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Quarterly Journal of the Hungarian Meteorological Service

Editorial

In January 1995, after 15 years of editorial work, *Prof. Ernő Mészáros*, retired from the position of Editor-in-Chief of *Időjárás*. During those 15 years the scientific journal of the Hungarian Meteorological Service increased its scientific standard, had an attractive presentation and was regularly published in each quarter of the year. *Prof. Mészáros* continues his scientific activity at the University of Veszprém (Hungary). We wish him good health and further successes!

The President of the Hungarian Meteorological Service, *Dr. Iván Mersich*, nominated me as Editor-in-Chief for the next years. No changes in the policy of the journal are planned. Most of the members of the previous editorial board will kindly continue to help the editorial work in realizing the basic purpose of the Journal: to publish high quality articles from any field of the atmospheric sciences written in English language.

As regards my scientific background. I graduated from mathematics, physics and meteorology at the Eötvös Loránd University in Budapest. After a year of work in thefield of agrometeorology I became engaged in studies of atmospheric radiation. A UN fellowship gave me the opportunity to spend a year to study the utilization of radiation data measured by meteorological satellites with such famous supervisors as *K. Ya. Kondratyev, V. E. Suomi, T. H. VonderHaar* and *J. S. Winston*. Taking part in the activities of the international radiation community I was elected member of the International Radiation Commission of the IAMAP between 1979–1987 and of the Working Group on Radiation and Turbidity Measurements of CIMO/WMO between 1984–1992. I spent more than 30 years with the Hungarian Meteorological Service. Currently I am leading a research group that deals with satellite, climate impact and agrometeorological problems. In editing of *Időjárás* I receive a valuable help from *Ms. M. Antal*.

Next year the *Időjárás* will celebrate its 100th birthday. It is one of the oldest meteorological journals in the world. I express my sincere thanks to the authors and the readers for their interest in our Journal.

Dr. G. Major
Research Professor

IDŐJÁRÁS

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Circumsolar radiation calculated for various aerosol models

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(Manuscript received 16 February 1995; in final form 3 May 1995)

Abstract—Theoretical calculations of circumsolar radiance and irradiance are carried out for various aerosol models: two maritime, two urban, two background and one mountain aerosol models. It is found that, in general, the angular distribution of the circumsolar radiance function is determined by the aerosol size distribution, whereas the amount of the radiance depends mainly on the air mass (which depends on the sun's elevation) and the aerosol optical depth. The ratios of circumsolar to direct solar irradiance were calculated as a function of the aerosol optical depth. The ratio at 5° is less than 5% in most of the cases.

Key-words: circumsolar radiation, direct radiation, diffuse radiation, global radiation.

1. Introduction

The circumsolar radiation is the scattered sky radiation in the forward directions near to the direction of the sun. Because the aerosol particles scatter mainly forward, the radiance in the circumsolar region is much higher than in other directions.

The investigation of the circumsolar radiation is important for several reasons:

(1) The direct solar irradiance measured by pyrheliometers have a systematic error due to the fact that the pyrheliometer measures not only the direct solar radiation but some part of the circumsolar radiation, too. This fact complicates the comparability of pyrheliometric measurements in case of different instrument geometry.

(2) If the global solar irradiance is determined by measuring direct and diffuse radiation independently (*WCRP-64*, 1991) an error can arise if the pyrheliometer measured and the diffusometer excluded circumsolar radiations are different (*Major*, 1992). Accurate measurements of global solar radiation are necessary for monitoring of possible climate changes.

(3) Accurate knowledge of the incoming direct solar energy flux and of the energy flux of the circumsolar radiation is needed at the planning of solar power plants.

Calculations of the circumsolar radiation have been carried out by several authors (*Grassl*, 1971; *Eiden*, 1968; *Green at al.*, 1971; *Fröhlich* and *Quenzel*, 1974; *Putsay*, 1980; *Major*, 1980; *Thomalla et al.*, 1983). Some of these calculations (*Grassl*, 1971; *Eiden*, 1968; *Green et al.*, 1971; *Fröhlich* and *Quenzel*, 1974; *Putsay*, 1980) were made for a few wavelengths only without integration over the whole solar spectral region. *Eiden* (1968) and *Green et al.* (1971) solved the inverse scattering problem by estimating the concentration and size distribution of aerosol particles from circumsolar radiation measurements. *Fröhlich* and *Quenzel* (1974) and *Putsay* (1980) calculated the error of several Volz type sunphotometers as a function of the aerosol optical thickness. *Major* (1980) calculated spectrally integrated radiances for a few scattering angles, but did not calculate the circumsolar irradiance. *Thomalla et al.* (1983) investigated both the spectrally integrated circumsolar radiances and irradiances for various atmospheric conditions. Their conclusion is that a field of view larger than the angular size of the sun gives rise to a significant increase in the total (solar plus circumsolar) irradiance only if a thin cirrus layer is present.

In this paper the results of calculations for the circumsolar radiation for various aerosol types are presented. Effects of the variability within the aerosol types are also discussed. Both the circumsolar radiance and irradiance were calculated for the following aerosol models: two maritime type, two urban type, two background type, and a mountain type aerosol models. The results are integrated over the whole solar spectrum region.

2. Method

The circumsolar radiances were calculated for a horizontally homogeneous atmosphere. The spectral absorption and scattering processes were taken into account, but the multiple scattering effects were neglected. This approximation is justified in the forward scattering region (*Thomalla et al.*, 1983). The spectral radiance L_λ can be determined from the solution of the radiative transfer equation. The radiative transfer equation is described in a (θ,φ) polar coordinate system where θ is the angular distance from the sun's center and φ is the azimuth angle. Assuming the sun as a point source, the solution of the radiative transfer at a given wavelength λ is:

$$L_\lambda(\theta,m) = F_{o_\lambda} \exp(-\delta_{o_\lambda} M) \left[P_{m\lambda}(\theta)\,\delta_{msc\lambda} + P_{a\lambda}(\theta)\,\delta_{asc\lambda}\right] \tilde{\omega}_\lambda$$

$$\times \frac{m}{M-m} \left[\exp(-\delta_\lambda m) - \exp(-\delta_\lambda M)\right], \qquad (1)$$

where F_o is the incident solar irradiance at the top of the atmosphere, $\tilde{\omega}_\lambda$ is the single scattering albedo, $P_m(\theta)$ and $P_a(\theta)$ are the phase functions at scattering angle θ for the molecules and for the aerosol particles, respectively. δ_o, δ_{msc}, δ_{asc} are the absorption coefficient of ozone, and the scattering coefficients of molecules and aerosol particles, respectively. δ_λ is the extinction coefficient of the subozone layer, which is the sum of the scattering coefficients of air molecules (δ_m), the extinction coefficient of aerosol particles (δ_a), and the absorption coefficient of H_2O. M and m are the relative air masses in the direction of the sun and in the viewing direction, respectively.

The scattering by air molecules is described by the Rayleigh theory. The scattering of the aerosol particles is calculated by Mie theory and depends on their size distribution and refractive index.

In our calculation the sun is assumed to be a point source. This approximation is very good for a scattering angle greater than about 1 degree (*Grassl*, 1971).

To get the integral radiance of the circumsolar radiation at a distance θ, Eq. (1) is integrated over the wavelength:

$$L(\theta, m) = \int_0^\infty L_\lambda(\theta, m)\, d\lambda. \tag{2}$$

The integration was performed from $\lambda = 0.3$ μm through $\lambda = 4.0$ μm.

The circumsolar irradiance $E_{sc}(\theta)$ is the irradiance on an area normal to the sun direction up to angular distance θ from the center of the sun. $E_{sc}(\theta)$ results from the integration of the radiance $L(\theta,m)$ over the corresponding solid angle:

$$E_{sc}(\theta) = \int_0^{2\pi} \int_0^{\theta} L(\theta', m(\theta', \varphi))\, \cos\theta'\, \sin\theta'\, d\theta'\, d\varphi. \tag{3}$$

The irradiance from the attenuated direct solar flux over the total solar spectrum is given by

$$E_{sun} = \int_0^\infty F_\lambda \exp\left(-(\delta_\lambda + \delta_{o\lambda})M\right) d\lambda. \tag{4}$$

The total irradiance $E(\theta)$ is the sum of Eqs. (3) and (4):

$$E(\theta) = E_{sun} + E_{sc}(\theta). \tag{5}$$

The coefficients δ and the phase functions P necessary to evaluate the above expressions, can be calculated using atmospheric models.

3. Model atmospheres

The atmosphere is assumed to be horizontally homogeneous. Molecular scattering, water vapour and ozone absorption, aerosol scattering and absorption are taken into account. It is supposed that there is no cirrus cloud in front of the sun.

The calculations were performed for two groups of aerosol models:

(1) The first aerosol model group contains three models from the well-known Standard Radiation Atmosphere (SRA): CONT-I, MAR-I and URBAN. The full description of these models can be found in Refs. (*Deepak* and *Gerber*, 1983; *WCRP-112*, 1986).

(2) The other group contains models based on aerosol size distributions measured by Hungarian scientists (*Major*, 1980; *Mészáros* and *Vissy*, 1974). These aerosol models represent continental background (B), urban (U), oceanic (O) and mountain (M) aerosol distributions. The background and the urban type aerosol size distributions were measured in Hungary, the mountain type aerosol size distribution was measured in Caucasus in USSR, and the oceanic type on the Indian Ocean (*Mészáros* and *Vissy*, 1974). The size distributions of the dry aerosol particles was approximated by the following equation:

$$\frac{1}{N_o}\frac{dN}{dr} = \sum_{i=1}^{n} a_i \exp\left[-b_i (\log r + c_i)^2\right]. \tag{6}$$

Table 1 shows the coefficients of Eq. (6) and other characteristics of the atmospheric models (*Major*, 1980). The coefficients of the dry aerosol size distribution functions according to Eq. (6) are listed in the first five lines. $\tilde{m}$ is the complex refractive index of the aerosol particles, N_o is the total number of particles in the atmospheric column of 1 μm^2 cross section, the humid particles are x times larger than the dry ones, *RH* is the relative humidity and p is the surface pressure.

Fig. 1 shows the size distributions of the humid particles of the second group of aerosol models. The increase of the size of the humid particles was taken from *Hänel* and *Bullrich* (1978). All atmospheric models have fixed but different aerosol load. The aerosol optical depths for all aerosol models are tabulated in *Table 2*.

4. Results

The results of our investigations are presented in two stages:

(1) In part 4.1 the function $\bar{L}(\theta)$ is discussed. $\bar{L}(\theta)$ represents the averaged radiance around the sun at a given angular distance θ:

$$\bar{L}(\theta) = \frac{1}{2\pi}\int_0^{2\pi} L(\theta, m(\theta,\varphi))\, d\varphi\,. \tag{7}$$

The results can be used to estimate the differences between the circumsolar radiations measured by two pyrheliometers with different geometry. If the global irradiance is measured by the direct-diffuse method (*WCRP-64,* 1991) there is a difference between the pyrheliometer measured and the diffusometer excluded circumsolar radiations. The above results can be useful to estimate these differences.

(2) In part 4.2 we discuss the ratio of the circumsolar irradiance E_{sc} to the direct solar irradiance E_{sun}. The results are mainly of interest for the calculation of optimum receiver apertures of solar power plants.

Table 1. The parameters characterizing the atmosphere models *M* (mountain), *B* (background), U (urban) and O (oceanic)

Models	M	B	U	O
n	4	4	4	3
a, b, c	53, 12, 1.8	24, 9.1, 1.8	36, 9.7, 1.8	12, 24, 1.25
a, b, c	16, 44, 1.25	9.5, 17, 1.25	7.9, 27, 1.25	4.9, 28, 0.94
a, b, c	5, 18, 1.0	1.9, 50, 0.83	2.2, 14, 0.96	0.1, 2.85, 1.00
a, b, c	0.05, 4.5, 0.7	0.13, 3.7, 1.00	0.015, 4.8, 0.7	
N_0 (μm)	0.52	1.9	3.94	0.095
$\tilde{m}$	1.48–0.01i	1.46–0.04i	1.46–0.08i	1.36–0.005i
x	1.02	1.066	1.16	1.7
RH (%)	40	65	56	85
p (hPa)	911	1013.2	1013.2	1013.2

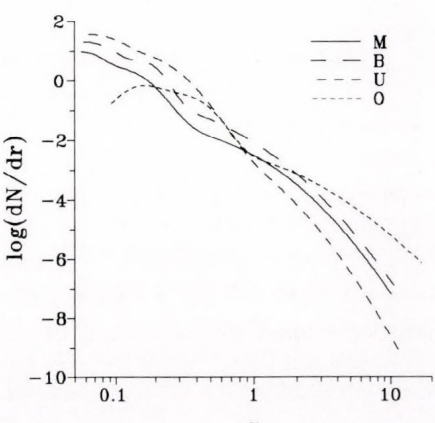


Fig. 1. Size distribution functions of humid particles for the U (urban), B (background), M (mountain) and O (oceanic) models.

Table 2. The aerosol optical depth τ (at $\lambda = 0.55$ μm), the direct solar irradiance E_{sun} and the ratio of the circumsolar to the direct solar irradiances $E_{sc}(\theta)/E_{sun}$ for different model atmospheres for a few θ values and for three sun elevations h. θ is the angular distance from the center of the sun

Aerosol model	τ	h	E_{sun} (W m^{-2})	$E_{sc}(\theta)/E_{sun}$ (%)			
				θ			
				2°	5°	7°	10°
O	0.05	60°	921	0.6	1.1	1.3	1.7
		45°	857	0.7	1.3	1.6	2.1
		20°	596	1.4	2.8	3.4	4.3
MAR-I	0.08	60°	893	0.5	1.1	1.5	2.0
		45°	825	0.6	1.4	1.8	2.5
		20°	550	1.2	2.9	3.8	5.2
M	0.07	60°	1000	0.3	0.9	1.2	1.7
		45°	940	0.4	1.1	1.5	2.1
		20°	677	0.7	2.2	3.1	4.3
B	0.19	60°	854	0.6	1.8	2.5	3.5
		45°	777	0.7	2.2	3.1	4.3
		20°	468	1.4	4.4	6.3	8.9
CONT-I	0.23	60°	846	0.5	1.0	1.5	2.2
		45°	768	0.6	1.3	1.8	2.7
		20°	459	1.2	2.5	3.6	5.3
U	0.4	60°	713	0.8	2.3	3.4	5.0
		45°	623	0.9	2.8	4.1	6.0
		20°	299	1.8	5.6	8.2	11.8
URBAN	1.03	60°	469	0.4	1.3	2.2	3.8
		45°	380	0.5	1.5	2.5	4.4
		20°	126	0.8	2.5	4.1	7.0

4.1 Radiance of the circumsolar radiation

The aerosol particles scatter mainly forward, so the circumsolar radiation decreases strongly with increasing angular distance from the sun.

In *Fig. 2a–d* the averaged radiance $\bar{L}(\theta)$ is plotted as a function of the angular distance θ from the sun's center for different aerosol types and for three different sun elevation angles. Fig. 2a–c presents curves for two related aerosol models: one of the SRA models and one of the measured aerosol models. On Fig. 2d the results for the M model are shown, which has no SRA counterpart. The aerosol optical depths at $\lambda = 0.55$ μm are indicated on the figures. For the sake of comparison, the same optical depths were taken for the related aerosol models.

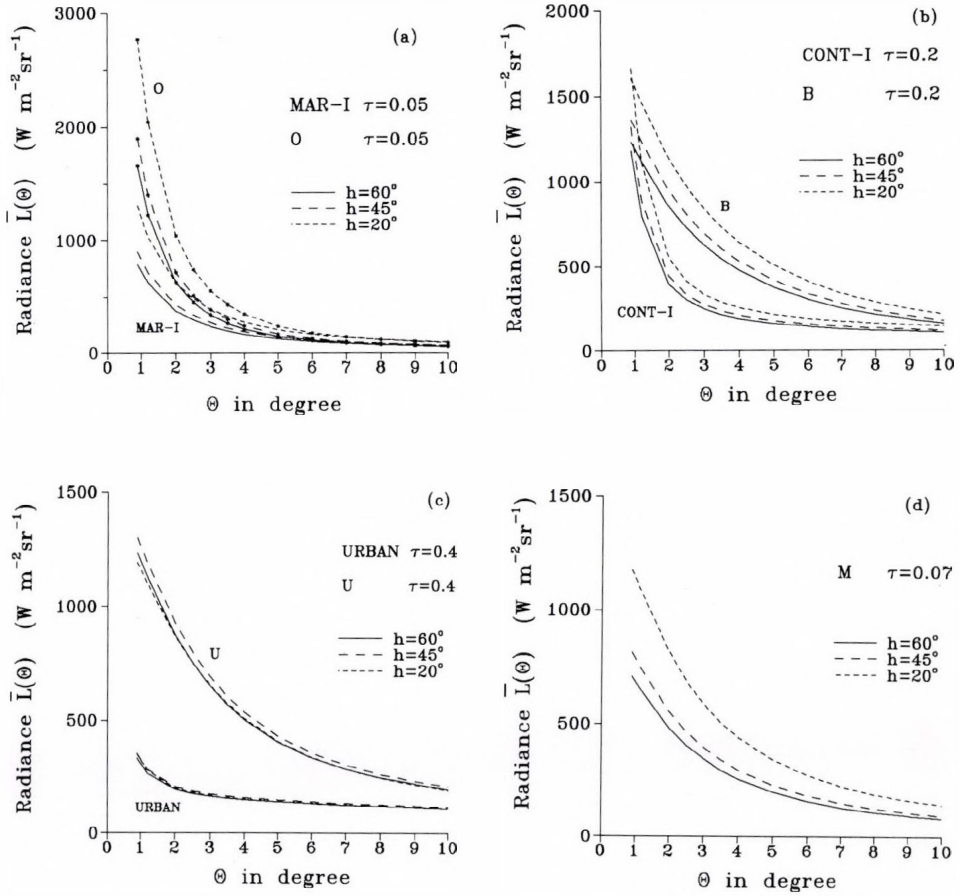


Fig. 2. Radiance $\bar{L}(\theta)$ for aerosol models (*a*) O and MAR-I, (*b*) B and CONT-I, (*c*) U and URBAN, (*d*) M. (Averaged around the sun at the θ angular distance. In each case with three different values of sun elevation h. The τ values given are the aerosol optical depths at wavelength $\lambda = 0.55$ μm.)

The radiance curves of aerosol models with relatively more large particles show a stronger decrease than those of aerosol models with relatively less large particles. As a result the curves in Fig. 2a (model O and MAR-I) have the steepest slope, and the URBAN aerosol in Fig. 2c has the shallowest one. These two aerosol models represent extreme cases of atmospheric aerosol concerning size distribution, model O with high proportion of large particles, model URBAN of SRA with a high proportion of small particles.

The models O and MAR-I are very close to each other (see Fig. 2a). The curves of the model O are a little higher than those of model MAR-I. Fig. 2b shows the results for the models B and CONT-I. The curve of model CONT-I

is the steepest, because it contains more large particles. Fig. 2c shows the curves for the model URBAN of SRA and for the model U measured in Hungary. One can see that the results differ significantly. The reason of this difference could be that the measurements were made at the border of Budapest, where the aerosol size distribution is not really of a typical urban type, rather a mixture of urban and background types. As a consequence model U contains relatively more large particles. Model URBAN of SRA contains much more small particles. Fig. 2d shows the curve for the mountain (M) model. The values are relatively small because of the low aerosol optical depth and the low relative humidity.

In the case of low optical depths (see Fig. 2a–b, and 2d) the circumsolar radiance increases with decreasing sun elevation. In the case of high optical depths, however, this behaviour changes (Fig. 2c). The reason is simple. If the radiation beam meets more particles on its path through the atmosphere, then more photons scatter, but the extinction of the scattering radiation is also higher.

We have also investigated the dependence of the circumsolar radiation upon the aerosol optical depth for each model. In general, with increasing aerosol optical depth the radiance first increases and then decreases. The angular distribution of the circumsolar radiance function is determined by the aerosol size distribution, while the height of the $\bar{L}(\theta)$ curves depends mainly on the air mass (which depends on the sun's elevation) and the aerosol optical depth.

4.2 Ratio of circumsolar to direct solar irradiance

The ratio of the circumsolar to the direct solar irradiance $(E_{sc}(\theta)/E_{sun})$ gives information about the circumsolar radiation involved into the pyrheliometric measurements. *Fig. 3* shows the ratio of the circumsolar to the direct solar irradiance as a function of the angular distance θ for various model atmospheres. The aerosol optical depths tabulated in Table 2 were used. The sun elevation was h = 45°. The same ratios for three different sun elevations and the corresponding direct solar irradiance in W m^{-2} are tabulated in Table 2 for a few θ values. Since measurements are usually carried out only if E > 400–500 W m^{-2}, and the most frequently used pyrheliometer have a field of view of 4–6 degree, the circumsolar contribution to the pyrheliometric measurements is less than 5%, mostly about 2%.

We have also investigated the dependence of the circumsolar radiation upon the aerosol optical depth. We calculated the ratios of circumsolar to direct solar irradiance for the seven atmosphere models varying the aerosol optical depth (see *Fig. 4*). The ratio at 5° is less than 5% in most of the cases. This percentage may be higher for greater values of optical depth and for low sun elevation, but in this cases the attenuation of the direct sun radiation is so great that the absolute increase is still small. Furthermore, in the case of low direct irradiance, pyrheliometric measurements are usually not carried out.

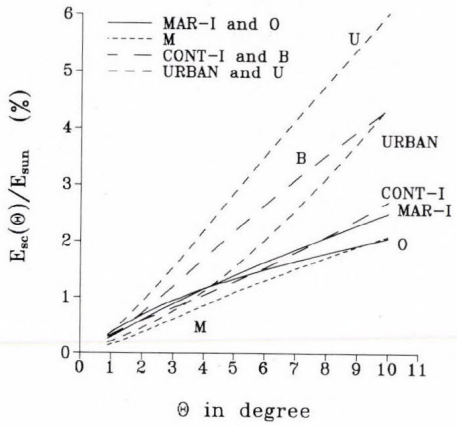


Fig. 3. The ratio of the circumsolar to the direct solar irradiance for seven aerosol models as a function of θ. The sun elevation is h = 45°.

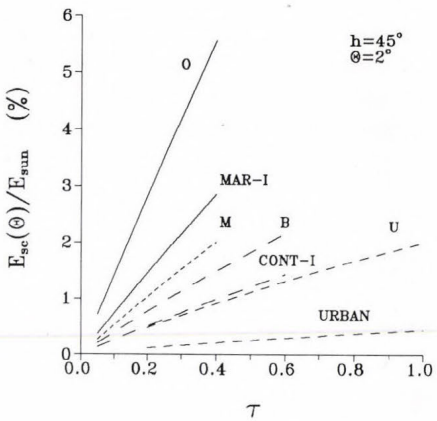


Fig. 4. The ratio of the circumsolar to the direct solar irradiance for seven aerosol models at $\theta = 2°$ for sun elevation $h = 45°$ as a function of the aerosol optical depth τ at $\lambda = 0.55$ μm.

5. Conclusion

We have calculated the variation of the circumsolar radiance and irradiance taking into account the relevant optical parameters: extinction and scattering of the solar radiation by molecules and aerosol particles, absorption by gases, and different elevation angles of the sun.

The calculations have been carried out for seven different aerosol models which belong to four aerosol types (maritime, urban, background and mountain). We have compared the radiances of the related model pairs. We have found that the circumsolar radiance functions $L(\theta,m)$ were very close to each other for the two maritime type aerosol models. The difference was greater for the two continental background type models, but still not significant. However, the circumsolar radiance functions for the two urban type models showed a significant difference due to the different aerosol size distributions and the optical depths of these models.

In general, the angular distribution of the circumsolar radiance function is determined by the aerosol size distribution, while the height of the $\bar{L}(\theta)$ curves depends mainly on the relative air mass (which depends on the sun's elevation) and the aerosol optical depth. The radiance curves of aerosol models with a greater proportion of large particles show a stronger decrease than those of

aerosol models with a lower proportion of large particles. We have also investigated the influence of the optical depth. We have found that for a given model with increasing aerosol optical depth the radiance first increases and then decreases. The effect of the sun elevation on the circumsolar radiance depends strongly on the aerosol optical depth. For low optical depths the circumsolar radiance increases with decreasing sun elevation, for high optical depths it decreases, and for medium optical depth it shows a maximum.

The ratio of the circumsolar to the direct solar irradiance was calculated for different sun elevations, angular distances, aerosol optical depths and aerosol models. If the direct solar irradiance is greater than 500 W m^{-2} (i.e. under good measuring conditions) then the ratio is less than 5%, mostly about 2% at a field of view of 5°. The ratio can be higher for greater values of optical depth and for low sun elevation, but in these case the attenuation of the direct solar radiation is so great that the absolute value of the circumsolar irradiance is still small.

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IDŐJÁRÁS

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The role of geometry in the comparison of standard pyrheliometers

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(Manuscript received 16 February 1995; in final form 10 April 1995)

Abstract—The recently valid pyrheliometric scale (World Radiometric Reference) is based on cavity pyrheliometers. The geometrical characteristics of these cavity instruments are closer to each other than those of pyrheliometers manufactured earlier. Some of the Regional and National Standard Pyrheliometers are different types of Ångström pyrheliometers, their geometry differ significantly from that of the cavity ones and from each other. Using different distributions of scattering aerosol, calculations have been made for determining the difference of the circumsolar radiation measured by the standard pyrheliometers altogether with the actual direct radiation. The geometrical factor, necessary to calculate the longwave radiation exchange between the pyrheliometric sensor and the outer environment, has also been derived. The results show that in the case of high precision comparison of standard pyrheliometers the circumsolar effect is of the same order as the reliability of the comparison.

Key-words: pyrheliometer, circumsolar radiation, pyrheliometric IR loss.

1. Introduction

In 1977 the World Meteorological Organization changed its Technical Regulations (*WMO*, 1977): after 1 January 1981 all pyrheliometric measurements should be expressed in the scale of the World Radiometric Reference (WRR). This change affects all solar radiation measurements, since in the meteorological radiometry the pyrheliometers are the only absolute instruments. The WRR is maintained by a group of selected cavity pyrheliometers.

Most of the existing cavity pyrheliometers have been designed after 1970. Previous types of pyrheliometers were significantly different in respect of geometry. The different view limiting geometry results in different contribution of the circumsolar radiation measured altogether with the actual direct radiation.

Hence the instrument outputs could not been precisely compared. The geometry of different cavity pyrheliometers is more uniform than that of the older pyrheliometers. The International Pyrheliometer Comparisons have proved that the ratio of the measurements of cavity pyrheliometers has the precision of 10^{-4}. Regarding this high precision of comparability, all factors have to be taken into account that might affect the ratio of the measurements of pyrheliometers.

In this paper the effect of view limiting geometry is analyzed regarding the circumsolar irradiation and the longwave radiation exchange of the pyrheliometric sensors. Not only the cavity type instruments are taken into account but also the other standard pyrheliometers that took part in the last International Pyrheliometer Comparison in 1990.

2. *Method*

In this work the geometry of pyrheliometers is described by their penumbra function (the derivation is shown in *Pastiels*, 1959 or *Major*, 1994). The effective penumbra function, $F(z,\varphi)$, gives that part (fraction) of the receiver surface, weighted by the sensitivity, that can be seen from the (z,φ) direction. Here z is the angle between the optical axis of the pyrheliometer and the viewing direction, φ is the azimuth angle of the direction in a plane perpendicular to the optical axis. The geometrical penumbra function, $G(z,\varphi)$, gives the fraction of the receiver surface that can be seen from the (z,φ) direction. If the receiver has uniform sensitivity along its surface, the two functions are identical.

In the case of cavity pyrheliometers the entrance of the cavity is regarded as receiver surface. According to the physical nature of the cavity, this 'receiver surface' has uniform sensitivity distribution. Moreover, these pyrheliometers have rotational symmetry around their optical axis. Therefore, the penumbra values do not depend on the azimuth, so that the geometry of the cavity pyrheliometers is fully described by the geometrical penumbra function $G(z)$. In the case of circular pyrheliometers, having the radius of the entrance aperture (R), the radius of the receiver (r) and the tube length (L, the distance between them), the geometrical penumbra values can be calculated by an analytical form (*Pastiels*, 1959).

In the case of Ångström pyrheliometers and NIP (the Eppley factory made Normal Incidence Pyrheliometer) the sensitivity is not uniform along their sensing surface. The ouput of these instruments is connected with their effective penumbra function. This function was derived by numerical simulation (*Major*, 1994) for different types of Ångström pyrheliometers taking into account the calculated sensitivity distribution (*Major*, 1968) derived from the 'analog' procedure suggested by *Pastiels* (1959).

To calculate the difference of the circumsolar radiation involved in the outputs of different pyrheliometers, the radiance distribution has to be known

along the circumsolar sky. These functions were calculated by *Putsay* (1995) using different aerosol models.

To calculate the longwave radiation exchange between the receiver and the environment outside of the pyrheliometer let us define the following ratio:

$$\psi = \frac{\text{irradiation received through the aperture}}{\text{irradiation received from the hemisphere}}.$$

This ratio can be calculated if the radiance distribution is isotropic. It can be shown easily, that for a pyrheliometer

$$\psi = \int_0^{z_1} F(z) \sin(2z)\, dz\,.$$

Here z_1 is the limit angle of the pyrheliometer. This is the largest angle from the optical axis from which the receiver can be seen at all. For the circular case $z_1 = \text{atn}\,((R + r)/L)$.

The assumed isotropy does not limit the applicability of this ratio, since within the field of view of a pyrheliometer the atmospheric infrared radiation is almost isotropic at any elevation angle.

If the pyrheliometer has a receiver with uniform sensitivity and a circular structure, the ψ value can easily be calculated using *Pastiels'* (1959) theorem:

$$\psi = (a^2 + b^2 + 1) - \sqrt{(a^2 + b^2 + 1)^2 - 4a^2}\,,$$

here $a = R/r$ and $b = L/r$.

3. Basic geometric data

Table 1 is taken from the report of the *IPC VII* (1991). It contains the basic geometric data of the different types of standard pyrheliometers which took part in that comparison.

The given sizes do not characterize directly the viewing angles, therefore in *Table 2* the characteristic angles are shown for the circular pyrheliometers. The slope angle (z_s) is the largest angle between the optical axis and the direction from that the full receiver can be seen. In the circular case $z_s = \text{atn}\,((R - r)/L)$.

Table 1. The basic geometrical data of cavity, NIP and Ångström pyrheliometers taken part in the 1990 International Pyrheliometer Comparisons. (Here v is the length, w is the width of the entrance aperture of Ångström pyrheliometers.)

Instrument	R (mm)	r (mm)	L (mm)
Cavity			
PMO2	3.6	2.5	85.0
PMO5	3.7	2.5	95.4
CROM 2L	6.29	4.999	144.05
CROM 3L	6.25	5.0	144.0
PAC 3	8.18	5.64	190.5
HF 18748	5.81	3.99	134.7
MKVI 67814	8.2	5.65	187.6
PMO6generic	4.1	2.5	94.0
PMO6-5	3.6	2.5	84.2
PMO6-10	4.25	2.5	95.4
EPACgeneric	8.32	5.64	190.5
HFgeneric	5.81	3.99	134.7
MKVIgeneric	8.2	5.65	187.6
MKVI 67401	8.2	5.64	190.5
PCC3-005	10.0	5.0	114.5
Thermopile			
NIP 18653	10.3	4.0	203.0
Ångström	v (mm)	w (mm)	
A-7	9.5	7.5	150.0
A-171	10.25	2.4	72.2
A-212	11.8	2.5	50.0
A-559	10.0	8.0	70.0
A-564	10.3	2.5	75.1
A-568	10.6	4.0	55.5
A-576	10.0	2.5	82.0
A-578	10.3	2.5	70.5
A-Eppley	10.3	4.1	111.0

The PCC3 differs much from the other cavity instruments. A bolometric pyrheliometer constructed by Sklyrov had similar geometry (*Voytyuk* and *Sklyrov*, 1973). It is an experimental version, which is not available commercially. The limit angles of the other standard pyrheliometers are relatively similar to each other. The CROM 3L has the smallest, the PMO6–10 has the largest slope angle. The remaining devices are quite similar, so their group will be represented in this paper by a symbolic absolute instrument ABS (R = 8.2 mm, r = 5.7 mm, L = 191 mm). Similarly, the Ångström pyrheliometers have been grouped into 4 symbolic instruments: Eppley Ångström (EPA), Smithsonian Ångström (SMA), Short Tube Ångström (SHA) and Modern Ångström (MOA).

Table 2. Characteristic angles of the circular pyrheliometers taken part in the 1990 International Pyrheliometer Comparisons

Instrument	Slope angle (deg)	Limit angle (deg)
PMO2	0.74	4.10
PMO5	0.72	3.72
CROM 2L	0.51	4.48
CROM 3L	0.50	4.47
PAC 3	0.76	4.15
HF 18748	0.78	4.16
MKVI 67814	0.78	4.22
PMO6generic	0.98	4.02
PMO-5	0.75	4.14
PMO6-10	1.05	4.05
EPACgeneric	0.81	4.19
HFgeneric	0.77	4.16
MKVIgeneric	0.78	4.22
MKVI 67401	0.77	4.16
PCC3-005	2.50	7.46
NIP 18653	1.78	4.03

Table 3 contains the effective penumbra functions for the above mentioned pyrheliometers.

Table 3. Effective penumbra functions of the representative standard pyrheliometers

z (deg)	ABS	CRO3	PMO6	PCC	EPA	SMA	SHA	MOA
0	1.00	1.00	1.00	1.00	0.95	1.00	1.00	1.00
1	0.95	0.88	1.00	1.00	0.92	0.96	1.00	0.99
1.5	0.78	0.72	0.87	1.00	0.60	0.62	1.00	0.92
2	0.59	0.56	0.67	1.00	0.29	0.22	1.00	0.85
2.5	0.41	0.41	0.46	1.00	0.03	−0.04	0.99	0.69
3	0.25	0.27	0.26	0.93	−0.04	−0.12	0.96	0.53
3.5	0.11	0.15	0.10	0.82	−0.09	−0.19	0.91	0.42
4	0.01	0.05	0.03	0.73	−0.13	−0.23	0.85	0.30
6	0	0	0	0.21	−0.12	−0.01	0.33	−0.06
8	0	0	0	0	−0.03	0	−0.01	−0.15
10	0	0	0	0	−0.01	0	−0.09	−0.07
15	0	0	0	0	0	0	−0.06	−0.02

The Ångström pyrheliometers have negative penumbra values at some angles. This means that their shaded strip area is larger than the open strip area seen from that angle.

4. The sky functions

The model atmospheres are plan-parallel and cloudfree. Molecular scattering, water vapour and ozone absorption, as well as aerosol scattering and absorption are taken into account. The calculations were made for two groups of aerosol distribution. The first group contains three models of the Standard Radiation Atmosphere (*WCRP*, 1986): continental (CONT), maritime (MAR), and URBAN. The second group contains four models, described by *Major* (1980): continental background (B), urban (U), oceanic (O) and mountain (M) aerosol. The two urban models are similar to each other in having high turbidity values, but they differ in the size distribution.

The details of the calculation are described by *Putsay* (1995). In this work only those results are used that refer to optical depths typical for the given aerosol and to solar elevation angles of 20, 45 and 60 degrees.

5. Calculated circum differences

Using the sky functions derived for the mentioned aerosol models, differences of circumsolar radiation between the representative pyrheliometers and the ABS have been calculated (see *Table 4*). Applying the penumbra functions, the following formula served this purpose (shown the CROM as example):

$$C_{CROM\,-\,ABS} = \pi \int_0^{z_1} \left[F(z)_{CROM} - F(z)_{ABS} \right] \sin(2z)\, dz\,.$$

As it is expected (knowing the characteristic angles and the penumbra functions), the CROM 3L measures less, the PMO6–10 measures more circumsolar radiation than the ABS. The difference is less than 0.5 W m^{-2}, but it is of the order of 10^{-4}. The World Standard Group of cavity pyrheliometers defining the World Radiometric Reference ought to avoid such possibility of disturbance.

The PCC instrument has to be reconstructed from the point of geometry. The deviation of the different Ångström type instruments is of the order of 10^{-3}.

6. The infrared radiation exchange

The thermal environment of a pyrheliometer receiver is homogeneous except the open aperture hole. The infrared or longwave radiation energy exchange through the aperture can be calculated using the forementioned ψ factor:

$$IR = \psi \sigma \left[(T_r)^4 - (T_e)^4 \right],$$

where T_r is the temperature of the receiver, T_e is the effective environmental temperature outside of the pyrheliometer.

Table 4. The difference between the circumsolar radiation measured by the pyrheliometers named in the left column and the ABS. The values are in W m^{-2} for 20, 45 and 60 degrees of solar elevation angle

	O	M	MAR	B	CONT	U	URBAN
CROM	-0.21	-0.04	-0.11	-0.01	-0.11	-0.01	0
	-0.15	-0.03	-0.08	-0.01	-0.09	0	0
	-0.13	-0.03	-0.07	-0.01	-0.08	-0.01	-0.01
PMO	0.54	0.34	0.46	0.50	0.32	0.33	0.07
	0.37	0.24	0.33	0.41	0.27	0.49	0.12
	0.32	0.21	0.29	0.37	0.23	0.50	0.12
PCC	5.53	4.86	5.68	7.88	3.73	5.47	1.12
	3.82	3.28	4.06	6.40	3.12	7.97	2.02
	3.35	2.84	3.56	5.74	2.82	7.94	2.14
EPA	-2.44	-1.96	-2.36	-3.09	-1.56	-2.12	-0.42
	-1.68	-1.32	-1.69	-2.51	-1.30	-3.11	-0.76
	-1.47	-1.14	-1.49	-1.26	-1.18	-3.10	-0.81
SMA	-2.70	-2.29	-2.71	-3.68	-1.76	-2.55	-0.51
	-1.87	-1.55	-1.94	-2.99	-1.47	-3.71	-0.92
	-1.63	-1.35	-1.70	-2.68	-1.33	-3.70	-0.97
SHA	4.42	3.91	4.55	6.36	3.31	4.43	0.90
	3.05	2.63	3.36	5.17	2.51	6.44	1.64
	2.67	2.29	2.86	4.64	2.28	6.43	1.74
MOA	1.98	1.66	1.97	2.66	1.31	1.84	0.37
	1.36	1.12	1.41	2.16	1.10	2.69	0.67
	1.19	0.98	1.24	1.95	1.39	2.69	0.71

Table 5 contains values of ψ factor for some cavity pyrheliometers altogether with some examples of the infrared energy loss. Except the PCC instrument, the atmospheric infrared energy loss is almost the same for the other standard pyrheliometers. The difference remains negligible even in the hypothetical case of looking into the deep space ($T_e = 0$) through an open aperture.

Table 5. The IR exchange factor (ψ) and energy loss values (W m^{-2}) for some pyrheliometers. The receiver temperature is 300 K

Instrument	ψ	$T_e = 290$	$T_e = 280$	$T_e = 270$	$T_e = 0$
ABS	0.00184	0.11	0.20	0.29	0.85
PMO6-10	0.00198	0.12	0.22	0.31	0.91
CROM 3L	0.00188	0.11	0.21	0.30	0.87
PCC	0.00756	0.44	0.84	1.20	3.49

7. Conclusions

The latest development in pyrheliometry, the appearance of cavity instruments, has led to the definition a much more precise pyrheliometric scale than the previous one, but the problem of different geometry has not been eliminated fully, since the effect of circumsolar radiation is of the same order as the comparability (10^{-4}) of this instruments.

The WRR scale would be transferred more reliably if all the Regional and National Standard Pyrheliometers would be cavity instruments, since the circumsolar effect of other type pyrheliometers is of the order of 10^{-3}.

The infrared energy loss of most of the cavity pyrheliometers is quite similar. In the case of extreme geometry it should be taken into account.

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Variation of daily extreme temperatures in Hungary

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Abstract—Six Hungarian meteorological stations were used to investigate the variation of daily maximum and minimum temperatures for the period 1901–1990. In the initial phase of the survey linear trend analysis was applied. In this paper results of the analysis are presented and discussed. Significant trend was found only in a very few cases. No significant increasing or decreasing change can be stated for the daily extreme temperatures based on stationary data. Suggestions are made for the further analysis.

Key-words: climate change, daily extreme temperature, trend analysis, Hungary.

1. Introduction

The increase of the concentration of the greenhouse gases in the atmosphere might result in an increase of the global average temperature, as well. According to the GCMs it is forecasted that the average temperature will rise by some degrees, if the CO_2 concentration is doubled. However, local temperature series do not seem to confirm this former statement. Namely, according to the measurements the northern hemisphere is presently not warming in a greater extent than the southern. Furthermore, temperature values do not show greater increase in the higher latitudes than in the lower ones (*Ecsedy* and *Murphy*, 1992). It seems to be very probable that — provided, the scenarios produced by GCMs are correct — we have to wait for about 50 years for the realization of temperature increase.

Recently the idea arose that extreme temperature values, better to say their variation might reflect an initial signature of global warming. It means that the meteorological events show more extreme character, namely the changes experienced in relative frequencies and intensity of the extremes might be considered as the first signs of a possible climate change. However, it demands

a great caution to draw conclusions for the climate change. *Balling et al.* (1990) have pointed out that rising mean temperatures are associated with changes in the occurrence of extreme minimum temperatures (more days of extreme high minimum temperatures), however they are less related to the occurrence of extreme maximum temperatures.

Concerning the annual and monthly average maximum and minimum temperatures in the northern hemisphere it was experienced in the past 40 years that difference between the maximum and minimum values has been decreased. It is due to the fact that the increase of minimum values is greater than the change of maximum temperatures (*Karl et al.*, 1984). The physical mechanism resulting in the observed changes is still not clear. Among the reasons changes in cloudiness, concentration of aerosols, atmospheric water-content and carbon-dioxid might play an important role. *Karl et al.* (1991) suggest that analyzing minimum temperature series (especially cloudless nights) will best indicate the green-house effect.

Variation of extreme meteorological elements was one of the main issues of 5th International Meeting on Statistical Climatology held in Toronto, Ontario, Canada 22–26 June 1992. Chinese researchers made extensive studies in this field. By using 60 stations variation of daily maximum and minimum temperatures for series of 35 years was investigated. Taking into account of geographical distribution it was found that in Northern-China temperature minima were increasing at a greater rate than the maxima. It should be emphasized that in South-East-China an opposite trend (i.e. decreasing) was experienced. The trend changes according to seasons, as well (*Zhuang* and *Jiliang*, 1992). Warming has been observed mostly in winter and at night (*Zhongwei*, 1992). In the middle part of China the winter temperature has increased in the past 40 years, a peak was found between 1986 and 1991 (*Qun* and *Yiwen*, 1992). A good correlation was obtained between the extent of warming and the CO_2 content of the atmosphere.

In Canada and the United States no warming trend was observed except Western-Canada (*Gan*, 1992). It seems probable that warming or cooling trends have a regional character, both can occur for the same period, but in different areas. Gap between daily maximum and minimum has changed in a small-extent in Finland, as it was shown by *Heino* (1992). During the investigated period minimum temperatures approximately remained constant, but maximum temperatures have decreased to a certain extent. *Karl et al.* (1993) have shown that for over 50% of Northern Hemisphere landmasses minimum temperature increased at a rate three times compared to that of maximum temperature during the period 1951–1990. This change was detected in all seasons and most of the regions studied. *Brázdil et al.* (1994) investigated trends of maximum and minimum daily temperatures in Central and South-Eastern Europe. Using station data for the period of 1951–1990 area averages were calculated for each season and linear trend analyses were carried out. With a few exceptions it was found

that no significant trend exists for the seasonal temperature extremes concerning area-averages. It seems reasonable to investigate extreme temperature data experienced in the stations for a long period.

In Hungary about 100 year long temperature-series are available for some stations. The paper was motivated by this fact, namely it seems worthwhile to analyse minimum and maximum temperatures. The question to be investigated is the following: can any trend be seen in the long-term daily maximum and minimum temperatures in Hungarian stations?

2. Database

Before introducing database used for this study, one important issue must be stressed. It is well-known that in urban areas a similar phenomenon can be observed, i.e. at night minimum temperature is higher than over the suburban areas. This is the so called urban heat-island which has been known for a long time. From this fact it can be concluded that when trend of minimum temperature is to be investigated, urban areas must be excluded. Another important issue is whether data available are homogeneous. For the verification of the homogeneity of climatological series cumulative sums of deviations were made by *Craddock* (1979) calculating the differences between the reference station and other stations considered. *Coops* and *Schuurmans* (1986), furthermore *Pettit* (1979) made similar investigations. For summarizing it can be stated that information content of the observed data series should be preserved, namely the applied statistical method may not destroy the original structure of data. Artificial manipulation of the observations, which might lead to the decrease of the information content has to be avoided, because it can result in distortion of estimations. What is the most important for it, to provide the homogeneity of data series in climatological sense.

The purpose of the present study — analysis of the long term series of maximum and minimum temperatures — means a strong restriction for data to be included into the investigation. The homogeneity stressed above is not fulfilled in a clear sense for data available in Hungary, since meteorological station situated outside of towns was not found, which were not moved to another place during the history. After having information about the history of the stations, checking the position and the new circumstances, the following stations were chosen for the study: Mosonmagyaróvár, Szombathely, Kalocsa, Kecskemét, Túrkeve, Nyírergyháza. These meet the following requirements:

— data series are satisfactorily long (it was chosen 90 years),
— stations are situated outside of urban areas,
— stations cover more or less the territory of Hungary.

Database provided by the above mentioned stations were used for the study without any modification or homogenization. No area averages were calculated, because we were interested in it, how surface temperatures measured in individual stations have been changing.

Daily extreme temperature values were considered for the period between 1901 and 1990. A seasonal separation was made, namely extreme temperatures were determined for winter, spring, summer and autumn. For each case absolute and average maximum and minimum values were treated separately. It was supposed that the trend is a linear function of time. For the variation of average and absolute extreme temperatures graphs were made for each season and the trend function was compiled by using the least-square method. Significance of trend was checked by using the *t*-test.

3. Results and discussion

Findings of the investigation are presented to look over data coming from western part of Hungary to the east. Mosonmagyaróvár situated in the north-western part of the country shows no sign of any marked change in any of the seasons. Maximum temperatures show a slight increase with the years, except in summer. Concerning minimum temperatures a slight decrease was found in each season. Similar results were received for Szombathely located at the western border of Hungary. In both stations minimum temperatures seem to decrease to a small extent in every season. For illustrating results the above mentioned variation of extreme temperatures are presented for Mosonmagyaróvár in winter (*Fig. 1*).

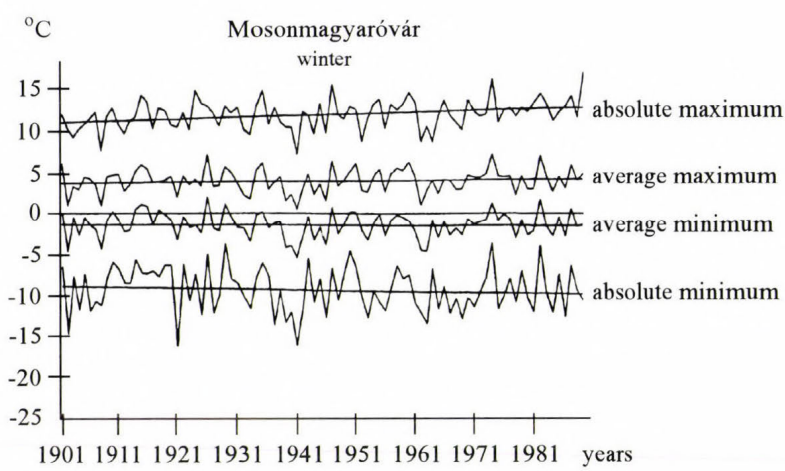


Fig. 1. Variation of extreme temperatures.

Kalocsa represents the middle part of Hungary. Minimum temperatures were decreasing in each season, the rate was highest in summer and autumn. In summer maximum temperatures seemed to be almost constant. It is very interesting that the two other stations, Kecskemét and Túrkeve, which are situated not far from Kalocsa show different tendencies. As regards minimum temperatures, data for Kecskemét seem to be quite steady in winter, but increase in summer. Maxima decrease in summer, but increase in other seasons. In Túrkeve both maximum and minimum temperatures increase, the rate for maximum values is a little bit higher than for the minima except in winter. Till this time no explanation can be given for the difference experienced in the stations situated not far from each other in the central part of Hungary. Further detailed analyses are required for revealing the history of the observations, furthermore homogeneity of the data-series have to be checked. Nyíregyháza located in the eastern part of the country represents a stations having the most continental character. It was found that in summer maximum temperatures decrease, minimum values increase during the period investigated. In winter no essential change was experienced. In spring and autumn slight increase was observed in the past 90 years.

Table 1 shows the rate of variation of temperature extremes quantitatively. Experienced changes of temperature extremes are very different. These results are not in agreement with other experiences, namely maxima are increasing at a smaller rate than minima. In many cases minima decrease, however these are not significant, except one case. Only in a very few cases significant trend was found (Table 1). No conclusion can be drawn concerning diurnal range of temperature, since no significant trend was obtained for both maximum and minimum temperature at any of the stations.

In order to illustrate the test for characterizing statistically the trend, two samples are presented. *Fig. 2a* shows the significantly increasing trend of absolute minimum temperature series found in Nyíregyháza in summer. Remind that no significant trend occurred for the maximum temperatures for the same case. *Fig. 2b* presents the significantly decreasing trend of absolute minimum temperature experienced in Kalocsa in summer. These two figures and the table show, how contradictory results were received. So, no conclusion can be made concerning the direction of temperature extreme experienced in the individual stations in various parts of Hungary. Further investigations are necessary including the following tasks:

- homogeneity of data-series has to be checked statistically,
- analyses is to be carried out for temperature-series averaged for some territories,
- other methods than the linearity of the trend are to be used for the trend-analysis.

Table 1. Linear trends (°C/10 yr) for daily temperature extremes. Significant trends are marked by an asterisk, where $p < 0.05$.

Stations	Absolute maximum	Average maximum	Average minimum	Absolute minimum
Moson-magyaróvár				
Spring	0.06	0.05	–0.02	–0.11
Summer	–0.05	0.01	–0.06	–0.19
Autumn	0.19	0.16	–0.01	–0.09
Winter	0.21	0.06	–0.02	–0.11
Szombathely				
Spring	0.02	0.01	–0.04	–0.13
Summer	–0.02	–0.03	–0.03	–0.15
Autumn	0.24	0.16	–0.04	–0.13
Winter	0.23	0.03	–0.08	–0.11
Kalocsa				
Spring	0.03	0.03	–0.10	–0.16
Summer	–0.11	–0.06	–0.19*	–0.27*
Autumn	0.08	0.11	–0.11	–0.22
Winter	0.02	–0.03	–0.06	–0.12
Kecskemét				
Spring	0.02	0.04	0.11	0.10
Summer	–0.14	–0.06	0.13	0.15
Autumn	0.03	0.09	0.11	0.08
Winter	0.14	0.04	0.06	0.05
Túrkeve				
Spring	0.12	0.08	0.08	–0.01
Summer	0.04	0.11	0.05	0.02
Autumn	0.14*	0.12*	0.06	0.04
Winter	0.21	0.08	0.15	0.19
Nyíregyháza				
Spring	–0.01	0.03	0.10	0.04
Summer	–0.30	–0.08	0.15*	0.18*
Autumn	0.01	0.05	0.06	0.01
Winter	0.06	0.01	0.05	–0.01

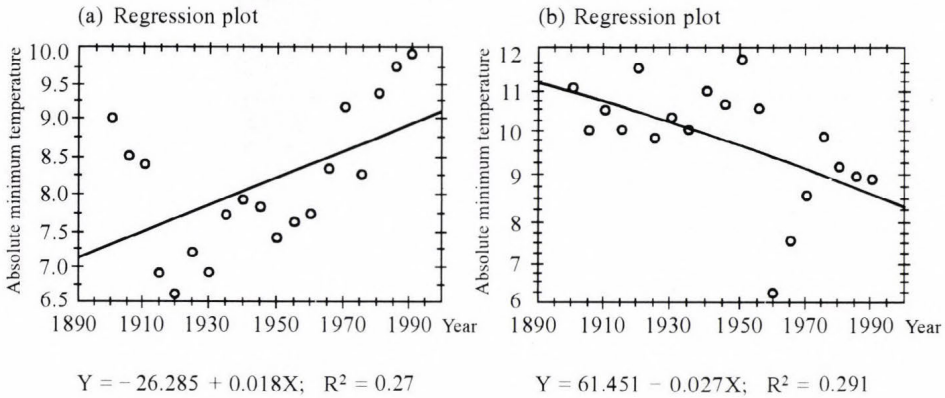


Fig. 1. Statistical characteristics of variation of absolute mimimum temperatures in summer (*a*) Nyíregyháza, (*b*) Kalocsa.

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A dry matter mass growth model for maize based on meteorological and nutrient supply data

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Abstract—A dynamic model was developed to describe the total dry matter mass above soil surface and grain dry matter mass increase for maize hybrid, Pioneer 3901 as a function of biometeorological time. It also provides estimations of the occurrence of the phenological times and of yields with accuracy of approximately 10 days and 0.8 t/ha, respectively. This corresponds to the estimation values and precision provided by other commonly used international models as CERES (*Jones* and *Kiniry*, 1986), SUCROS (*Spitters et al.*, 1989), *Dmitrenko* (1971), *Sirotenko* (1978) etc. and national models as *Ábrányi* (1979), *Dunkel et al.* (1984, 1987), *Pletser et al.* (1981) etc. As regards the number of the input parameters, the model uses 4 variables, while the nutrient supply calculation submodel, developed earlier, uses 3 variables. These variables are: data on air temperature (°C), taken at 2 meters to characterize thermal conditions; data on soil moisture deficit which is the difference between the minimum field water capacity and actual soil moisture content of a 1 m deep soil layer expressed in mm-s, to represent the hydrological conditions, global radiation in MJ/m^2 to characterize the radiation, and the nutrient supplying power of the soil, calculated by our earlier developed submodel, expressed in mg/100 g to describe the nutrient conditions. The 3 variables of the submodel are the following: temperature at 1 m deepness in °C, moisture content of a 1 m deep soil layer and precipitation, both expressed in mm. The model uses a 5 day time scale. It describes the plant dry matter mass increase with the sum of the product of response — temperature, soil moisture deficit, solar radiation, nutrient supply — and weighted functions based on probability data. As a consequence, the dual, deterministic and stochastic character of plant development is considered.

Key-words: maize, dynamic model, dry-matter, response-function, weight-function, biometeorological-time, phenological phases, grain yield.

1. Introduction

Maize used to be one of the most important food crops in Mexico, Central and South America for several centuries. According to *Weatherwax* (1954), the early civilizations of tropical America such as the Incas (in Peru, Equador,

Bolivia), the Mayas (in Central America, Yucatan) and the Aztecs (in Mexico) can be considered as maize-civilizations. In Europe, maize and silage maize are produced in the areas up to latitudes 52 and 60, respectively. The size and shape of the grain vary greatly. The plant has high requirements for heat, light and water, — climatic conditions to which it was adapted in its original homeland. Had man not interfered maize it might have become extinguished by now simply because it has no mechanism for the dissemination of seeds. The high productivity can be explained by its C_4 type photosynthetic characteristics: one single seed can produce 600–1000 new ones (this number is only 50 in wheat). Researchers agree that the genetic potential of maize has far not been utilized totally yet.

This paper is dealing with maize dry matter production as a function of time and climatic factors (air temperature, soil moisture, radiation) and nutrient supply.

2. Background

According to *Szász* (1978), two main stages of the history of Agrometeorology can be distinguished:

- visual observations of climatic effects and their empirical description and classification,
- establishment of quantitative relationship among plant growth, development and productivity by statistical calculations.

The computer based modeling of plant growth and yield formation started in the nineteen seventies. Modeling at the start concerned the description of the dependence of basic physiological processes — photosynthesis, respiration — upon climatic conditions. Models were prepared to estimate yield formation as a function of photosynthetically active absorbed radiation and temperature, preconditioning that the rest of the factors — water and nutrient supply — is optimal. These models e.g. SUCROS (*Spitters et al.*, 1989), describe the potential biomass production on a particular site. Of course, water supply and transpiration have also got a significant impact on actual yield formation.

Several models had been developed by the early eighties, that described the relationship between photosynthesis and water (*Sirotenko*, 1981; *Penning de Vries*; *van Laar*, 1982). Those models that describe photosynthesis and respiration as a gas diffusion process through the stoma, consider water supply on the basis of stoma resistance and point out the importance of stoma resistance in the material and energy flow between plant and air (*Goudriaan*, 1977). Those models, on the other hand, that reduce a supposed production ratio maximum through environmental response functions, include soil water content and evaporation in considering water supply, by using a response

function (or stress functions), too (*Matthaus et al.*, 1986). In recent years, a new aspect, that of modeling the effect of nutrient supply has been attracting researchers' attention. The models usually use one-day time steps, but there also exist ones operating with decade or shorter than one-day time steps.

What all the models have in common is that they all deal with a smaller or higher number of plant parameters and that they estimate yield formation on the basis of climatic and soil property characteristics. Plant development can be modeled only when the way in which the plant reacts to outside effects is known. For this, a certain knowledge of plant physiology is required. *Kenworthy* (1949), *Richards* and *Wadleigh* (1952) pointed out that plant development is inhibited even before temporary wilting point is reached. *Hagan* (1957) found that the development of plant organs and mass growth are more dependent upon soil water supply capacity than photosynthesis and respiration. He also showed in clover seed experiments that high soil water content inhibits seed production. When soil water content is low, green matter production will drop, whereas seed production will increase significantly. Temperature conditions in a particular geographical area represent decisive criteria for the natural development of a plant. All the physiological processes take place within certain ranges or tolerance intervals. As concerns temperature, it has to reach a certain minimum which is indispensable for biological activities. The activity will be at its highest when temperature is at its optimum. At maximum temperatures, however, life processes will stop working. These are the three cardinal temperature ranges. They vary widely according to the age, developmental stage and very significantly, to the species of the plant.

Simulation models, quite often represent the most basic plant functions only, such as photosynthesis, respiration and transpiration. In most of the cases, plant dry matter production as a function of time is estimated. A simulation model generally incorporates several sub-models, each of which describes a particular basic plant function. Input data:

- meteorological factors (temperature, humidity, radiation etc.),
- soil physical and chemical characteristics (soil moisture, soil temperature, water level, nitrate content etc.),
- processes that take place on the leaf surfaces (photosynthesis, respiration, transpiration etc.),
- characteristics in the stand (leaf area index, radiation distribution etc.).

Simulation models are elaborated for monitoring the plant throughout its whole life cycle and, also for estimating the yields. Since these models describe the plant development as a function of time, they are called dynamic simulation models.

3. *Material*

The model has to meet the requirements of both complexity and simplicity. Obviously, involving a high number of variables would provide more precise results — provided the effect of each factor is interpreted in the correct way —, a higher number of calculations, however, would result in a higher number of errors. Being aware of this and taking physiological requirements into consideration, we decided to deal with four variables (air temperature, soil moisture, global radiation and nutrient supply of the soil) these are essential for plant development.

Air temperature, and *solar radiation* data, the latter being equivalent to the global radiation measured at MJ/m^2 units as well as meteorological data necessary for submodeling the production of NO_3^-–N, by natural processes, such as *soil temperature*, *soil moisture, precipitation* were observed at Agrometeorological Observatory of Agricultural University, Debrecen, Hungary (φ = 47°30′N, λ = 21°42′E, H = 112 m asl). The climatological data were collected in years 1964–1994.

Soil moisture data are based on lime coated chernozem soil (clay content 47%) samples taken in the observatory area, where the water table was at 8–10 m. The minimum field water capacity of the soil is 280 mm/m. In the calculations we used the moisture index (total soil moisture) expressed in millimeters for a 1 m deep sample. Let the soil moisture deficit, SMD, be equivalent to the difference between the field water capacity of a 1 m deep soil layer and the actual soil moisture content of a similar depth soil layer. The model uses this parameter instead of soil moisture value. The soil moisture data were collected in years 1964–1994, too. *Hunkár-Bacsi* (1993) found this depth satisfactory for running the CERES-model, noting, however, that in dry periods the water supplies of the deeper layers can become of importance, too.

The soil *nutrient supply* was considered equivalent to the amount of naturally produced NO_3^-–N, in a 1 m deep soil layer, expressed in mg/100 g. The annual course of N-formation well characterizes the degree of the biological activities of the soil. With the Nutrient Supply Predicting Submodel, namely (NSPS) the mineralized NO_3^- amount can be estimated with 16% accuracy using the r = 0.76 correlation coefficient significant at 0.1%. The data were calculated by our earlier developed model for years 1964–1994 (*Lakatos-Szász,* 1991).

Of *plant* data, dry matter measurements were supplied by the Experiment Station of the Department of Plant Production. This place is not more than 5 km far from the Observatory and the soil samples showed identical soil types in both places. The data were collected in years 1990–1994. The phenological and grain yield data between 1975–1990 were taken at the Variety Experiment Station, which is in the neighborhood of the Observatory. All the plant data apply to 300 FAO group maize hybrid, Pioneer 3901.

4. Method

Our essential condition is quite similar to the methods applied by *Baier* (1973), *Dmitrenko* (1969, 1973), *Landsberg* and *Cutting* (1977), and *Varga-Haszonits* (1986) models. That is to say the yield formation or dry matter mass increase can be calculated by the summation of products of the environmental variables such as air temperature, soil moisture, nutrient supply and photosynthetically active radiation. In both Dmitrenko and *Rickman et al.* (1975) models describing the dry matter mass increase the variables are expressed by response functions. We suppose that the response functions are equivalent to the annual average rhythm of temperature, soil moisture, global radiation, and the nutrient supplying power of the soil. With trigonometrical series expanded by the Bessel's polinoms and extrapolation into the range of 0–1 interval, the equations of response functions — temperature, soil moisture deficit, global radiation, nutrient supplying power of the soil — can easily be determined. We also introduced such weight functions, it is quite similar to the development rate function (*Monteith*, 1981), which express the effect of a particular variable on plant development. According to *Klages* (1930, 1934), it can be supposed that the average values of the long time series, in our case it is 30 years, during the growing season are equivalent to the ecological optimum demands of the plants, which is due to the adaptation processes.

If air temperature, soil moisture deficit, solar radiation or nutrient supply data over the given period — 5 days time step — are higher or lower than the average values of long time series, the weight function values will also be lower, than the optimum values.

If the starting and ending points of the plant mass increase are known, with the summation of the products of 4 response function and the weight function minimum — according to Liebig's minimum law, the joint effect of four variables will equal the effect of the variable of the lowest value — the plant dry matter mass increase as a function of time, can be calculated.

5. Response function

In our model we used four response functions, to characterize all the principal factors of plant development i.e. the functions of thermal, hydrological, radiation, nutrient supply conditions. The response functions represent the annual climatic rhythm of the given element. According to *Klages* (1934) 'plants that are well adapted will necessarily produce a vegetational rhythm of different climatic elements in the area'.

The speed of development and biological activity of a well adapted plant, such as the maize, are influenced by the climatic, thermal, hydrological etc. conditions, which are typical of the area. Hungary's geographical situation, a

little bit north of the centre of the European corn belt, shows that the maize has been well adapted here. The response functions can be produced with expansion of the average annual course of the long time series in trigonometrical series. If the maximum and minimum values of the time series are known, after the expanding in series the extrapolation into 0–1 range will produce the following response functions:

Temperature Function [*TF*(*t*)]

As it is known, temperature and day-length regulate the speed of differentiation. The differentiation of the apex, in turn, sets the speed pattern for development (*Petr et al.*, 1985).

$$TF(t) = 9.88 + 11.84 \sin\left[\frac{2\pi t}{74} + 0.26\right]. \tag{1.1}$$

Soil Moisture Deficit Function [*SMDF*(*t*)]:

$$SMDF(t) = 67.83 + 58.45 \sin\left[\frac{2\pi t}{74} + 0.68\right]. \tag{1.2}$$

Solar Radiation Function [*SRF*(*t*)]:

$$SRF(t) = 68.00 + 49.96 \sin\left[\frac{2\pi t}{74} + 0.69\right]. \tag{1.3}$$

Nutrient Supply Function [*NSF*(*t*)]:

$$NSF(t) = \left\{14.34 + 10.63 \sin\left[\frac{2\pi t}{74} + 1.1\right]\right\}\left\{1.13 + 0.61 \sin\left[\frac{2\pi t}{37} + 2.81\right]\right\}. \tag{1.4}$$

The correlation coefficient that expresses the closeness of the relationship between the measured and calculated values is r = 0.97 – 0.99. If we know the minimum and maximum values of the annual average course of the above mentioned variables we can calculate the following response functions.

Temperature Response Function [*TRF*(*t*)]:

$$TRF(t) = \frac{TF(t) - TF_{min}}{TF_{max} - TF_{min}}, \tag{2.1}$$

$TF(t)$: see on Eq. (1.1),
TF_{min} : minimum value of temperature function ; –1.95,
TF_{max} : maximum value of temperature function ; 21.71.

Soil Moisture Deficit Response Function [*SMDRF*(*t*)]:

$$SMDRF(t) = \frac{SMDF(t) - SMDF_{min}}{SMDF_{max} - SMDF_{min}}, \tag{2.2}$$

$SMDF(t)$: see on Eq. (1.2),
$SMDF_{min}$: minimum value of soil moisture deficit function ; 31.07,
$SMDF_{max}$: maximum value of soil moisture deficit function ; 126.23.

Solar Radiation Response Function [*SRRF*(*t*)]:

$$SRRF(t) = \frac{SRF(t) - SRF_{min}}{SRF_{max} - SRF_{min}}, \tag{2.3}$$

$SRF(t)$: see on Eq. (1.3),
SRF_{min} : minimum value of solar radiation function ; 3.62,
SRF_{max} : maximum value of solar radiation function ; 23.58.

Nutrient Supply Response Function [*NSRF*(*t*)]:

$$NSRF(t) = \frac{NSF(t) - NSF_{min}}{NSF_{max} - NSF_{min}}, \tag{2.4}$$

$NSF(t)$: see on Eq. (1.4),
NSF_{min} : minimum value of nutrient supply function ; 2.34,
NSF_{max} : maximum value of nutrient supply function ; 35.68.

The four response functions are represented in the *Fig. 1*. The response functions have to satisfy the assumption of normal distribution — as proved by Geary's test — and the following conditions: $0 \leq TRF(t) \leq 1$, $0 \leq SMDRF(t) \leq 1$, $0 \leq SRRF(t) \leq 1$, $0 \leq NSRF(t) \leq 1$.

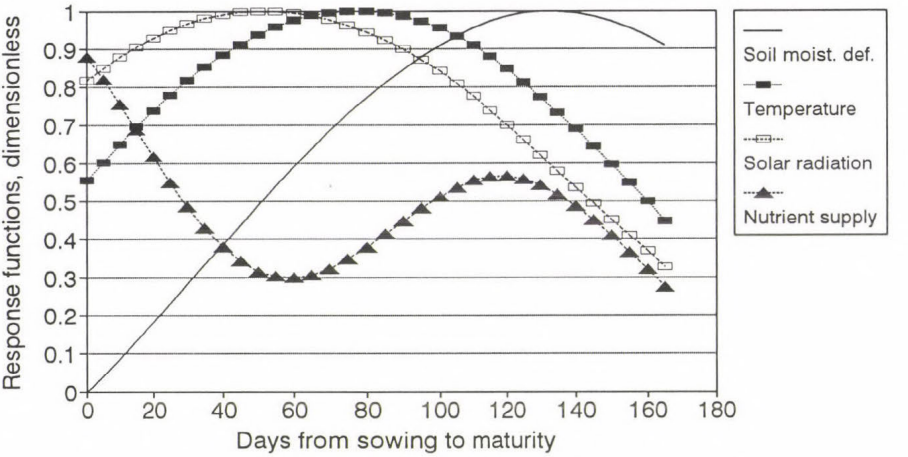


Fig. 1. Temperature, soil moisture deficit, solar radiation and nutrient supply response functions.

6. Weight functions

According to *Schimper* (1903) and *Klages* (1930, 1934) the optimum ecological requirements (thermal, hydrological, radiation, nutrient supply) of maize are more or less equal to the long term (temperature, soil moisture, solar radiation, nutrient supply of the soil) averages, during the growing season, especially in those particular geographical areas where the annual yields are high with low variability. Thus, the temperature or solar radiation, etc. optimum daily variations over the growing season correspond to the long term daily averages.

The distribution examinations — Geary's test — show that the long term 5-day temperature, soil moisture deficit, solar radiation, nutrient supply series follow a normal distribution pattern.

Let us standardize the data of the temperature and other variables series between the average sowing and maturity times for the 30 years investigated. After calculating the density function and extrapolating the ordinates of the density function of the standard normal distribution from the range of 0–0.4 into the range of 0–1, we will obtain a function which is suitable for weighting. Defining the standardized distribution functions in every 5 days and identifying the standardized values with the abscissa values of the weight function, on the ordinate the weight of the given period can be produced. For the reason of easier handling we substituted the extrapolated standard normal distribution density function as 'weighted function' with a linear curve η(T); η(SMD); η(SR); η(NS) (*Fig. 2*).

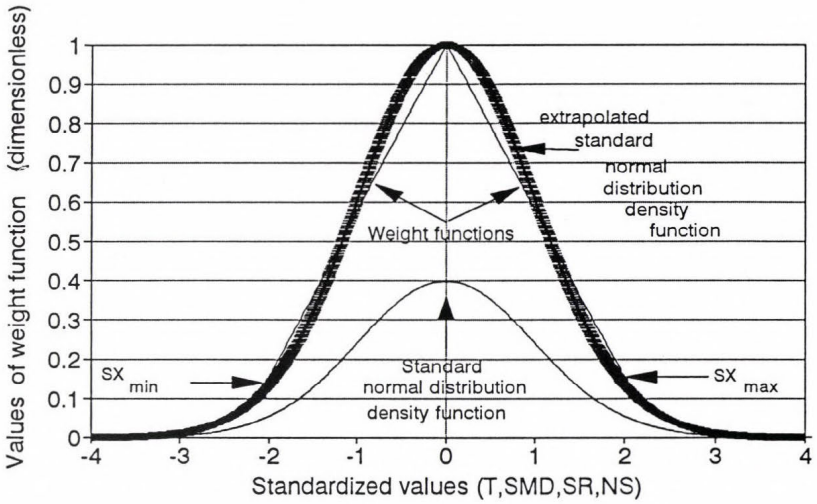


Fig. 2. Interpretation of weight functions.

As the mean value of the standardized normal distribution is 0 and the dispersion is 1, by such sample size the average produced will be equal to the mean value and in this case the weight of the period will be 1.

In the case of a satisfactory length of samples the weight of the minima and maxima would be 0, as it follows from the density function of the standard normal distribution. This, however, is not fulfilled in our case, and, so, the weights of the maxima and minima for each of the 5-day growing season periods have to be determined. As the results showed little variation over the growing season — the value of the variation coefficient (CV), never exceeded 19% maximum/minimum — we supposed that the substitution of the weight of the minimum or maximum values for the average values will not result in errors in the definition of the end value weights of the periods. The minimum values received were between 0.11–0.27 with CV-s between 8–16.

The maximum values were between 0.05–0.20 with between 6–19 CV values. Based on these values, the weight function of the variables, in 5-day time step, over the growing season can yearly be determined.

Temperature Weight Function [$\eta(T)$]:

The minimum and maximum values received were 0.11 and 0.14 with 12% and 14% CV values, respectively. Based on this knowledge, the temperature weight function, in 5-day step, between sowing and maturity, can yearly be determined with the help of the following equations.

If $T < \bar{T}$, then

$$\eta(T) = 1 - (1 - ST_{min}) \left| \frac{T - \bar{T}}{\bar{T} - T_{min}} \right|, \qquad (3.1.1)$$

where

ST_{min}: the probable value of the minimum determined earlier; 0.11,
T : actual temperature of the period,
$\bar{T}$: long term average (30-year) temperature,
T_{min} : absolute minimum of the 30-year temperature series.

If $T > \bar{T}$, then

$$\eta(T) = 1 - (1 - ST_{max}) \left| \frac{T - \bar{T}}{\bar{T} - T_{max}} \right|, \qquad (3.1.2)$$

where

ST_{max} : the probable value of the maximum determined earlier; 0.14,
T_{max} : absolute maximum of the 30-year temperature series.
The rest of expressions is equivalent to the previous ones.

Soil Moisture Deficit weight function [$\eta(SMD)$]:

Calculated from the standard normal distribution density function, the minimum and maximum values were 0.27 and 0.05 with 8% by 6% CV values. The distribution investigations show that, by normal distribution temperature and soil moisture deficit series, soil moisture distribution is deviated towards the lower ranges. There is higher probability of low values than of high ones, which is a consequence of the climatic conditions in the basin.

If the average soil moisture deficit over the given period is less than the long term average, i.e. $SMD < \overline{SMD}$:

$$\eta(SMD) = 1 - (1 - SSMD_{min}) \left| \frac{SMD - \overline{SMD}}{\overline{SMD} - SMD_{min}} \right|, \qquad (3.2.1)$$

where

$SSMD_{min}$: the probable value of the minimum determined earlier; 0.27,
SMD : actual soil moisture deficit of the period,
$\overline{SMD}$: long term (30-year) average of the soil moisture content,
SMD_{min} : absolute minimum of the 30-year soil moisture deficit series.

If $SMD > \overline{SMD}$:

$$\eta\,(SMD) = 1 - (1 - SSMD_{max}) \left| \frac{SMD - \overline{SMD}}{SMD_{max} - SMD} \right|, \qquad (3.2.2)$$

where

$SSMD_{max}$: the probable value of the maximum determined earlier; 0.05,
SMD_{max} : absolute maximum of the 30-year soil moisture deficit series.
The rest of expressions is equivalent to the previous ones.

Solar Radiation weight function [$\eta(SR)$]:

As it is generally known, the efficiency of the solar energy utilization, for the maize plant, is only 3–4% maximum. It is also known that the intensity of the photosynthesis is proportional to the number of photons mainly. Moreover, solar radiation is not a continuos process, unlike temperature and soil moisture. As mentioned the solar radiation is considered as an equivalent to the global radiation. Based on the standard normal distribution density investigations, the minimum value of the density functions was 0.13 with 13% CV value and the maximum value was 0.15 with 14% CV value. On the basis of all these, the solar radiation weight function, when the solar radiation average over the given period is below the long term average $SR < \overline{SR}$, can be written as follows:

$$\eta\,(SR) = 1 - (1 - SSR_{max}) \left| \frac{SR - \overline{SR}}{SR_{max} - \overline{SR}} \right|, \qquad (3.3.1)$$

where

SSR_{min} : the probable value of the minimum determined earlier; 0.13,
SR : actual solar radiation value of the period,
$\overline{SR}$: long term (30-year) average solar radiation,
SR_{min} : absolute minimum of the 30-year solar radiation series.

In that case, if $SR > \overline{SR}$:

$$\eta\,(SR) = 1 - (1 - SSR_{min}) \left| \frac{SR - \overline{SR}}{\overline{SR} - SR_{min}} \right|, \qquad (3.3.2)$$

where

SSR_{max}: the probable value of the maximum determined earlier; 0.15,
SR_{max} : absolute maximum of the 30-year solar radiation series.
The other expressions are equivalent to the earlier.

Nutrient Supply weight function [$\eta(NS)$]:

As mentioned above, the soil nutrient supply is considered equivalent to the amount of naturally produced NO_3^-–N, in a 1 m deep soil layer. These values are calculated with our model developed earlier (*Lakatos-Szász*, 1991).

Based on the standard normal distribution density investigations, the minimum value of the density functions was 0.18 with 16% CV value and the maximum value was 0.20 with 19% CV value. So, the nutrient supply weight function, when the nutrient supply average over the given period is less than the long term average $NS < \overline{NS}$:

$$\eta\,(NS) = 1 - (1 - SNS_{\min}) \left| \frac{NS - \overline{NS}}{\overline{NS} - NS_{\min}} \right|, \tag{3.4.1}$$

where

$SNS_{\min}$: the probable value of the minimum determined earlier; 0.18,
NS : actual nutrient supply value of the period,
$\overline{NS}$: long term (30-year) average nutrient supply,
$NS_{\min}$: absolute minimum of the 30-year nutrient supply series.

In that case, if $NS > \overline{NS}$:

$$\eta\,(NS) = 1 - (1 - SNS_{\max}) \left| \frac{NS - \overline{NS}}{NS_{\max} - \overline{NS}} \right|, \tag{3.4.2}$$

where

$SNS_{\max}$: the probable value of the maximum determined earlier; 0.20,
$NS_{\max}$: absolute maximum of the 30-year nutrient supply series.
The other expressions are equivalent to the earlier.

Biometeorological time [$t_{biomet}(t)$]

For the description of the development of a certain plant part (grain, cob, leaf, stem) as a function of time, a reliable time scale is needed. Mass growth (total above ground or grain mass) will start at a certain stage of the plant development. For the determination of the starting point we have to introduce a biometeorological time scale. This name was introduced by *Robertson* (1968). It has to be stressed, however, that our scale is not identical with the scale used by Robertson as, besides daily temperature maxima and minima, he introduced day and night length, as well. The word 'scale' is only used to indicate that more than thermal time derived from temperature summation is meant (*Monteith*, 1981).

The character of the scale is determined by the temperature only, the daily increases, however, are in complete accordance with the plants' ecological, physiological requirements.

When constructing the scale, the external effects were taken into consideration from both meteorological and biological aspects. It was presupposed that the daily *temperature optimum* of maize plant equals the long term *temperature averages* in the particular geographical area. Thus, daily variations of the temperature optimum over the growing season correspond to the long term daily averages.

So, if the products of multiplying the values of 5 day time step temperature weight function by the corresponding values of the temperature response function are summed over the period between the sowing and maturity time, we will obtain the 'biometeorological' time.

So, the time scale is based on statistical data and alongside with its deterministic character it is also capable of treating the stochastic effects, which appear as a sum of effects taken at any point of plant development.

$$t_{biomet}(t) = \sum_{t\,=\,sowing}^{maturity} TRF(t)\ \eta\,(T(t))\,, \tag{4}$$

where

$TRF(t)$: see on Eq. (2.1),
$\eta(T(t))$: see on Eq. (3.1.1),
t : normal time (in 5-day time steps).

Estimating the starting point of the phenological phases

A biometeorological time scale characterizes the development speed of the plant. If the scale is correctly defined, it is expected to exactly express the occurrence of the phenological phases. In our case this requirement is met as the correlation between the measured and calculated values is 0.75–0.84, and the greatest difference between the actual and estimated occurrence of the phenological phases in none of the investigated 20 years exceeds 10 days. If the biometeorological time is known, the occurrence of the phenological phases can be estimated with the following regression equations:

Emergence	(t_{biom})	=	$12.15t_{biom}$	+ 9.24	(5.1)
Tasseling	(t_{biom})	=	$3.11t_{biom}$	+ 49.36	(5.2)
Silking	(t_{biom})	=	$2.76t_{biom}$	+ 56.05	(5.3)
Maturity	(t_{biom})	=	$4.59t_{biom}$	+ 77.86.	(5.4)

The least exact fitting was found with estimating tasseling time r = 0.75. Emergence, silking and maturity times were estimated with correlations

r = 0.84, r = 0.77, and r = 0.78, respectively. This shows our model is suitable for the estimation of the occurrence of phenological phases and that it provides results with acceptable precision.

The dynamics of dry matter accumulation

According to *Vrkoc* (1977), soil and climatic conditions have a significant effect on the amount and dynamics of the biomass formation. This fact and our previous observations in the plant physiology eventually led us to conclude the biomass growth as a function of time can be described with four variables: i.e. air temperature, solar radiation, soil moisture deficit, nutrient supply. The joint effect of the four variables can be interpreted by additive or multiplicative relations. The multiplicative approach is supported by the fact that each of the variables is essential for survival which means that minimum availability of any of the four factors will result in a significant decrease in their joint effect. In the additive case it is not realized in the same extent. Knowing the response functions and probability weights of each variable — and using the Liebig's minimum law — effect is the summation of the products of the four response functions multiplied by the lowest value of the weight function, the dry matter production of maize can be described. Accordingly, the model equation is this:

$$DM(t_{biom}) = \sum_{t_{biom}=0}^{m} \{MRF(t_{biom})\}\{WF(t_{biom})\}, \tag{6}$$

$DM(t_{\text{biom}})$: plant mass increase as a function of biometeorological time,
$MRF(t_{\text{biom}})$ = $TRF(t_{\text{biom}})$ $SRRF(t_{\text{biom}})$ $SMDRF(t_{\text{biom}})$ $NSRF(t_{\text{biom}})$,
$WF(t_{\text{biom}})$ = min $[\eta(T(t_{\text{biom}})), \eta(SR(t_{\text{biom}})), \eta(SMD(t_{\text{biom}})), \eta(NS(t_{\text{biom}}))]$.

With the help of the equation above, the daily (5 day) plant mass growth can be determined. The relationship between the dimensionless cumulative results of our model the dry matter content expressed in g/plant dimension can be characterized by the following equations:

$$DM_{meas}(dm_{calc}) = 44.13\, dm_{calc} - 23.09, \tag{7.1}$$

for total biomass above the soil surface (*Fig. 3*) and

$$DM_{meas}(dm_{calc}) = 78.10\, dm_{calc} - 77.85 \tag{7.2}$$

for grain mass on the cob (*Fig. 4*). In these equations *DM* is the measured and *dm* is the calculated dry matter content.

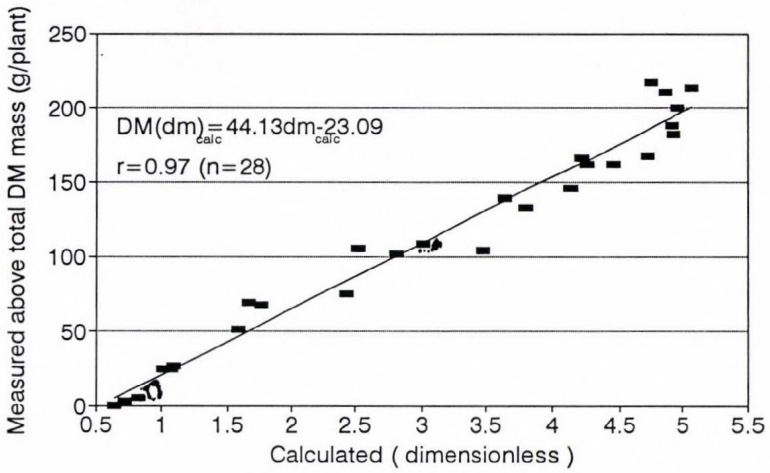


Fig. 3. Relationship between measured total biomass above soil surface and estimated dry matter mass.

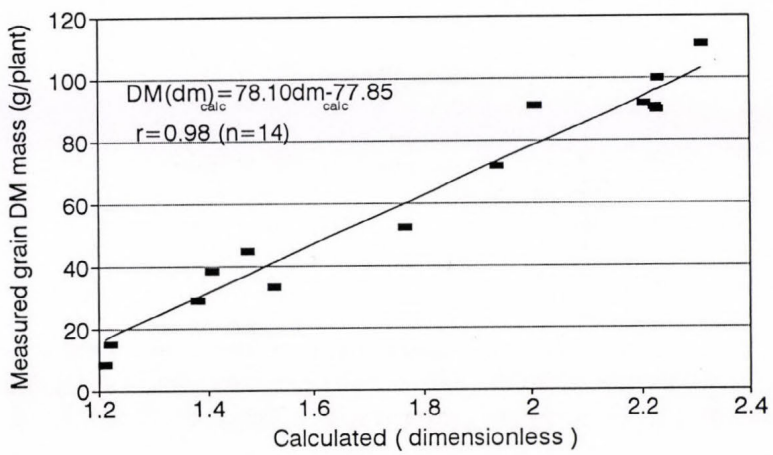


Fig. 4. Relationship between measured grain mass and estimated dry matter mass.

There is a significant relation between the measured and the calculated values, in above soil biomass total and grain mass accumulation dynamics, $r = 0.97$ and $r = 0.98$ at $p = 0.1\%$. The testing of a model is usually done on outside control material. In our case it was the dry matter mass growth prediction for year 1994. If the *starting point* of grain formation which can be read on the biometeorological time scale (on the basis of 3 investigated years

it was 12.5, with very slight differences) and the *final point*, i.e. the maturity date (it was 22.0, also with a very slight differences) are known, the grain dry matter mass increase can be calculated, with the model being run between these two points.

As, it can be seen in *Fig. 5*, both the total biomass above the soil surface and grain mass growth as a function of time can be predicted with the precision of 8%.

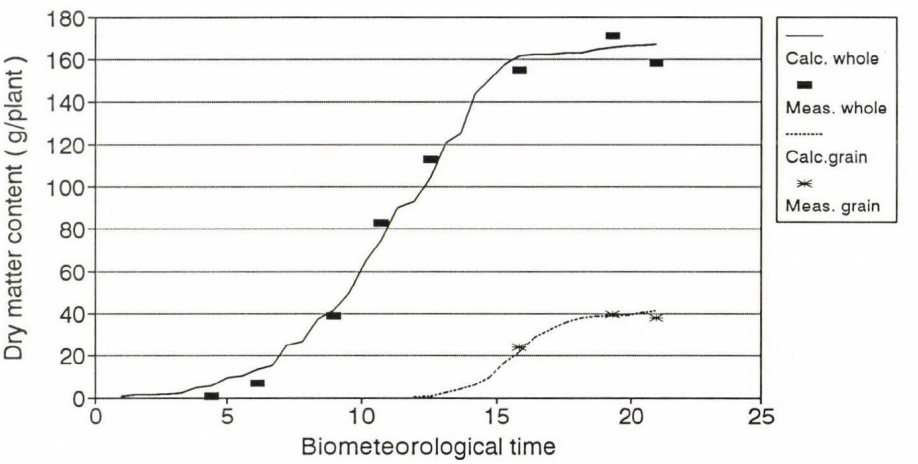


Fig. 5. The mesured and estimated dry matter mass growth of the total biomass above soil surface and the grain yield in 1994.

Prediction of the grain yield quality

The mass growth data of the total plant and grain dry matter data are essential for making yield estimations. The relation between dry matter accumulation and the yield quantity was examined by *Hunkár* (1990). She found that there is a significant relation between the yield quantity and the maximum dry matter content values.

The data of the available 4 test years — period between 1991–1994 — show a significant, at p = 0.1%, relation between the measured maximum dry matter content value and the grain yield amount, the correlation coefficient is r = 0.96. The regression equation is:

$$Y(\max DM_{grain}) = 0.08 \max DM_{grain} - 0.12, \tag{8}$$

where Y is the quantity of grain yield in (t/ha), and $max\ DM_{grain}$ is the

maximum grain dry matter content value in (g/plant). This equation can be generalized only if the stem numbers/ha rate is the same in every investigated year (it was about 70 thousand stems/ha in our case). Let us suppose that this assumption is realized in every investigated year.

The outside control material, which is necessary for testing, in the current case, data series between 1975–1990 obtained at the Variety Research Station. If we run the model from the starting point of grain formation determined earlier — it is 12.5 — to the maturity date, i.e. 22 biometeorological time points, the grain dry matter content maximum value can be determined. In the investigated period of 1975–1990, the values received show a significant relation with grain yield quantity ($r = 0.90$) at $p = 1\%$. The average error of measured and calculated values was below 0.8 t/ha (*Fig. 6*).

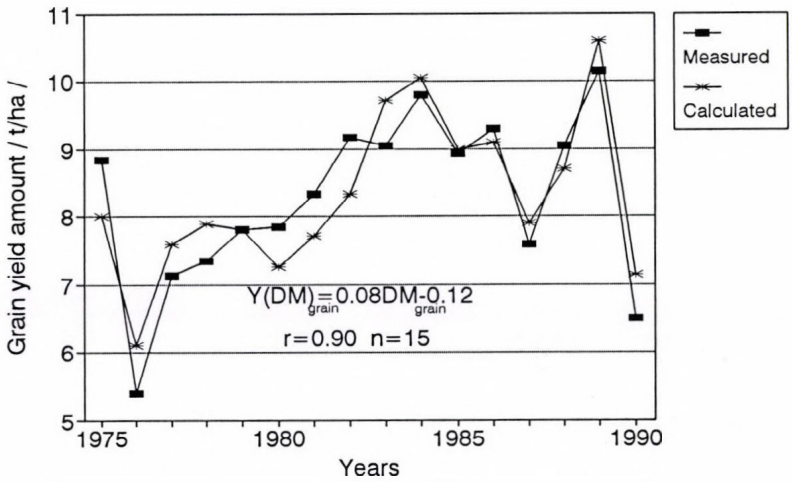


Fig. 6. The measured and estimated grain yield amount (t/ha) during the period of 1975-1990.

7. Conclusions

The results apply to a medium-duration maize hybrid, Pioneer 3901. This hybrid and 300 FAO-groups are the major cultivated hybrids in eastern and other regions of the country. The annual yield average of a large cultural area involves the yields of several different varieties. There are large differences in their productivity, drought and disease resistance. Varieties with new traits can change significantly in their weather tolerance, their tolerance to certain climatic effects may increase, to others it may decrease. Long duration cultivation of a variety may cause changes in certain characteristics.

So, we cannot expect that a plant-weather model developed for a variety with certain genetic potentials to work perfectly for varieties with genetic potentials other than those. The model presented here did not take the dry matter decrease of maize during its growing period into consideration.

We supposed that the mass growth of dry matter was a monotonously increasing process. We think that, this supposition could be realized, if the principal supplies (thermal, hydrological, radiation, nutrient) were nearby optimum. The model uses a low number of input parameters which makes it easier to deal with. Moreover, the development of a variety function for maturity groups would widen the range of model utilization.

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IDŐJÁRÁS

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Influence of the hilly relief on the water balance of vineyard

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Abstract—Under various hilly relief, according to the locality of the plots the moistening conditions change essentially. The different moistening forms various conditions of water consumption and moisture supply of the vineyard. An uninterrupted three-year microclimatic experiment upon vine plantations, grown without irrigation in the various localities of the hilly relief in the region of the town of Perushtitsa, Plovdiv district, has been carried out for determining the influence of the hilly relief microclimate upon above mentioned agricultural-climatic indices in South Bulgaria.

The estimation of the hilly relief influence on the water regime, the water consumption and the moisture supply of vineyard have been obtained after a detailed analysis of a complex of meteorological, agrometeorological and biological factors in different relief. It has been established that the vine-stocks grown without irrigation, are supplied with moisture in the beginning of the vegetation and through the interphase periods from the budding to the end of blooming. During the interphase periods from the end of blooming to the defoliation the moisture content has been mainly below the optimal ones. The moisture content has been the highest in the beginning of the vegetation, after that it has continuously decreased and in the beginning of the autumn it has become the lowest. The moisture accumulation has started with the transition of vineyard from vegetation to quiet and with increasing of the precipitation amount. The total water consumption of vine-stock, grown without irrigation, has been in direct connection with the amount of precipitation, fallen during the vegetation period. It has shown that in various conditions of hilly relief the differences in the microclimate, the soils and the vineyard water consumption have led to considerable changes in grape yield.

Key-word: water balance, water consumption, water supply of vineyard, soil moisture.

1. Introduction

The unsteady moisture supply of vineyard, grown without irrigation in plots situated on the slopes of various inclinations and exposures in the hilly relief, has been consequence of different water quantities resulting from the precipi-

tation and its redistribution there. The differences in the conditions of moistening have created such differences in the water consumption and the moisture supply of vineyard too. It follows to expect high yields with excellent quality of grapes there, where the microclimatic and soil conditions have been the most favourable and the moisture conditions — nearest to the optimal ones. The knowledge of the microclimatic features in the distribution of these agroclimatic indices is important for the agricultural practice.

2. Research material and methods

The present investigation has been a part of a large microclimatic experiment, carried out continuously for three years (Jan 1978–Dec 1980) in the vine-stock plantations of the Scientific and Industrial Complex 'G.Dimitrov' in the region of the town of Perushtitsa, district of Plovdiv. The territory under study is situated in the central part of South Bulgaria, in the region near the north slopes of the Rhodope mountain. It spreads over 20 km^2, and is found at 199 to 400 m above sea-level and as a matter of fact is a valley with a slight inclination to the N (up to 1°) bordered from the S by the North-Rhodopean slopes, which in the given region are over 1000 m above sea level, from the E, W and to a great degree from the N by hillranges with a relative height up to 100 m, which are off-branches of the North-Rhodopean slope. The valley is ellipsis-shaped with 4 and 2 km axes.

The continuous microclimatic observations have been implemented in two profiles, situated in massifs of vine-stock plantations mainly of the variety Bolgar. The plots with variety Bolgar are located in the middle and lower parts of the slopes and throughout the valley. The peaks and the upper parts of the slopes are pastures with well developed herbage. The vine-bushes are planted at 3.40 × 1.20 m distance in 'high-stem Guillot' forming. The grape-vine is grown without irrigation and is not covered up for the winter. The characteristics of the microclimatic points along the profiles, where the soil moisture has been determined as well as of the reference meteorological station for the experiment which is found at the basic profile, taken from the topographical map, are presented in *Table 1*.

In the profiles which have been investigated on the slopes with 3–7° steepness there are medium eroded brown forest soils (points 2 and 5), high-carbonated, heavy clayey, and among them some islands of humous carbonated, slight clayey and stony ones (point 3). The valley is covered by alluvial soils, slightly clayey ones (point 6). In the upper sections of the slopes and on the tops of the elevations the soils are humous-carbonated, fine, highly eroded and stony.

In these profiles the humous horizon reaches 20 cm with alluvial soils and 40–50 cm with the rest. The whole profile of the humous carbonated soil is

about 40–60 cm thick, of the brown forest soil about 100 cm and of the alluvial soil over 200 cm. The humous and carbonates content is low with the alluvial soil (up to 1% and 4.3%, respectively) and is the highest with the humous-carbonated soil (2.0–2.2% and 23.8–27.6%). The brown forest soils content 1.4–1.8% humous in the ploughed layer and a low quantity of carbonates. The soil pH varies between 6.0 and 7.2, i.e. is neutral and has got low alcalinity.

Table 1. Characteristics of the microclimatic points in which soil moisture has been determined and of the base meteorological station at Perushtitsa

No. of point	Location	Exposure	Distance between points (m)	Altitude asl (m)	Elevation (m)	Steepness of the slope (degree)	Vegetation
2	A	NW	675	314	115	5	Bolgar
3	B	NW	835	268	69	3	Bolgar
0	C	NW	2675	244	45	1	Vineyard at a distance of 100 m
6	D	NW	925	199	0	<1	Bolgar
5	E	NE		220	21	7	Italian Riesling

Legend: A – middle part of the slope; B – lower part of the slope; C – meteorological station; D – valley; E – lower part of the slope

Agrohydrological constants of the soil vary mainly because of differences in the mechanical composition. Humidity of the steady withering varies from 7.3% with alluvial soil to 18.2% with brown forest soil. The limited field capacity reaches 17.8% in the case of alluvial soil and 30.4% at some horizons of the brown forest soils (*Stoychev* and *Dimov*, 1986).

The weather during the investigation period was marked by a heightened background of the air humidity, higher recurrence of changeable-cloudy weather, lower values of the radiation characteristics and suppressed temperature regime in comparison to the many years' average. The amount of precipitation in general during these years was near the normal value, but its distribution within the period was extremely uneven.

Microclimatic observations were made continuously in 6 points from meteorological instrument shelters including maximum, minimum and time dependently the air temperature every day according to a schedule. At all points the 24-hour changes in temperature were registered uninterruptedly by thermographs. The shelters were placed at the height of 150 cm. At the same points precipitation was measured with Wild's raingauge. All the visual meteorological

and agrometeorological observations were made, too. The shelters and the gauges placed at the points in the vineyards were put just between the rows. Raingauges were placed where there were no vine-stocks. The standard station of the meteorological network at Perushtitsa, which has been operated with some interruptions between 1934 and 1981, was the basic station for the experiment. The meteorological observations took place regularly 3 times a day in the standard for Bulgaria time-step (at 7, 14 and 21 h according to Sun Mean Time) following the Manual (*Dabov*, 1971).

In the region of 2, 3, 6 and 5 (see Table 1) systematically and according to the method generally accepted (*A Guide for Agrometeorological Observations*, 1960) the soil moisture was determined by soil sampling with a fourfold recurrency on every 7th, 17th and 27th day of the month. Samples got evaluated immediately at the soil laboratory nearby.

At the points situated in vineyards there were daily phenological observations throughout the vegetation period as well as some others aimed at the state of the culture and at the proceeding of the agricultural work in accordance with the method accepted at the National Institute of Meteorology and Hydrology of Bulgaria (*A Guide for Agrometeorological Observations*, 1960).

All microclimatological observations in the grape-vine culture were made at ordinary production plots of the Scientific and Industrial Complex. The Perushtitsa region is known as one of the basic producer regions of the country for table wine, mainly of the basic variety for export — Bolgar.

The water balance of vineyard under natural circumstances of moistening was investigated on the basis of the materials on the dynamics of productive moisture contents at different sites of the hilly relief and with different types of soil within the experimental period.

The water consumption i.e. the effective evapotranspiration during the vegetation period has been determined with the method of water balance:

$$E = W_1 - W_2 + z - f,$$

where E is the water consumption for a given period in mm, W_1 is soil moisture content at the beginning of the period in mm, W_2 is soil moisture content at the end of the period in mm, z is precipitation amount for the period in mm and f is surface run off from the precipitation assessed by the method of run off coefficients in mm (*Onchev*, 1974).

The vineyard's moisture supply has been assessed by making a comparison between the productive soil moisture content and the lower border of the optimum moistening (70–75% of the limited field moisture capacity).

The biological observations upon the vine-stocks have been carried out through common accepted methods with participation of a collective from Department of Viticulture of the High Agricultural Institute in Plovdiv.

3. Results and discussion

The investigation period has been characterized with considerable amounts of precipitation and comparatively high soil moisture content both on the slopes and in the valley. For the water balance regime of vineyard at sufficient moistening the upper 1 m soil layer, which can name active (*Magrisso*, 1970), is of determinative importance. Therefore, the analysis of the water balance regime has been effectuated for the 0–50 and 0–100 cm soil layers in which the basic part of the vine-stock root system has been disposed.

The optimum moisture content of the root zone for the vine-stock is equal to 70–75% of the limited field moisture capacity (LFMC) and more (*Winkler*, 1962; *Turmanidze*, 1981; *Fursa*, 1986). At such a degree of the moistening of the soil during almost the whole vegetation period (from the beginning of vegetation till the beginning of ripening of the grapes) the vineculture has an optimal growing and developing and gives high yields. The soil moisture content in spring is determined basically by the precipitation fallen in the cold period of the year (November–March). In the region under study in the given period (November–March) for the time of investigation in the microclimatic points the precipitation amounted to 175–186 mm (82–87% of the many years'norm at the meteorological station, which has been 214 mm). As we can see in *Fig. 1*, where the average annual course of the soil moisture content is presented, during the cold period of the year when the natural moisture content in the soil occurs, the productive moisture content are high and near to LFMC all over.

Since during the cold period the vine culture does not vegetate, the water losses from the soil are not too much and occur on account of evaporation and run off only. During the warm period the moisture leaving the soil is determined mainly by transpiration and in a smaller degree by evaporation from the soil surface. The water consumption of grape-vine plants during the vegetation period is uneven and changes according to the phases of development. That is why it is more convenient to analyse the soil moisture content, the water consumption and the soil moisture supply of vine-stocks according to the interphase periods of the vine culture's evolution. Investigation has been performed for the following interphase periods: budding–beginning of blooming; beginning of blooming–end of blooming; end of blooming–beginning of ripening of grapes; begining of ripening of grapes–physiological ripeness; physiological ripeness–defoliation. The dates of the beginning, the end and duration of these interphase periods during the years of investigation at the microclimatologic points situated in vineyards are presented in *Table 2*. As it can be seen from Table 2 and Fig. 1 at the time of blooming in spring the productive moisture content, i.e. available water in the 0–50 and 0–100 cm layers were high and near to LFMC. They varied between 44 and 90 mm in the 0–50 cm layer and between 148 and 180 mm in the 0–100 cm layer depending on the type of soil and the weather during the period.

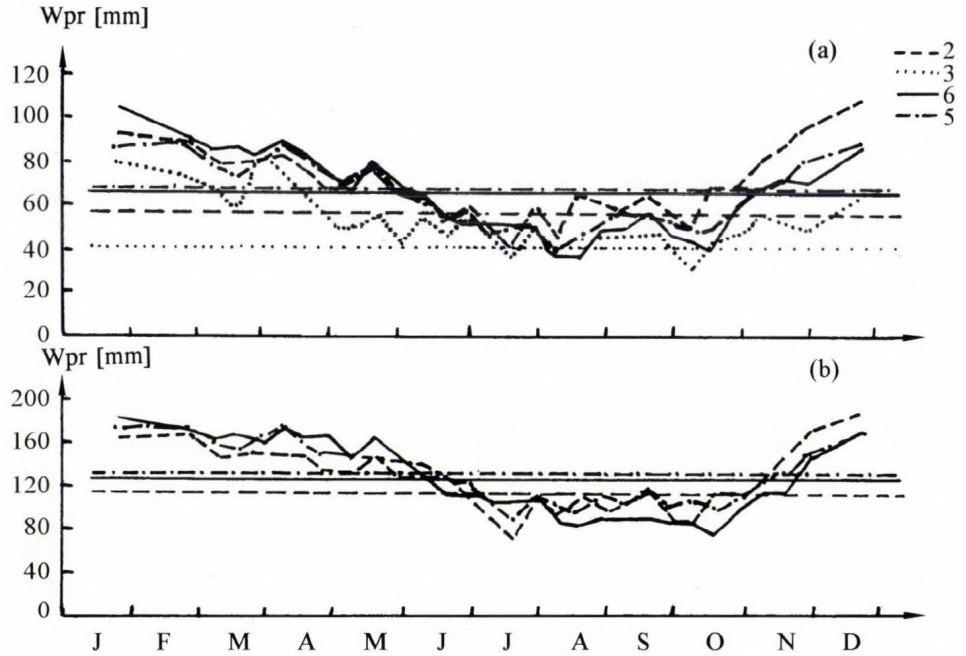


Fig. 1. Annual course of productive moisture (Wpr) in the investigation period (1978-1980). (*a*) 0–50 cm soil layer, (*b*) 0–100 cm soil layer; 2, 3, 6 and 5 — microclimatic points.

During the 'budding–beginning of blooming' interphase period, the duration of which depending on the plot's location comes up to 55–62 days in average (Table 2), the mean water consumption from the soil is negligible and its value was 6–21 mm in the 0–50 cm soil layer and 26–38 mm in the 0–100 cm layer. The average amount of precipitation is 141 mm, while the normal value being 153 mm (*Table 3*). In the course of this interphase period in the years of investigation the available soil moisture was all over big (Fig. 1). The air temperature was moderate. The foliage surface not everywhere developed. Under such circumstances the average summary of the water consumption of the vineyard varied from 168 mm in the 0–50 cm soil layer to 182 mm in the 0–100 cm layer (Table 3).

The analysis of the moisture content has revealed that on the plots of investigation the stocks of productive moisture for this interphase period stayed at the optimum level i.e. they were near and over 75% from LFMC; hence the vine-stocks were well supplied with moisture during the interphase period lasting from the budding till the beginning of blooming. This time all parts of vine-plant are in intensive growing, first of all its sprouts and leaves and from the latter the lower ones in particular, which at the end of the period reach their normal size.

The 'beginning of blooming–end of blooming' interphase period which is of short duration — 6 to 8 days in general — occurs in June (Table 2). It is essential as regards to the outcome of the yields both for the current and the next year. At this time the fecundation of the blossoms is going on and the next year yield's buds are being lain. Beside the necessary air temperature for the grape-vine's getting through this interphase period normally also optimum soil moisture content is needed.

Table 2. Mean dates of the beginning, end and duration of the interphase periods (days) at the microclimatic points in the investigation period (1978-1980)

Plot points	Budding – beginning of blooming			Beginning of blooming – end of blooming			End of blooming – beginning of ripening of grapes		
	A	B	C	A	B	C	A	B	C
2	09.04	10.06	62	10.06	16.06	6	16.06	12.08	57
3	08.04	08.06	61	08.06	16.06	8	16.06	10.08	55
6	12.04	08.06	57	08.06	16.06	8	16.06	09.08	54
5	10.04	04.06	55	04.06	11.06	7	11.06	12.08	62

Continued Table 2

Beginning of ripening of grapes – physiological ripeness			Physiological ripeness – defoliation		
A	B	C	A	B	C
12.08	22.09	41	22.09	03.11	43
10.08	16.09	37	16.09	04.11	49
09.08	11.09	33	11.09	02.11	52
12.08	21.09	40	21.09	03.11	43

Legend: A – beginning, B – end, C – duration

The mean productive moisture content was 47–60 mm (0–50 cm) and 118–130 mm (0–100 cm), respectively (Fig. 1). The moisture content in this interphase period with rare exceptions (point 6 in 1979) has been at the optimum. The vineyard's total water consumption from the 1 meter soil layer during this interphase period was 2–15 mm of water in average. In some years the fluctuations in the water consumption values depending on the locations of

the plots and the soil type reached up to 25 mm. Generally speaking, during this period the mean moisture loss is low (Table 3) and in the case of precipitation of 3 mm even moisture accumulation could be observed (point 2).

Table 3. Mean water consumption of vineyards (mm) in two different soil layers by interphase periods in the region of Perushtitsa (1978–1980)

Plot points	0 – 50 cm			0 – 100 cm		
	From the soil	Precipitation	Amount	From the soil	Precipitation	Amount
			Budding — beginning of blooming			
2	6	162	168	26	162	188
3	15	152	167	–	–	–
6	16	144	160	28	144	172
5	21	157	178	38	157	195
			Beginning of blooming — end of blooming			
2	2	3	5	–1	3	2
3	3	2	5	–	–	–
6	7	2	9	8	2	10
5	15	2	17	2	2	4
			End of blooming — beginning of ripening of the grapes			
2	5	92	97	16	92	108
3	2	75	77	–	–	–
6	19	71	90	41	71	112
5	19	73	92	45	73	118
			Beginning of ripening of the grapes — physiological ripeness			
2	–7	76	69	–6	70	64
3	–4	80	76	–	–	–
6	–21	86	65	1	61	62
5	–13	100	87	–18	72	54
			Physiological ripeness — defoliation			
2	–13	70	57	–6	70	64
3	–4	70	66	–	–	–
6	–6	61	55	1	61	62
5	–12	72	60	–18	72	54
			Total amount for the budding — defoliation period			
2	6	333	339	30	333	363
3	16	309	325	–	–	–
6	21	303	324	55	303	358
5	42	332	374	64	332	396

In the course of this interphase period the moisture content continuously decreased, remaining at the optimum level throughout the 1 m soil layer. So the conditions of the moistening of vineyard's root zone stayed at the optimum level in the mentioned interphase period during the years of investigation.

The 'end of blooming–beginning of ripening of grapes' interphase period is long: 54–62 days (Table 2). This is a period of intensive growing of the grapes and maximum development of the vegetative mass of the vine-plant. During this period the mean moisture content in the 0–50 cm soil layer amounted to 44–51 mm and in the 0–100 cm one to 96–105 mm. The available water content here was characterized by constant decrease as the time passed; it was the most explicit in the valley. It has to be taken into consideration that to a large extent of the period passed with soil moisture content below optimum, particularly in the valley, but in consequence of the well developed root system the vine stocks in the valley have used water from the 100–200 cm soil layer (Fig. 1).

The mean summary of the water consumption from the 1 m soil layer amounted to 108–118 mm of water, from which 16–45 mm were utilized from the soil and 71–92 mm were from precipitation.

During the 'beginning of ripening of grapes–physiological ripeness' interphase period the necessity of the plants in water decreases considerably in consequence of the reduced activity of the lower and middle range of foliage, the standstill in the growing of the sprouts and their intensive lignification. The available water content in the soil during the period was mainly below optimum with the exception of the humous-carbonated soil (point 3) and amounted to 92–108 mm in the 1 m soil layer. The mean amount of precipitation during this period was considerable: 117 mm with many years' average being 101 mm.

The total water consumption of the vineyard was lower than during the previous interphase period (Table 3). The moisture supply of the grape-vine for the period was mostly satisfactory (Fig. 1).

In the 'physiological ripeness–defoliation' interphase period the grape-vine's water demand becomes still lower. This is the period when the vine-stock makes a transition from vegetation towards a quiet. The mean available water grew gradually and at the end of the period amounted to 43–78 mm (0–50 cm) and 90–126 mm (0–100 cm) i.e. over or near the optimum level (70–75% of LFMC). The mean amount of the precipitation was 93 mm i.e. below many years' average, which was 104 mm. During this period the accumulation of soil moisture content occurs (Fig. 1).

The total water consumption of the vineyard at this time is considerably less compared to the previous period (Table 3). During the whole interphase period the vine stocks are well supplied with moisture (Fig. 1).

The vineyard mean total water consumption for the vegetation period from budding till the physiological ripeness of grapes, which is of economic significance, made up to 325–374 mm in the 0–50 cm soil layer and to 358–396 mm in the 0–100 cm layer, when the mean precipitation amount was 303 to 333 mm for the same period (Table 3). The moistening circumstances of the investigated region make possible the receiving of fairly good yields of table grapes of superior quality.

The effective evapotranspiration value depends on the soil moisture content and on the biological properties of the vineculture (*Fursa*, 1986). Based on our experimental data the biological curves of the vineyard water consumption for the period of investigation have been drawn (*Fig. 2*). Taking into consideration the biological peculiarities of grape-stock we have drawn biological curves for the basic periods of development we have studied already. The total water consumption was brought to the average for a given interphase period since in this case one can see most clearly the differences in the factual water consumption by individual phases, which are conditioned by the seasonal course of evaporation. The 'beginning of blooming–end of blooming' interphase period was not studied separately because of its shortness (6–8 days).

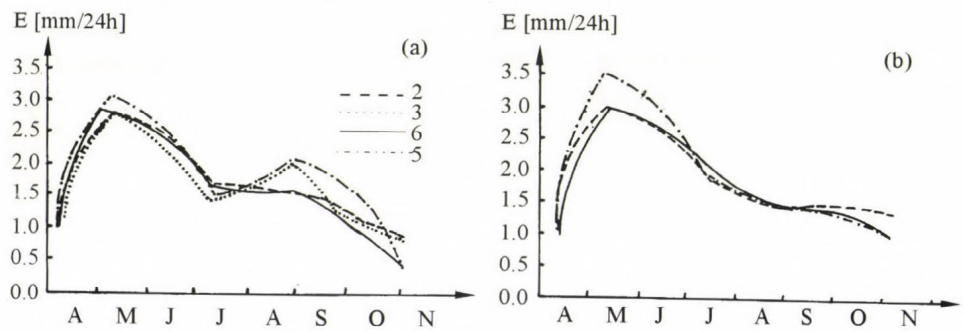


Fig. 2. Biological curves of the water consumption of vineyard for the region of Perushtitsa (1978–1980). (*a*) 0–50 cm soil layer, (*b*) 0–100 cm soil layer; 2, 3, 6 and 5 — microclimatic points.

Although the phenological observations have been effectuated on different grape-vine varieties Bolgar and Italian Riesling, their water consumption was allied, as at the latter variety it was little bigger.

In Fig. 2 it can be seen that the biological water consumption of the vineyard differs during the different interphase periods and also that the water consumption from the 0–50 cm soil layer varies to a significantly greater degree. The curves of water consumption for the 0–100 cm soil layer are smoother although the water consumption from the 50–100 cm soil layer goes up significantly in the 3rd interphase period 'end of blooming–beginning of ripening of grapes' when the amount of available water in the halfmeter surface soil layer decreases considerably.

Minimum water consumption is characteristic of the phases at the beginning and the end of development, but it is the highest during the period of active vegetation with maximum increase of the biomass of the bush. According to Fig. 2 the 24-hour maximum of water comsumption occurs through the

vegetation from the beginning of blooming till the beginning of ripening (growing) of the grapes and amounts to 2.7–3.2 mm in the 0–50 cm soil layer and to 3.0–3.5 mm in the 0–100 cm soil layer. From the analysis of the correlation of the vineyard actual water consumption in the halfmeter and onemeter soil layers follows, that if the halfmeter soil layer is well supplied with moisture then the water consumption of the vineyard comes basically from this layer. According to the drying out of the surface soil layer the vine-plant starts to use moisture from deeper soil layers.

As a supplementation to the characteristics of the moistening for the microclimatological observation points the hydrothermical coefficient (HTC) has been calculated for the basic interphase periods in the greater part of the crop vegetation. Results are presented in *Table 4*.

Table 4. Mean values of the hydrothermic coefficient (HTC) during the different interphase periods of vinestock in the investigation period (1978-1980)

Plot points	Beginning of juice circulation – mass budding	HTC	Mass budding-mass dis-volving of leaves	HTC	Mass disvol-ving of leaves – mass blooming	HTC
2	21.03–09.04	1.73	09.04–28.04	1.67	28.04–13.06	1.50
0	20.03–10.04	1.55	10.04–30.04	1.96	30.04–12.06	1.47
6	20.03–12.04	1.58	12.04–01.05	1.67	01.05–11.06	1.49

Continuated Table 4

Mass blooming – mass beginning of ripening of grapes	HTC	Mass beginning of ripening of grapes – mass physiological ripeness	HTC
13.06–21.08	0.66	21.08–16.09	1.30
12.06–20.08	0.64	20.08–14.09	1.41
11.06–19.08	0.65	19.08–11.09	1.47

The analysis of the table allows us to state that during the investigation period the vineyards, situated in the hilly relief, were well supplied with soil moisture.

In the first three interphase periods the moistening in all points of the relief had a HTC over 1.0. It was especially high in the second interphase period i.e. from the mass budding to the mass unfolding of the leaves. The lowest HTC was in the fourth interphase period i.e. from the mass blooming to the beginning of the mass ripening of grapes. It is obvious that such a distribution of the HTC during the vegetation periods is explained by the precipitation and temperature regime and only the taking into consideration of these two factors allows to speak about air dryness of the development period of grape-vine.

The water consumption coefficient (Cw) is a microclimatic index, which is in fact a ratio of the vineyard's water consumption of the points on the slopes to the standard — the valley (point 6) (*Table 5*). In Table 5 it can be seen that the values of Cw differ slightly. For the slopes, generally taken, a higher total water consumption is characteristic in comparison with the valley excepting of point 3, because of the little width of the soil profile, the soil type and the peculiarities of the moistening regime there.

Table 5. Mean values of the total water consumption coefficient (Cw) in the different months, seasons and for the whole warm period during the investigation (1978-1980)

Plot points	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr–May	Jun–Aug	Sept–Oct	Apr–Oct
2	0.89	0.87	0.91	0.74	1.12	1.07	1.08	0.88	0.91	1.07	0.93
3	0.73	0.46	0.42	0.47	0.73	0.75	0.79	0.58	0.52	0.76	0.58
6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	0.99	1.02	1.01	0.91	1.12	1.24	1.29	1.01	1.00	1.25	1.05

The soil moisture regime together with the thermic conditions are deciding for the achievement of high yields of excellent grape berry quality. The parallel observations made during the period of investigation in connection with the quality and quantity of the yields of Bolgar grapes variety grown under the different conditions of the experiment have shown that the highest yields were in the valley. While the quantity of bunches of grapes per vine-bush in all the three sections (plots) was the same (19), the mass of one cluster was 300 g at point 2, 402 g at point 3 and 426 g at point 6 as an average; the mass of 100 grapes was 394, 439 and 516 g in the very same points, respectively; grape-yields from one bush — 5.4, 7.3 and 8.1 kg and the yield of grapes from one hectare — 1.3, 1.7 and 1.9 ton. The quality of the yields, however, has an inverse dependence: the biggest quantity of sugar content (17%) and the lowest quantity of acids (5.6%) in grapes are observed in the middle part of the slope, followed by its lower part — 16.7% and 5.7% and the valley — 15.5% and 5.9% (*Babrikov et al.*, 1981).

4. Conclusions

(1) Under the conditions of the experiment the grape-vines are well supplied with moisture from the beginning of the vegetation period to the end of blooming. In the rest of the vegetation period the soil moisture content in the 1 meter layer is mostly below the optimum particularly in the valley but here the vine-plant retrieves the lack of moisture from the soil layers laying below.

(2) The soil moisture content is at its highest value at the beginning of vegetation, then decreases continuously and its value is at the minimum in the beginning of autumn. With the transition of the vine stock from vegetation to a quiet condition and the increase of the precipitation amount in autumn the accumulation of soil moisture content starts.

(3) The water consumption of the vineyard without irrigation depends directly on the amount of rainfall during the vegetation period. As a whole, for the 'budding - physiological ripeness' period the water consumption of the vineyards on the slopes amounts to 363–396 mm and to 358 mm in the valley. The 24-hour maximum of water comsumption amounts to 2.7–3.2 mm from the 0–50 cm soil layer and to 3.0–3.5 mm from the 0–100 cm soil layer in the period near and after vine blooming.

(4) The analysis of meteorological, agrometeorological and biological factors affecting the vine growth and grape yields leads us to the well founded conclusion that on the North-Rhodopean slope the most favourable conditions for achieving comparatively high yields with a high quality of grapes exist at sections of the slope to be found at a 40–70 m vertical displacement from the bottom of the valley.

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NEWS

The Hungarian Meteorological Service was founded 125 years ago

On the 3rd of May, 1995, the Hungarian Meteorological Service (HMS) celebrated the 125th anniversary of its establishment. In the ceremony participated *Mr. Ferenc Baja*, Minister of Environmental Protection and Regional Development. 25 years ago a detailed account was published covering the first century of the history of the HMS. As a continuation, recently a similar volume was prepared for the period of 1971–1995. Furthermore, a more concise historical reviews written by *Prof. Rudolf Czelnai*, has just been published. This book does not deal with the technical details, its purpose is to give a broad overview from the very beginnings. To give a short insight into the history of the HMS, the summary of this latter book (125 Years of the Hungarian Meteorological Service) is quoted below:

» Preconditions and antecedents

Sporadic Hungarian records relating to weather go back to the 11th century. From 1540 there is some record for every year. The first instrumental observations in Hungary were initiated by Ádám Gensili in Sopron, in 1717. Climatic conditions relating to viticulture were recorded, along with phenological observations of vine, by the town-councillors of Kőszeg, starting from 1740 through some 200 years. One of the stations of the famous meteorological network of the Societas Meteorologica Palatina was established in Buda in 1780. (There were only 8 stations that remained operational through the whole period of the existence of the Society, and Buda was one of those.)

The development of a Hungarian technical language for meteorology began in the early 19th century, and by 1870 it was mature enough to allow an accurate translation of any foreign technical texts into clear Hungarian. By that time there was already an increasing public demand for meteorological information in the country.

Two important antecedents played a direct role in the creation of the Hungarian institute. Firstly, the Austrian 'Zentralanstalt für den meteorologischen und magnetischen Dienst' (one of the oldest such institutes in the world) was founded in 1851, and thereby an example was set. Secondly, the Hungarian Academy of Sciences was established in 1827, and (following the Austrian scenario) the proposal for the creation of the meteorological institute came from the Academy.

Beginning and early development (1870-1919)

A sparse network of meteorological stations had been organized in Hungarian territory by the Austrian institute and, therefore, Guido Schenzl, upon his appointment to the post of director was in the position to take over a core network from Carl Jelinek, director of the Austrian institute. Schenzl's most urgent tasks were to accelerate the further development of the network and to organize the processing and publication of the data. He accomplished both tasks in the most praiseworthy manner.

The time was favourable. In 1870 a vigorous modernization effort commenced in the whole Central-European area. It was a period of rapid growth and of a seething intellectual life. Guido Schenzl was in office just in time to participate at the International Meteorological Congress in Vienna (from 2 to 16 September 1873), where the International Meteorological Organization was created. Thus, Hungary was one of the 20 founding countries of the predecessor of the World Meteorological Organization (WMO).

'The inspiration for the remarkable enterprise known as the First International Polar Year (1882-1883) has to be attributed to the foresight and determination of Karl Weyprecht, a navigation officer of the Austro-Hungarian Navy' (Steinhauser, 1994). This internationally co-ordinated research programme set the example for some later similar enterprises, including the large-scale experiments of the Global Atmospheric Research Programme (GARP) of the International Council of Scientific Unions (ICSU) and WMO.

In 1890 Dr. Miklós Konkoly-Thege, the famous astrophysicist of the time, and an exuberant personality, was appointed to the post of director of the Hungarian institute. A prominent task for the meteorological institute in that period was to assist the accomplishment of one of the largest scale water regulation projects in history (more than 30 thousand square kilometres were to be reclaimed from marshes). This provided a good argument for the transfer of the institute from the Ministry of Education to the Ministry of Agriculture. The change resulted in a significant improvement in funding of the development of meteorological activities. By 1911 the Hungarian meteorological institute moved into its impressive new headquarters building. The professional work was done according to world standards. International connections were excellent and wide-ranging. There was a particularly close co-operation between the Hungarian institute and the meteorological observatory in Belgrade (this was due to a deep personal friendship between Konkoly-Thege and Milan Nedelkovich).

Between two wars, and after (1919-1950)

In the years following the First World War professional perspectives had been dramatically reduced. International connections became scarce, and funding

insufficient even for a very limited scope of activities. Outstanding meteorologists went abroad: Aurél Anderkó was invited to Poland to assist in the organization of the meteorological service of the newly independent country; Antal Réthly was invited to Turkey for doing the same.

The only area, where something special was perhaps achieved, was upper-air research. Alfréd Hille carried out, between 1925 and 1943, altogether 1380 instrument flights with light aircraft. Géza Tóth, among other things, managed to make one of the earliest jetstream observations using traditional pilot balloon techniques. Thus there was some progress, but in relative terms the institute sank far below the professional world level.

The catastrophe that fell upon Hungary was manifold. The nation could not even recover from the consequences of the First World War, when came the second: the monstrosities of the holocaust and the total devastation of the country. The meteorological institute was not directly affected almost until the end of the war. But during the 51 days siege of Budapest the headquarters building of the institute was partly destroyed. After the communist take-over in 1948 (until then there was at least formally a parliamentary democracy) the professional staff was put under heavy pressure by a political commissar imposed upon the institute. During the night of 13 June, 1950, the director, Dr. Géza Tóth was arrested by the state security forces (as 'enemy of the state') and was interned to Recsk (the Hungarian gulag) until 1953 (when the whole prison-camp was abolished).

The 'socialist attempt at modernisation' (1950-1988)

In a way cold war helped. The threat of a military conflict made meteorology important. The supreme command could not afford shambles in the meteorological service. The institute was transferred to the Ministry of Defence and Lieutenant-Colonel Frigyes Dési was appointed director. He was a good scientist and a technocrat, but he had to make compromises with the leaders of the local organs of the communist party and the trade union (all of whom were non-professional staff members). He applied the Homeric principle of the 'lesser evil': yielded in many short-term affairs, but kept his hands free in the long-term issues of manpower development and international co-operation.

A meteorological faculty was created at the Eötvös Loránd University of Budapest shortly after the war in 1945. Beginning from 1950 a high number of students were enroled. Although many of them dropped out, diplomas in meteorology could be conferred upon altogether 113 young men and women between 1954 and 1957. In the field of education the success is unquestionable. Although the numbers of enrolments had to be reduced later, the quality of the education steadily improved, which fact is demonstrated again and again by the successes of young Hungarian meteorologists abroad.

International co-operation was another major focus. When it came to defend professional positions against narrow-minded political considerations, international requirements and standards offered the obvious argument. This has become particularly important after the Hungarian revolution in 1956, from which the lesson was learned that the West would not help, Hungarians must manage the situation and find the ways to make the best of it.

In 1968 the institute was transferred under the supervision of the National Council for Technical Development. The leadership of that organization was in the good hands of clear thinking technocrats. From that time onwards, through several years, the meteorological institute received a support unprecedented in its history.

The institute was transformed to become the Hungarian Meteorological Service (HMS) with three decentralized institutes belonging to it. A meteorological computer center (based on a Hungarian made EMG-830 processor) was established in 1970 and an IBM-System-7 telecommunication center in 1976. A number of specialized observatories were built and the scope of meteorological services was vastly expanded. One feature of this development was that in the spirit of the 'new economic mechanism' (an attempt to mix planned economy with some elements of market economy) commercial meteorological services were introduced. The development in this area was much faster than expected and around 1986 almost 60 per cent of the total financial support of the HMS came from extrabudgetary sources. This has become soon a major cause of concern.

Crisis and change (years after 1988)

In April 1988 the HMS was transferred to the Ministry of Environment and Water Management. Increasing financial difficulties caused that between 1990 and 1992 some 60 per cent of the staff had to be dismissed. There was also a need for a re-structuring in order to transform the Service into a western type public organization. In this new structure a separate 'commercial division' was created, which now has to finance itself from its own income. Having done all this streamlining, the HMS has left behind — we all hope — the inevitable phase of 'creative destruction'.

The most positive aspect of all recent changes is the very substantial and rapid technical development that has been accomplished since 1991. The HMS now has a highly advanced telecommunication system and an ETHERNET computer network within its own premises, consisting of 11 servers and more than 250 workstations. This system is connected — through a CISCO 4000 router — to the world-wide INTERNET computer network, to the European Center for Medium-range Weather Forecasting (ECMWF) in Reading, to the Lake Balaton Storm Warning Center at Siófok and to the LACE system in Vienna. Linkages to the Global Telecommunication System of WMO, to the

aeronautical meteorological network (MOTNE) and to a number of users in Hungary and abroad is ensured through a UNIX-based dual NetSys 9700 telecommunication computer. In conclusion it may be stated with absolute certainty that the HMS is fully prepared to join the European systems both regarding its professional staff and its technical facilities.

Optimistic epilogue

The current political key word in Hungary is 'Europe'. Hungarians want to find the way back to the values of the successful/victorius West. The whole country wants to be prepared for joining the European systems as soon as possible. At least the HMS has done its home work.«

G. Major

Festive session of Meteorological Department Eötvös Loránd University, Budapest, Hungary

A special session was held at Eötvös Loránd University on 3 May 1995, on the occasion of the 50th anniversary of the foundation of the Meteorological Department.

Meteorologists and non-meteorologists, representatives of Eötvös Loránd University, Hungarian Academy of Sciences, Department of Climatology József Attila University (Szeged, Hungary), Department of Meteorology Kossuth Lajos University (Debrecen, Hungary), Debrecen Agricultural University, Hungarian Meteorological Service, Hungarian Meteorological Society, Meteorological Service of Hungarian Army, Department of Civil Engineering Nebraska-Lincoln University (U.S.A.), Meteorological and Geophysical Department Zagreb, University Croatia were present.

Festal address was delivered by *Prof. Ferenc Rákóczi*, head of the celebrating department, with the title of 'Past creating future'. A summary of the address is given below. The idea of the establishment of the Meteorological Department arose far before its realisation. The first meteorological lectures related to geography were given by *Lajos Lóczy, Radó Kövesligety, Géza Czirbusz, Jenő Klupáthy* at around 1920 , however no independent meteorological department was created at the time. Some 20 years passed, when finally a decision was made and published in the Hungarian Bulletin, on 11 November 1945, stating that 'by approval of Council of Ministers *Dr. József Száva-Kovács*, university professor is appointed to the Department of Atmosphere and Climatology, Philosophical Faculty of Pázmány

Péter University'. On 16 May 1949 the university was reorganised and the Meteorological Department became part of the newly created Faculty of Natural Sciences. Education of meteorologists started only in 1950. The staff of the first Meteorological Department were as follows: *József Szava-Kovács, Zoltán Dobosi, Zoltánné Dobosi, István Dvorcsák, Tamás Révész*. Some years later *László Erdős* and *László Felméry* joined and a curriculum was elaborated, some elements of which are still used in the present education. The period of training of meteorologists was 4 years.

From 1953 until 1972 *Frigyes Dési* was the head of department. In 1957 the education period was extended to 5 years, which is still valid. The education system was changed: no 'independent' meteorologists were educated, but undergraduates studying on the faculty of mathematics, physics and geography could join the meteorological training and finally receive a double diploma. From 1980/81 the earlier system was restored, with some modifications of curriculum. Only one diploma, i.e. that of 'meteorologist' was released, however new subjects such as numerical forecasting, satellite meteorology, environmental protection, computer technics were introduced. The high level of education was admitted by WMO, as well. Between 1972 and 1983 Zoltán Dobosi led the department. In 1983 *Ferenc Rákóczi* was appointed to the leading post. From 1993 another new system of education was introduced: postgraduate course was organised, the educational period for achieving Ph.D. degree is 3 years.

Beside their educational activity, the staff of the department carry out scientific research in various fields, such as dynamical meteorology, climatology, agrometeorology, information theory, planetary boundary layer, meteorological application of statistical meteorology. Researches related to topical problems such as theory of forecast, climate change and environmental protection are also being made.

The Meteorological Department has widespread internal and international connections. It has close relation with the Hungarian Meteorological Service and also with the Meteorological Service of Hungarian Army, for which several courses are organised. International relations are also fruitful with Meteorological Departments of various universities. Close co-operation exists with the universities of St. Petersburg, Zagreb, Wien, Sofia, Padova, Berlin, München, Bratislava, Nebraska and Seattle.

In conclusion *Ferenc Rákóczi* expressed his conviction that the Meteorological Department of Eötvös Loránd University would form young meteorologists of high knowledge in the future as well.

At the end of the celebration participants greeted the department. The festive mood was enhanced by Orchestra of Eötvös Loránd University performing a splendid musical composition of Handel.

Zs. Iványi

ATMOSPHERIC ENVIRONMENT

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To promote the distribution of Atmospheric Environment *Időjárás* publishes regularly the *contents* of this important journal. For further information the interested reader is asked to contact *Dr. P. Brimblecombe,* School for Environmental Sciences, University of East Anglia, Norwich NR 7TJ, U.K.

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