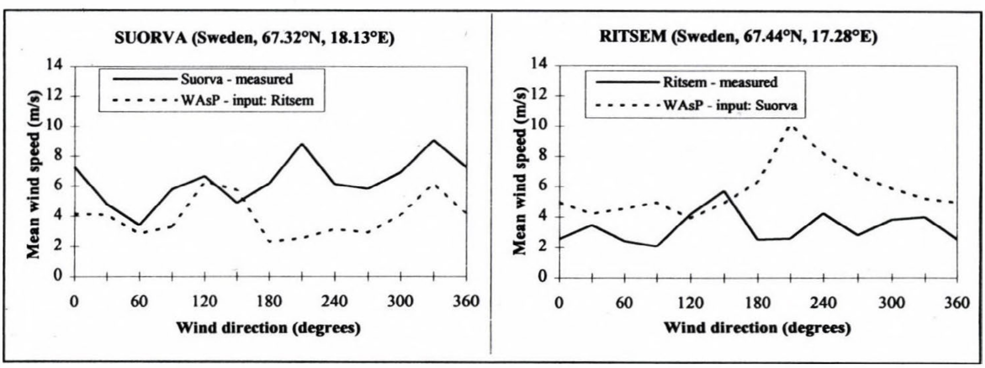

Fig. 8. Comparing measured and simulated wind speed values at Suorva and Ritsem stations.

For comparison, wind data measured at Suorva has been used to model the wind field at Ritsem. Simulated and observed values are compared in Fig. 8. The simulated mean wind speed is 5.83 m s^{-1} while the mean wind speed calculated from the observations at Ritsem is 3.36 m s^{-1}, which is a significant overestimation (with 74%). In this case the values of simulated mean wind speed are much larger than the wind observed at Ritsem. Nevertheless, the largest differences occur at the same directions as before.

Suorva and Ritsem stations are located in a steep valley. In both cases, simulations fit measurements the best at south-easterly directions. Considering the orientation of the valley (315°–135°), it can be concluded that large errors originate from the steep terrain that surrounds the valley.

Testing the validity of WAsP simulations, data measured at Suorva have been applied to reconstruct wind field at the same site using two different sets of input data (*Sandström*, 1994). First, flat topography has been considered, then zero roughness-change line has been set in the model. The results are shown in *Fig. 9*.

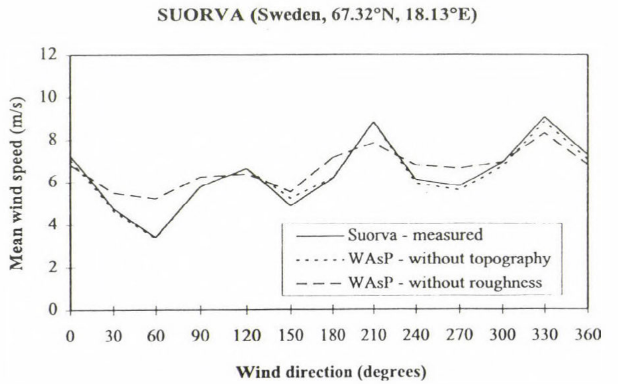

Fig. 9. Comparing measured and simulated wind speed values at Suorva station.

Considering flat topography, simulated mean wind speed is 6.26 m s^{-1}, while the mean measured wind speed is about the same, 6.31 m s^{-1}. The two curves do not differ very much and the courses are almost the same. Without the effect of the regional land use, the simulated mean wind speed is 6.63 m s^{-1}. The model overestimates the mean wind speed by only 5%, however, larger differences appear between the curves than in the previous case. Therefore, it is obvious that the topography is responsible for the large errors of WAsP simulations.

Because of large differences between model outputs and weather station time series, data sets of two other stations (Vietas and Juobmotj kk) of the valley have been included in the analysis. Since large errors have not disappeared in the simulations in spite of increasing the number of input stations, we do not present these other results in detail. After reconstructing wind fields for all the four stations, it can be concluded that WAsP is not able to model correctly the topographical influences of the steep valley. Therefore, caution is needed when using WAsP in steep terrain.

4.2 WAsP simulations for hilly terrain (case study for Hegyhátsál)

Wind speed and wind direction are measured on a 117 m tall, free-standing TV and radio transmitter tower (*Haszpra et al.,* 2001) owned by Antenna Hungaria Corporation. As shown in *Fig. 10*, the lower part of the tower (56 m) is a 7.75 m diameter cylinder made of reinforced concrete, while the upper part (61 m) is a cylinder of 1.82 m diameter. The tower located in Hegyhátsál, which lays in a flat region of northwestern part of Hungary (46.96°N, 16.65°E), at an altitude of 248 m above sea level. Profile measurements of wind speed began at the end of September 1994 on 4 levels. The measuring station is surrounded by agricultural fields (mostly crops and fodder of annually changing types) and forest patches. Human settlements can be found within 10 km but only small villages with 100–400 inhabitants. The nearest villages are about 1 km to the northwest. The tower is also a NOAA/CMDL global air sampling network site (site code: HUN). In addition, carbon dioxide mixing ratios are continuously monitored at each level, and the atmosphere/surface exchange of CO_2 is measured by eddy covariance at 82 m height.

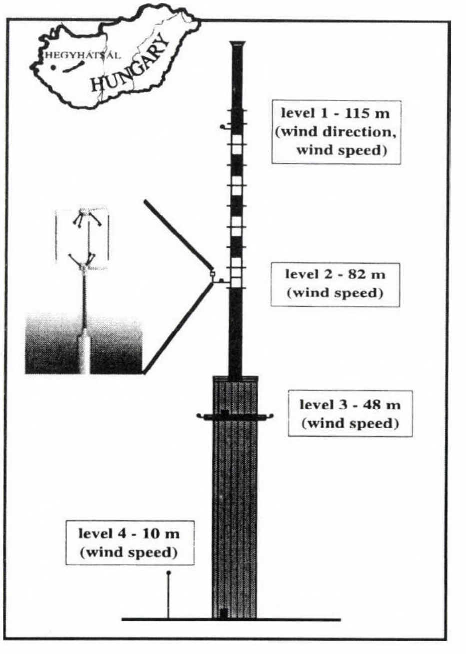

Fig. 10. Wind measuring station in Hegyhátsál.

In order to verify the adaptability of the WAsP model for Hungary, as in case of Suorva, input data measured at Hegyhátsál in 10 meter height have been used to regenerate the wind field at the same site over the hilly terrain. The topography has been included in WAsP as a height-contour map using 25 m isolines. The roughness-change lines have been determined by the same mathematic routine as before. Roughness length has been set to 1 m, 0.5 m, and 0.1 m for forests and cities, villages and orchards, and shrublands or grasslands, respectively. In case of water bodies, 0.001 m has been chosen. Effects of obstacles near the station have been taken into consideration. Results are shown in *Fig. 11*.

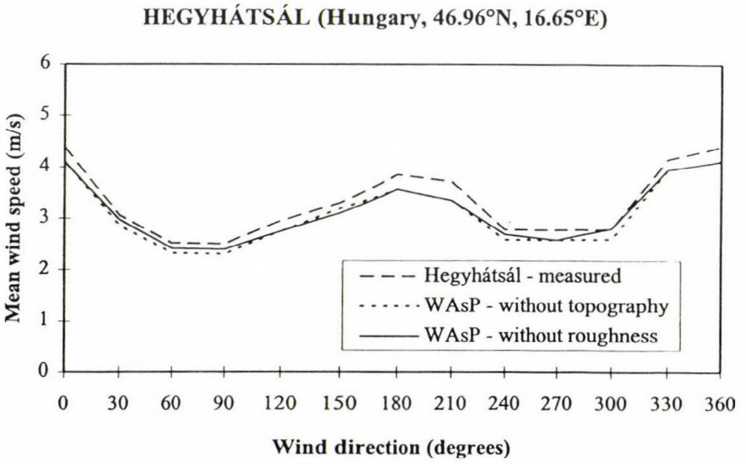

Fig. 11. Comparing measured and simulated wind speed values at Hegyhátsál station.

We did not find considerable differences between measured and simulated values; consequently, topography of flat terrain does not generate remarkable model errors. Therefore, it is possible to extrapolate wind data of Hegyhátsál in order to determine the wind field over the surroundings.

5. Conclusions

Wind climate and renewable energy resources of Hungary are analyzed, specially focusing on wind energy. A summary on recent wind climate research is presented for the Carpathian Basin.

Wind Climate Analysis – Wind Atlas: Field measured wind time series are compared to historical wind archive data. Using wind characteristics of 13 Hungarian climate stations, climatological and energetical diagrams are assembled according to the structure of the European Wind Atlas. On these charts, seasonality of the wind speed frequencies, annual distribution of wind duration and wind power, monthly wind speed anomalies and their cubic anomalies, relative frequencies of wind speeds in the least windy and the windiest month are presented.

Wind energetics: Temporary climate stations have been installed in the frame of field experiments for automated data collection and quality control. Vertical extrapolation of wind potential and calculation of the Weibull parameters were made to compare available and extractable wind power. Mean power outputs and errors of using different averaging times were estimated.

Modeling approaches: Using height and roughness parameters of the European Digital Terrain Model, a mesoscale wind model have been installed, adapted, and tested. Comparing complex and simple terrains, modeling errors are analyzed and the verification were done in the mountainous region of Lake Akkajaure (Sweden) and in a hilly part of western Hungary (Hegyhátsál). The WAsP model is not able to model the topographical influences of a steep valley (Sweden), while over a less complex hilly terrain (Hungary) the results are satisfactory.

Based on the five year results, it has been proved that Hungary has extractable wind power resources which was always used in the ancient times too. Results suggests that now and in the near future supporting energy supply systems can be one of the efficient forms of renewable (wind and solar) energy usage in Hungary.

A second part of this paper will appear soon, where concrete results of model experiments and estimation of local potential wind power will be discussed in order to define the different regions of Hungary on the basis of wind energy usage.

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BOOK REVIEWS

Jacobson, M.C., Charlson, R.J., Rodhe, H. and *Orians, G.H.* (reds.), 2000: **Earth System Science for Biogeochemical Cycles to Global Changes.** Academic Press, A Harcourt Science and Technological Company, San Diego, San Francisco, New York, Boston, London, Sidney and Tokyo. 527 pages, a large quantity of tables, figures, references and a detailed index.

This book is a good symbol of the present evolution in natural sciences indicating that something is changing in our concept about our planet, Earth. The first point is that classical Earth sciences constitute one unit, thus, for example, it is impossible to understand the atmosphere without the knowledge of processes in other terrestrial spheres. Secondly, by discussing our planet we cannot separate biological and non-biological phenomena, since they are so interrelated that such a separation would make the subject not meaningful. This means that the quality of different environmental media is governed by biogeochemical cycles, by this huge material flow in Nature, controlled by the interaction of the biosphere and other geo-spheres. This material flow is modified in the time being by human activities which alter the surface of the continents and release into the air, soil and water a large quantity of waste materials.

There is still a debate whether *Earth system science* in its present form is an interdisciplinary science or this is a new science, a separate discipline. Even, its name is not clear, since in many countries it is called *environmental science*. Anyway, this new development in sciences indicate without doubt that a new approach is necessary if we want to study our planet and we want to solve global environmental problems mankind is facing. We have to recognize that the investigation of our planet cannot be realized on the basis of classical compartments of natural sciences.

The problem is how to write such a book since we were trained at the universities only for one special branch of sciences. We are geologists, meteorologists, biologists and chemists to mention only some examples. For this reason the chapters of this volume are written by such specialists (American or Swedish) of their own field who have recognized already that Earth system science is a uniform subject. This certainly makes the problems treated more appropriate, but, at the same time, makes the volume a bit less consistent. Each chapter is followed by a detailed literature list and eventually by questions and appendices.

The first part of the book consists of five chapters and it is entitled "*Basic concepts for Earth system science*". In this part the reader find the principles of biogeochemical cycles as well as the bases of their numerical modeling. The origin and evolution of the planet and its biosphere are also presented together with equilibrium and rate of natural processes. The second part is devoted to the discussion of "*Properties of and transfers between the key reservoirs*". In this part the natural reservoirs (hydrosphere, atmosphere, soils and oceans) are discussed separately by taking into account their role in the control of natural material flows. In this respect the function of tectonic processes and erosion is presented in a separate chapter. The chapter on "*The Atmosphere*", prepared by *R.J. Charlson* from University of Washington, gives an excellent survey of relevant issues of atmospheric physics and chemistry.

The third part contain the most interesting chapters of the volume. It is entitled "*Biogeochemical cycles*". In this part good and up-to-date surveys are presented on the cycles of elements which play an important part in the control of the biosphere and other media of our planet. Thus, the cycles of carbon, nitrogen, sulfur and phosphorus are treated in details in separate chapters, while the cycles of trace metals are summarized in the last chapter of this part of the book. The cycle of metals is exemplified by mercury and copper. Finally, in the last part ("*Integration*") the chapters deal with such important problems as the acid-base and oxidation-reduction balances of the Earth, the coupling of biogeochemical cycles and climate, ice-records of climate changes as well as human modifications of the Earth system leading to global changes.

The present writer believes that even this short review makes it evident that this book is an important publication and its reading can be recommended for everybody who are interested in the evolution, state and function of our planet and its different media including the atmosphere.

E. Mészáros

Ernst, W.G. (ed.), 2000: **Earth Systems, Processes and Issues**. Cambridge University Press, Cambridge, United Kingdom. 566 pages, a large quantity of tables, figures, references and a detailed index.

This book, together with the previous one, indicate unambiguously that we are the witnesses of the birth of a new science. This means that the aim of the present volume is also to discuss our planet as a whole as well as its different spheres, including the biosphere. There is only a minor, but nevertheless important difference. In the book published by the Cambridge University Press plural is used concerning the word "system". Consequently, the expression of

Earth systems science is common in the volume. One can speculate, however, that the use of singular seems to be more appropriate if we want to emphasize the unity of the planet. It is interesting to note that the first part of the book is entitled correctly "*The Earth as a system*". The second difference with the book edited by the Academic Press is the fact that in the present volume no part is devoted to the biogeochemical cycles. Instead, the third (last) part deals with "*Societal and policy implications*" of Earth system(s) studies and engineering. On the other hand the similarity between the two books resides in the fact that even the chapters of the second volume were prepared by different authors specialized in their own respective field.

One of the most important feature of Earth system(s) science is outlined very clearly in the preface of the book. It is stated that the subject matter is based on an elementary course at Stanford University (California) entitled *Introduction to Earth systems* which integrates principle of physical sciences, engineering and economics as they pertain to the global environment. "The philosophy of the presentation is *problem-focused*, not discipline-focused". This aim suggests that we have to forget the classical division of natural sciences if we want to study processes governing our planet.

The second part of the book ("*Natural processes*") is devoted to the presentation of our knowledge (relevant to the subject) of the geosphere, hydrosphere, atmosphere and biosphere. The atmospheric section is written by *R. Chatfield* from NASA Ames Research Center and *S.H. Schneider* from Department of Biological Sciences at Stanford University (note that the latter world-famous atmospheric scientist works in a department of biology!). The atmospheric section consists of four chapters. One of the first two (written by Chatfield) discusses the atmospheric composition and mixing processes including the stratospheric ozone problem, while the other presents a brief summary of atmospheric motions and the greenhouse effect. Schneider's chapters are devoted to the forecasting of future climate (on the basis of past climate) as well as to the precision of the prediction of climate changes.

This is again a book which is recommended for libraries to buy it and for everybody to read it. As the previous volume, this book calls our attention to the fact that the understanding of the Earth's atmosphere is not easy without the knowledge of other parts of our planet.

E. Mészáros

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