Hrvatski meteorološki časopis, 33/34, 39–51, 1998/99.

UDK: 551.586
551.588.6
Izvorni znanstveni rad

MODELLING OF CLIMATIC VARIABLES AS PART OF A DENDROECOLOGICAL STUDY IN THE REPAŠ FOREST, PREKODRAVLJE, CROATIA

Modeliranje klimatskih varijabli kao dio dendroekološke studije u šumi Repaš, Prekodravlje, Hrvatska

[1]OLEG ANTONIĆ, [2]ANTUN MARKI and [3]DALIBOR HATIĆ

[1]Ruđer Bošković Institute
P.O. Box 1016, 10001 Zagreb, Croatia

[2]Andrija Mohorovičić Geophysical Institute, Faculty of Science, University of Zagreb,
Horvatovac bb, 10000 Zagreb, Croatia

[3]Oikon Ltd.
Vlade Prekrata 20, 10000 Zagreb, Croatia

Primljeno 20. rujna 1999, u konačnom obliku 15. studenog 1999.

Abstract: In this paper the preparation of climatic data for the purpose of a dendroecological study in the Repaš forest (Prekodravlje, Croatia) near Đurđevac is presented. The study was part of the research work done for future hydroelectric power plant ´Novo Virje´ on the river Drava. As the necessary climatic indicators were not measured in the Repaš forest, data from the nearest Đurđevac meteorological station for the period 1960–1997 were used (air temperature and precipitation were directly measured, and potential evapotranspiration and solar irradiation were modelled). These data were extrapolated backward to the year 1899 by the method of general linear modelling and using the secular data series of the Zagreb-Grič and Osijek meteorological stations. Additionally, the precipitation data were corrected on the basis of data (1987–1991) from the Gola station, which is the nearest to the Repaš forest. A dendroecological analysis of the correlation between the radial increment of a selected pedunculate oak tree in the Repaš forest and the described climatic variables is presented, using multiple linear regression. The climatic variables significantly influenced the radial increment of the observed tree (correlation coefficient 0.664) in the period 1899–1997.

Key words: air temperature, solar irradiation, potential evapotranspiration, precipitation, dendrochronology, general linear modelling, pedunculate oak

Sažetak: U ovom je radu prikazana priprema klimatskih podataka za potrebe dendroekološke studije u šumi Repaš (Prekodravlje, Hrvatska) nedaleko od Đurđevca. Studija je provedena u sklopu istražnih radova za hidroelektranu „Novo Virje" na rijeci Dravi. S obzirom na to da se u šumi Repaš neophodni klimatski pokazatelji ne mjere, korišteni su podaci s najbliže meteorološke postaje Đurđevac u razdoblju 1960–1997. (temperatura zraka i oborina mjerene su izravno, a potencijalna evapotranspiracija i dozračena sunčana energija modelirane su). Ti su podaci metodom općeg linearnog modeliranja i uporabom sekularnih podataka s postaja Zagreb-Grič i Osijek ekstrapolirani do godine 1899. Podaci za oborinu još su korigirani na temelju podataka (1987–1991) s kišomjerne postaje Gola, koja je najbliža šumi Repaš. Prikazana je dendroekološka analiza odnosa radijalnog prirasta odabranog stabla hrasta lužnjaka iz šume Repaš i opisanih klimatskih pokazatelja uz korištenje višestruke linearne regresije. Klimatske su varijable znatno utjecale na radijalni prirast promatranog stabla (regresijski koeficijent 0.664) u razdoblju 1899–1997. godine.

Ključne riječi: temperatura zraka, dozračena sunčana energija, potencijalna evapotranspiracija, oborina, dendrokronologija, generalno linearno modeliranje, hrast lužnjak

1. INTRODUCTION

The Repaš forest (latitude 46.104–46.182°N, longitude 17.060–17.189°E), one of the last flood-plain forests in the valley of the Drava River, was the research area for a dendroecological study. The study was done to describe the spatial and temporal variability of the radial increment of the dominant tree species (pedunculate oak – *Quercus robur* L., narrow-leaved ash – *Fraxinus angustifolia* Vahl. and sticky alder – *Alnus glutinosa* (L.) Gaertn.) as a function of groundwater level regime. This was a supporting study to the environmental impact assessment for the future hydroelectric power plant 'Novo Virje', which could cause changes in the groundwater level regime in the Repaš forest. These changes could result in the decline of forest ecosystems. The most endangered species is the pedunculate oak, which is very sensitive to groundwater level regime disturbance (e.g. Pranjić and Lukić, 1989; Prpić *et al.*, 1994).

The climatic variables which influence tree growth had to be included in the dendroecological study as independent estimators. These climatic variables are: air temperature, precipitation, solar irradiation and evapotranspiration. Air temperature and solar irradiation influence photosynthesis (e.g. Denfer and Ziegler, 1988; Penzar and Penzar, 1989). Precipitation and evapotranspiration are elements of the water regime (Vidaček *et al.*, 1993; Sraka, 1996).

Two basic problems had to be solved in the implementation of the climatic variables in the mentioned dendroecological study: 1) calculation of the variables which are not measured directly at a meteorological station (evapotranspiration and solar irradiation) from available data and 2) extrapolation of the measured and derived climatic variables for periods without any data, for a more reliable dendroecological analysis. The solution to these problems and an example of the dendroecological analysis are presented in this paper.

2. MATERIAL AND METHODS

The climatic variables used in this study are:

1. monthly mean air temperature (°C)
2. monthly precipitation (mm)
3. monthly mean solar irradiation ($Jcm^{-2}day^{-1}$)
4. monthly potential evapotranspiration (mm)

The Đurđevac basic meteorological station (latitude φ=46.050°N, longitude λ=17.067°E, altitude h=121 m is 11 km from the Repaš forest and it has been working continuously since 1960. Air temperature and precipitation are being measured directly at the station. Solar irradiation and evapotranspiration are not being measured directly and had to be estimated.

The monthly mean solar irradiation ($Jcm^{-2}day^{-1}$) on a horizontal surface on the Earth's surface has been estimated as a function of monthly mean cloudiness (in tenths, measured at the Đurđevac station) and extraterrestrial radiation, using the algorithm developed by Nikolov and Zeller (1992), which follows in short.

The monthly mean solar irradiation on a horizontal surface at the top of the atmosphere (G_0, $Jcm^{-2}day^{-1}$) is given by:

$$G_0 = S_c\ 458.37[1 + 0.033 \cos(360\ J / 365)]\ [\cos\varphi \cos\delta \sin\omega_0 + (\omega_0 / 57.296°) \sin\varphi \sin\delta] \quad (1)$$

where S_c is the solar constant (8.372 $Jcm^{-2}day^{-1}$), J Julian day, φ latitude, δ solar declination and ω_0 sunrise/sunset hour angle (°). Solar irradiation on the Earth's surface is smaller than the extraterrestrial solar irradiation G_0 due to the atmospheric effects of scattering and absorption. These effects can be estimated (in sense of monthly means) as:

$$G_E = G_0\ (n - 0.03259\ C) - m \quad (2)$$

where G_E is the monthly mean solar irradiation on the Earth's surface ($Jcm^{-2}day^{-1}$), C is monthly mean cloudiness (tenths of the sky) and m ($Jcm^{-2}day^{-1}$) and n are empirical parameters given by:

$$m = 4.186\ [32.9835 - 64.884\ (1 - 1.3614\ \cos\varphi)] \qquad (3)$$

$$n = 0.715 - 0.3183\ (1 - 1.3614\ \cos\varphi) \qquad (4)$$

G_E corresponds to solar irradiation at the altitude of 274 m based on empirical data used for the development of the above relations. The monthly mean solar irradiation for any particular location of interest G_Z ($Jcm^{-2}day^{-1}$) can be calculated from:

$$G_Z = G_E + (G_0 + 4.186 - G_E)\ [1 - \exp\{(-0.014 / \sin\alpha_m)\ (Z - 274) / 274\}] \qquad (5)$$

where Z is altitude (m) and α_m monthly mean solar elevation (°).

Topographic influence on solar irradiation (Dubayah and Rich, 1995; Antonić, 1996, 1998) has been neglected here, because the research location is flat (almost horizontal) and the sky is free of any obstructing natural or artificial object (mountains, buildings, etc.).

Potential (referent) evapotranspiration represents the amount of water, which is lost by the combined processes of evaporation and transpiration from a surface at optimal soil water supply conditions (the consumption is fully covered by water reserves). Potential evapotranspiration depends exclusively on climatic factors. Real evapotranspiration, which is smaller or almost equal to potential evapotranspiration, depends on both climatic factors and on available water reserves in the soil.

Potential evapotranspiration was estimated according to the model developed by Priestley and Taylor (1972, see Bonan, 1989 as well). Assuming that soil heat, averaged over several days, is constant and net solar irradiation (after the exclusion of the reflected radiation component) is proportional with solar irradiation, the original Priestley-Taylor equation can be approximated (Campbell, 1977) by:

$$E_p = 4.186\ a\ (T_a + b)\ R \qquad (6)$$

where E_p is the monthly mean energy expended on potential evapotranspiration ($Jcm^{-2}day^{-1}$), T_a the monthly mean air temperature at the Đurđevac station, R the monthly mean solar irradiation calculated by equation (5) ($Jcm^{-2}day^{-1}$), a and b are empirically derived constants for the location of the calculation. Constants a and b can be calculated as (Jensen and Haise, 1963; Jensen, 1973):

$$a = [38 - (2\ Z / 305) + 380 / / (e_2 - e_1)] - 1 \qquad (7)$$

$$b = 2.5 + 0.14\ (e_2 - e_1) + Z / 550 \qquad (8)$$

where Z is altitude (m), e_2 and e_1 are water vapour pressures (Pa) at the monthly mean daily maximum and minimum air temperatures of the warmest month of the year, respectively, at the Đurđevac station. Finally, the energy for potential evapotranspiration E_p has been recalculated into monthly water amounts (mm) by dividing it by the latent heat of evaporation and multiplying it by the number of days in a month.

The monthly values of all four mentioned climatic variables have been known for the Đurđevac station since the year 1960. Extrapolation models for the earlier period are derived from the Đurđevac station data and from analogous data from the Zagreb-Grič (φ=45.817°N, λ=15.992°E, h=157 m, data from 1862) and Osijek meteorological stations (φ=45.517°N, λ=18.717°E, h=89 m, data from 1899). Both stations are in a relatively similar climate characteristic of continental Croatia (Penzar, 1976). Air temperature maxima on both stations occur in July, and minima in January. Precipitation regimes in the vegetation period are similar (with maxima in June), but Osijek receives an annual average of approximately 30% less precipitation than Zagreb-Grič (693 mm vs. 907 mm). Solar irradiation amounts (with maxima in July) are also very similar. According to Köppen's classification, both stations are marked *Cfwbx*, i.e. they belong to moderately warm, rainy climate, without markedly dry periods, with most precipitation during the warm period. This type of climate is better known as beech-tree forest climate.

The method of general linear modelling (Ott, 1993) has been used for the development of the extrapolation models. The tested regression function was:

$$CV_{ĐU} = b_0 + b_1\, CV_{ZG} + b_2\, CV_{OS} + \\ + b_3\, CV_{ZG}\, CV_{OS} \qquad (9)$$

where $CV_{ĐU}$ is a dependent climatic variable (monthly mean air temperature – *MMAT*, monthly mean solar irradiation – *MMSI*, monthly precipitation – *MP* or monthly potential evapotranspiration – *MPE*) from the Đurđevac station, CV_{ZG} is the related climatic variable from the Zagreb-Grič station, CV_{OS} is the related climatic variable from the Osijek station, $CV_{ZG}CV_{OS}$ is the interaction variable and b_i (i = 0, 1, 2, 3) are empirical parameters. The final regression function includes only these linear estimators, where parameter b_i has a significant value according to the t-test, (Ott, 1993). Differences from month to month in the residuals around the regression models have been tested by the analysis of variance (Ott, 1993).

The monthly mean air temperature, monthly mean solar irradiation and monthly potential evapotranspiration related to the Đurđevac station are the nearest available data to the Repaš forest. Monthly precipitation data, measured by the rainfall gauge at the village of Gola (φ=46.197°N, λ=17.060°E, h=118 m) in the neighbourhood of the Repaš forest, are available for the five-year period 1987–1991. These data have been used for the development of a model of the correction of monthly precipitation data at Đurđevac station. The regression function was:

$$PR_{GO} = k_0 + k_1\, PR_{ĐU} \qquad (10)$$

where PR_{GO} is monthly precipitation at Gola, $PR_{ĐU}$ is monthly precipitation at Đurđevac, k_0 and k_1 are empirical parameters.

3. RESULTS AND DISCUSSION

The regression parameters and statistics of the models given by equation (9) are shown in table 1. Both stations (Zagreb and Osijek) significantly contribute to the Đurđevac model values for all four climatic variables. It means that these models can be used to extrapolate the values of observed climatic variables at Đurđevac in the period between 1899

Table 1. Models of estimation of climatic parameters at the Đurđevac meteorological station using the climatic parameters from the Zagreb-Grič and Osijek meteorological stations. *MMAT* – monthly mean air temperature, *MP* – montly precipitation, *MMSI* – monthly mean solar irradiation, *MPE* – monthly potential evapotranspiration. *N* – number of cases, *R* – regression coefficient, *F* – ratio between regression mean square and residual mean square, *p(F)* – probability of *F*, b_i – empirical parameter following equation (9), t–b_i – value of t-statistics for the parameter b_i, $p(t)$–b_i – probability of t–b_i (t-test used to test the hypothesis that b_i is equal to zero).

Tablica 1. Modeli za procjenu klimatskih parametara na meteorološkoj postaji Đurđevac pomoću klimatskih parametara na meteorološkim postajama Zagreb-Grič i Osijek. *MMAT* – mjesečni srednjak temeprature zraka, *MP* – mjesečna oborina, *MMSI* – mjesečna dozračena sunčana energija, *MPE* – mjesečna potencijalna evapotranspiracija, *N* – broj slučajeva, *R* – regresijski koeficijent, *F* – omjer varijance objašnjene regresijom i varijance ostatka, *p(F)* – vjerojatnost od *F*, b_i – empirijski parametar prema jednadžbi (9), t–b_i – vrijednost t-statistike za parametar b_i, $p(t)$–b_i – vjerojatnost za t–b_i (t-test je upotrijebljen za testiranje hipoteze da je b_i jednak nuli).

Variable	*N*	*R*	*F*	*p(F)*	b_0	b_1	b_2	b_3
MMAT	427	0.998	56882	0.000	–1.06875	0.45317	0.52217	–
MP	427	0.868	430.98	0.000	7.17791	0.50781	0.32091	0.00136
MMSI	426	0.996	19545	0.000	–30.70337	0.20706	0.84404	–0.00002
MPE	426	0.997	37754	0.000	–0.50286	0.22114	0.73417	–

Variable	t–b_0	$p(t)$–b_0	t–b_1	$p(t)$–b_1	t–b_2	$p(t)$–b_2	t–b_3	$p(t)$–b_3
MMAT	–16.68	0.000	13.40	0.000	16.58	0.000	–	–
MP	2.22	0.027	12.06	0.000	5.31	0.000	2.72	0.007
MMSI	–2.71	0.007	7.15	0.000	32.49	0.000	–2.41	0.016
MPE	–1.99	0.047	8.81	0.000	32.75	0.000	–	–

(beginning of measurements at the Osijek station) and 1960 (beginning of measurements at the Đurđevac station). Interaction variables are significant only for the monthly mean solar irradiation and monthly precipitation.

Table 2. Testing the significance of the differences between months in the residuals around regression models using ANOVA. *MMAT* – monthly mean air temperature, *MP* – monthly precipitation, *MMSI* – monthly mean solar irradiation, *MPE* – monthly potential evapotranspiration. *N* – number of cases, *F* – ratio between variance between months and variance within months, *p(F)* – probability of *F*.

Tablica 2. Testiranje signifikantnosti razlika između mjeseci u rezidualima oko regresijskih modela korištenjem ANOVA-e. *MMAT* – mjesečni srednjak temeprature zraka, *MP* – mjesečna oborina, *MMSI* – mjesečna dozračena sunčana energija, *MPE* – mjesečna potencijalna evapotranspiracija, *N* – broj slučajeva, *F* – omjer varijance objašnjene regresijom i varijance ostatka, *p(F)* – vjerojatnost *F*.

Variable	*N*	*F*	*p(F)*
MMAT	427	7.152	0.000
MP	427	1.842	0.045
MMSI	426	3.740	0.000
MPE	426	2.405	0.007

The analysis of variance (ANOVA) shows that the differences from month to month in the residuals around regression models are significant for all climatic variables (Tab. 2). Table 3 shows the mean residuals for each month.

We accepted 5% of the monthly average as the level of tolerance for the monthly mean residual during the vegetation period (from April to October). In this case it was possible to ignore the differences from month to month in the residuals around regression models for the monthly mean air temperature, monthly mean solar irradiation and monthly potential evapotranspiration. The regression model for monthly precipitation had to be corrected for each month by the absolute values of the monthly mean residual.

The relations between the modelled and observed values for the monthly mean air temperature and monthly precipitation are shown on figures 1 and 2. Since monthly mean solar irradiation and monthly potential evapotranspiration are not being measured at Đurđevac, the relations between the modelled values obtained by general linear model (GLM – equation 9) and the Nikolov and Zeller model and by Campbell's equation (6) are shown as scatterplots on figures 3 and 4, respectively. Figure 5 shows the comparison

Table 3. Monthly mean residuals around regression models exposed as absolute values and values according to the respective monthly average (%). *MMAT* – monthly mean air temperature, *MP* – monthly precipitation, *MMSI* – monthly mean solar irradiation, *MPE* – monthly potential evapotranspiration.

Tablica 3. Srednji mjesečni reziduali oko regresijskih modela prikazani kao apsolutne vrijednosti i relativne vrijednosti prema odgovarajućem mjesečnom prosjeku (%). *MMAT* – mjesečni srednjak temeprature zraka, *MP* – mjesečna oborina, *MMSI* – mjesečna dozračena sunčana energija, *MPE* – mjesečna potencijalna evapotranspiracija.

Month	*MMAT*		*MP*		*MMSI*		*MPE*	
	(°C)	(%)	(mm)	(%)	($Jcm^{-2}day^{-1}$)	(%)	(mm)	(%)
January	0.067	5.904	–2.570	5.206	7.822	1.975	0.303	7.626
February	–0.048	4.215	1.907	3.952	–2.913	0.414	–0.019	0.196
March	–0.144	2.670	–0.593	1.105	2.355	0.209	–0.148	0.542
April	–0.180	1.784	1.228	1.929	19.415	1.219	–0.045	0.085
May	0.025	0.169	0.144	0.195	35.323	1.773	1.142	1.264
June	0.360	1.968	–9.264	10.581	3.559	0.167	1.401	1.291
July	0.046	0.232	2.426	2.911	1.653	0.075	0.272	0.219
August	–0.084	0.442	–2.545	3.194	–15.661	0.800	–0.608	0.571
September	–0.184	1.213	–3.071	4.466	–26.704	1.825	–1.319	2.035
October	–0.275	2.778	–2.550	3.860	–29.364	3.104	–1.436	4.459
November	0.172	3.502	9.787	10.897	–2.792	0.569	0.178	1.619
December	0.249	37.700	5.435	8.042	7.746	2.404	0.292	6.519

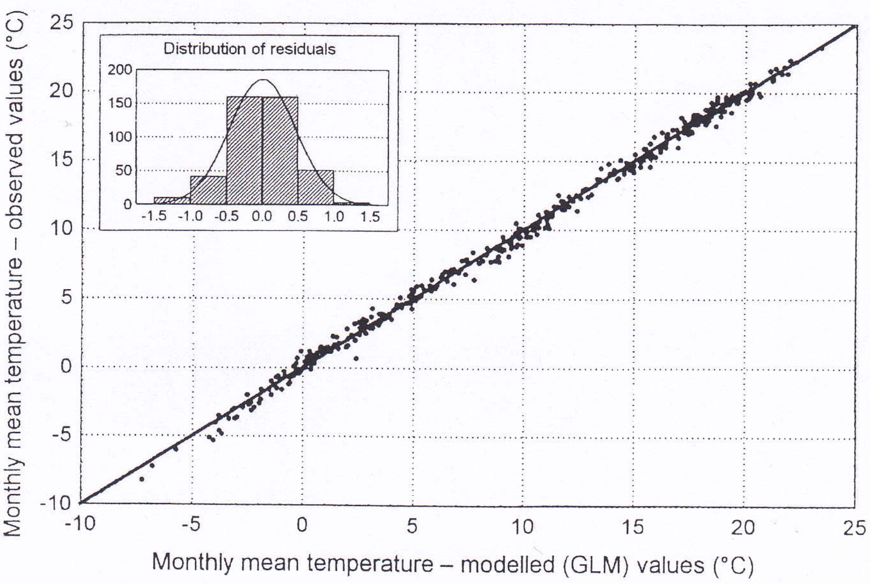

Figure 1. Relation between modelled (general linear model, GLM) and observed values of monthly mean air temperature for Đurđevac (1960–1997).

Slika 1. Odnos između modeliranih (opći linearni model, GLM) i opaženih vrijednosti srednje mjesečne temperature zraka za Đurđevac u razdoblju 1960–1997.

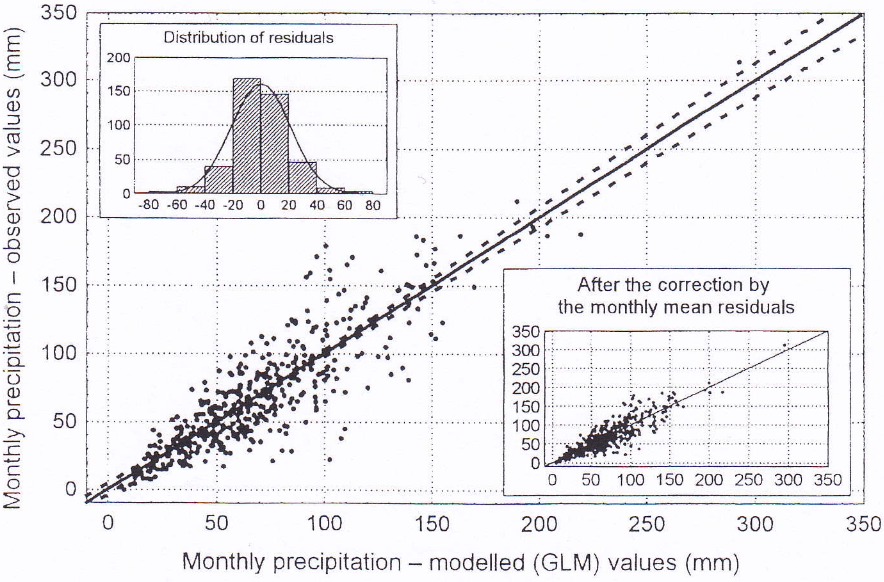

Figure 2. Relation between modelled (GLM) and observed values of monthly precipitation for Đurđevac (1960–1997) before and after (smaller frame right and down) the correction by the monthly mean residuals and localisation.

Slika 2. Odnos između modeliranih (opći linearni model, GLM) i opaženih vrijednosti mjesečne oborine za Đurđevac u razdoblju 1960–1997. prije i poslije (manja slika desno dolje) korekcije srednjim mjesečnim odstupanjima i lokalizacije.

between the time series of the modelled and observed values of monthly precipitation for the period 1960–1997. This has been omitted for the other variables because the differences between time series of the modelled and observed values are negligible.

The correlation between precipitation at Gola and precipitation at Đurđevac is very high (Tab. 4 and Fig. 6). ANOVA shows that the differences between months in the residuals around regression model following equation (10) are insignificant (Tab. 4). According to

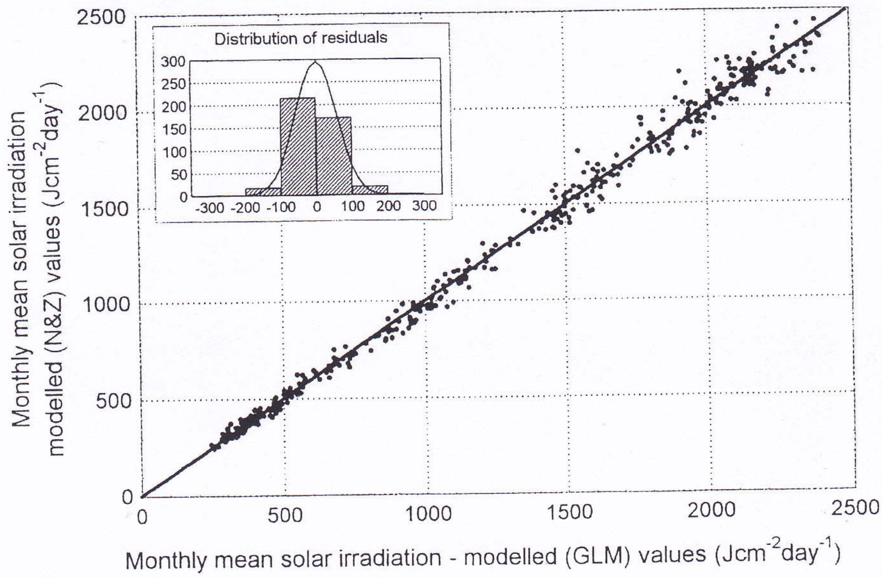

Figure 3. Relation between the values of monthly mean solar irradiation for Đurđevac (1960–1997) obtained by a general linear model (GLM) and the Nikolov and Zeller (1992) model.

Slika 3. Odnos između vrijednosti dozračene sunčane energije za Đurđevac u razdoblju 1960–1997. dobivenih općim linearnim modelom (GLM) i modelom Nikolova i Zellera (1992).

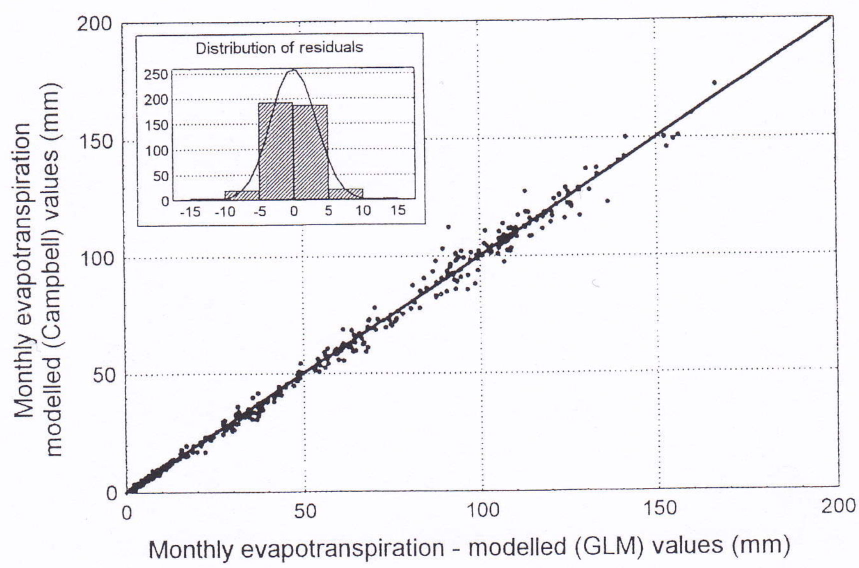

Figure 4. Relation between the values of monthly potential evapotranspiration for Đurđevac (1960–1997) obtained by a general linear model (GLM) and by Campbell's equation (6).

Slika 4. Odnos između vrijednosti mjesečne potencijalne evapotranspiracije za Đurđevac u razdoblju 1960–1997. dobivenih općim linearnim modelom (GLM) i Campbellovom jednadžbom (6).

the t-test (Ott, 1993), parameter k_1 is significantly lower than one ($t = -4.78$, $p(t) < 0.001$) which means that monthly precipitation at Gola is significantly lower than precipitation at Đurđevac for the same month. This result can be explained by the impact of the ridge of the Bilogora Mountain near Đurđevac. Bilogora is a dominant barrier in this area for the cyclones from the west and northwest (Pandžić, 1989). Therefore, the monthly precipitation amount based on the model described above (Tab. 1 and Fig. 5) had to be estimated for the particular research area (Repaš forest) using equation (10) and empirical parameters (k_0 and k_1) from table 4.

It is assumed that the differences in monthly

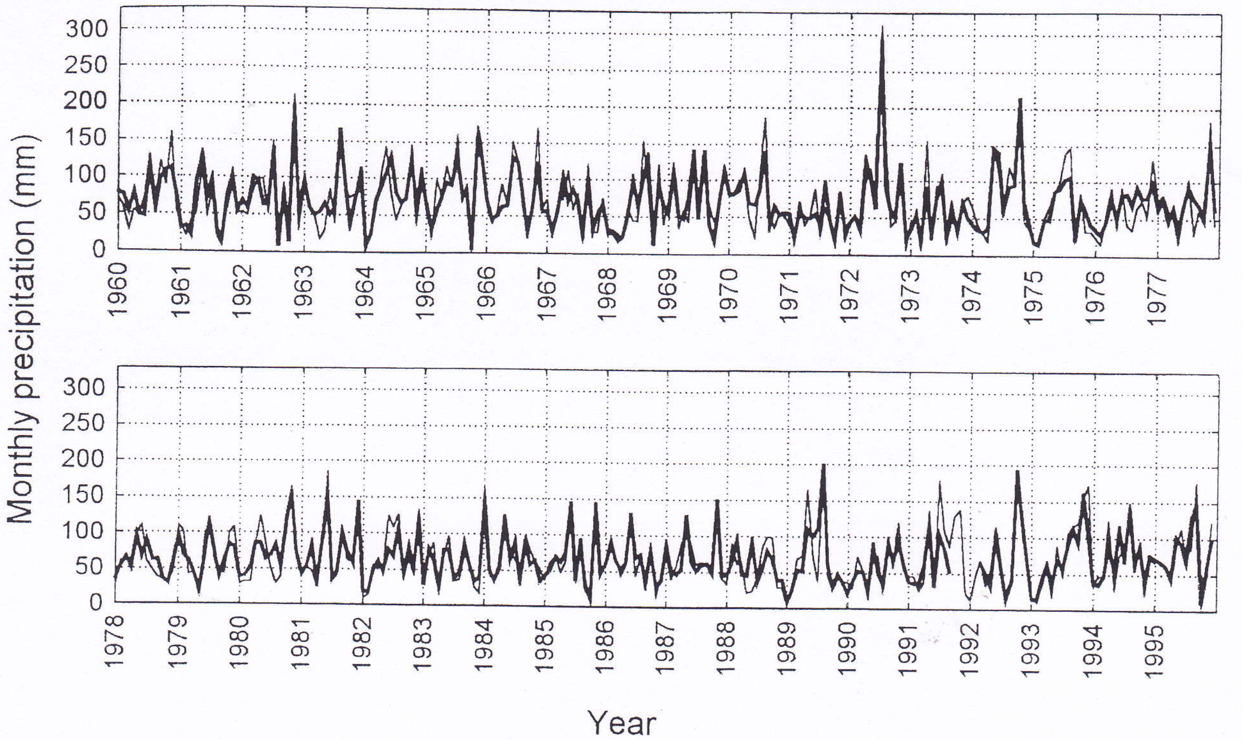

Figure 5. Relation between the time series of modelled (bright line) and observed (dark line) values of monthly precipitation at Đurđevac.

Slika 5. Odnos vremenskih nizova modeliranih (svijetla puna linija) i opaženih (tamna puna linija) vrijednosti mjesečne oborine u Đurđevcu.

Table 4. Model for the estimation of precipitation at the rainfall gauge at Gola as a function of precipitation at the Đurđevac station. N – number of cases, R – correlation coefficient, F – ratio between regression mean square and residual mean square, $p(F)$ – probability of F, k_i – empirical parameter following equation (10), t-k_i – value of t-statistics for parameter k_i, $p(t)$-k_i – probability of t-k_i (t-test used to test the hypothesis that k_i is equal to zero), F_m – ratio between variance between months and variance within months, $p(F_m)$ – probability of F_m. F_m and $p(F_m)$ are results of ANOVA.

Tablica 4. Model za procjenu oborine na kišomjernoj stanici Gola u funkciji oborine na meteorološkoj stanici Đurđevac. N – broj slučajeva, R – koeficijent korelacije, F – omjer varijance objašnjene regresijom i varijance ostatka, $p(F)$ – vjerojatnost od F, k_i – empirijski parametar prema jednadžbi 10), t-k_i – vrijednost t-statistike za parametar k_i, $p(t)$-b_i – vjerojatnost od t-b_i (t-test je upotrijebljen za testiranje hipoteze da je k_i jednak nuli), F_m – omjer varijance objašnjene regresijom i varijance ostatka, $p(F_m)$ – vjerojatnost F_m. F_m i $p(F_m)$ jesu rezultati ANOVA-e.

N	R	F	$p(F)$	k_0	k_1	t-k_0	$p(t)$-k_0	t-k_1	$p(t)$-k_1	F_m	$p(F_m)$
60	0.933	392.98	0.000	7.62513	0.80567	2.38	0.021	19.82	0.000	1.20	0.312

mean air temperature, monthly mean solar irradiation and monthly potential evapotranspiration between Đurđevac and the area of the Repaš forest can be ignored as insignificant.

Figure 7 shows the final time series (from 1899 to 1997) of the monthly mean air temperature and monthly mean solar irradiation used for the dendroecological analysis. These time series comprise modelled values (following equation 9) until the year 1959 and values measured at the Đurđevac station from 1960 to 1997. Figure 8 shows the same, only for monthly precipitation (corrected by the monthly mean residuals and localised) and monthly potential evapotranspiration. The

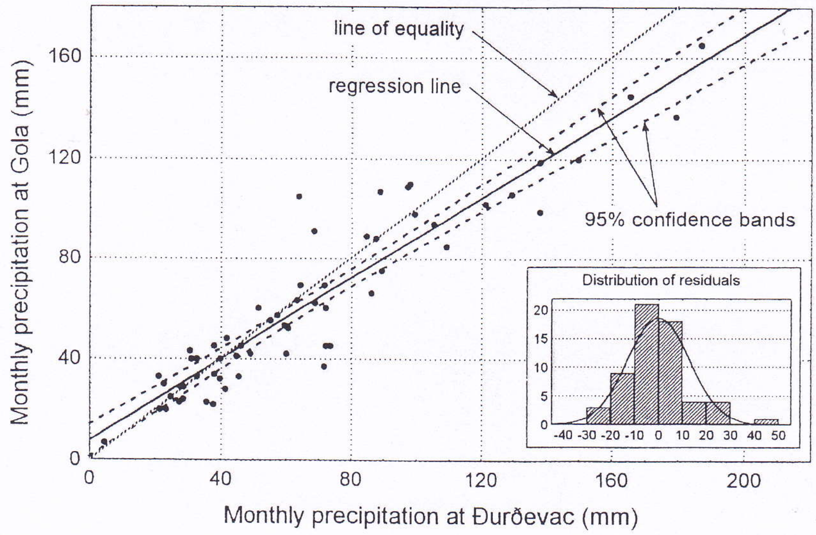

Figure 6. Relation between monthly precipitation at Đurđevac and Gola (1987–1991).

Slika 6. Odnos mjesečne oborine u Đurđevcu i Goli u razdoblju 1987–1991.

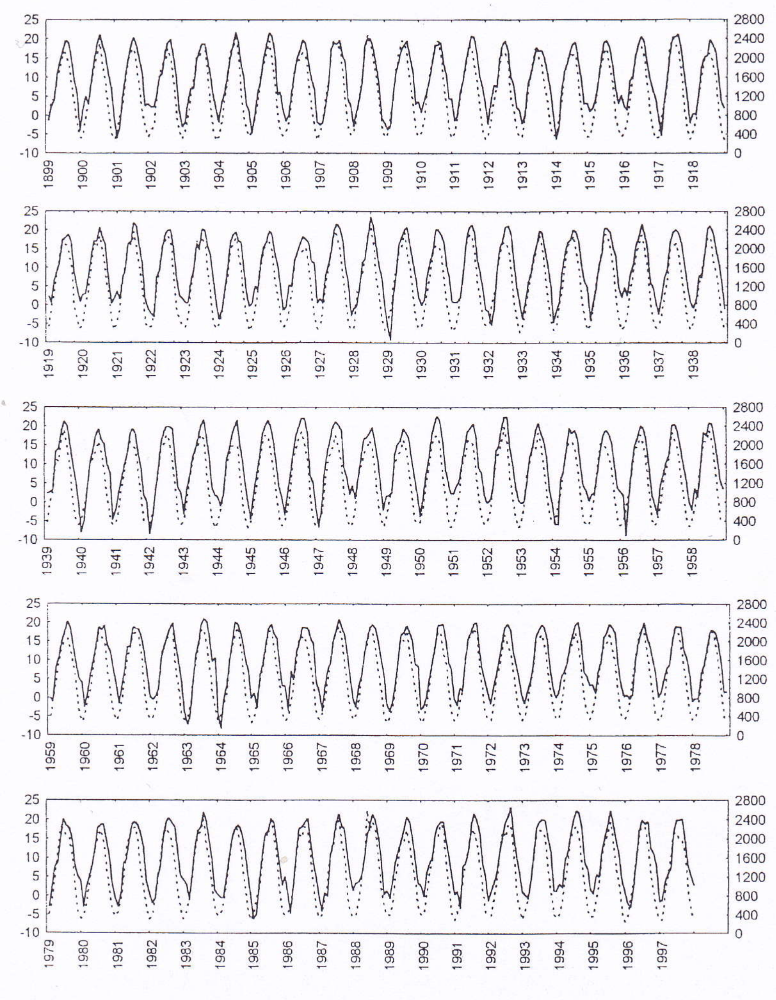

Figure 7. Monthly mean values of air temperature (°C, left ordinate, solid line) and solar irradiation ($Jcm^{-2}day^{-1}$, right ordinate, dotted line) for the area of the Repaš forest (1899–1997).

Slika 7. Prosječne mjesečne vrijednosti temeprature zraka (°C, lijeva ordinata, puna linija) i dozračene sunčane energije ($Jcm^{-2}dan^{-1}$, desna ordinata, točkasta linija) za područje šume Repaš (1899–1997).

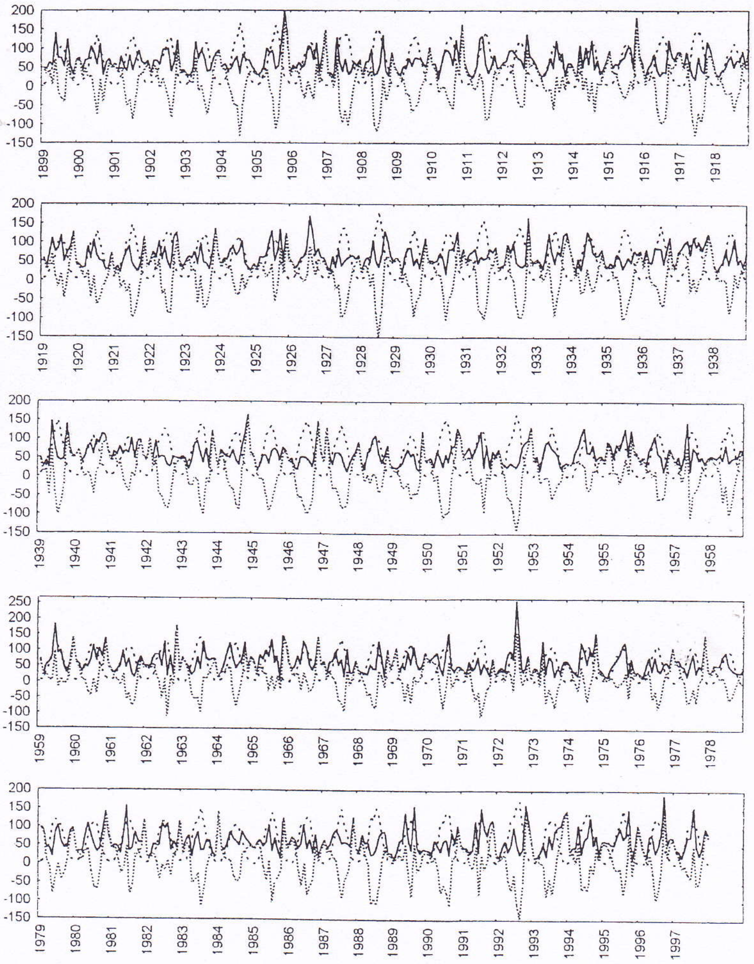

Figure 8. Monthly values (all in milimeters) of precipitation (solid line), potential evapotranspiration (hatched line) and their difference (dotted line) for the area of the Repaš forest (1899–1997).

Slika 8. Mjesečne vrijednosti oborine (puna linija), potencijalne evapotranspiracije (crtkana linija) i njihove razlike (točkasta linija), sve u milimetrima, za područje šume Repaš u razdoblju 1899–1997.

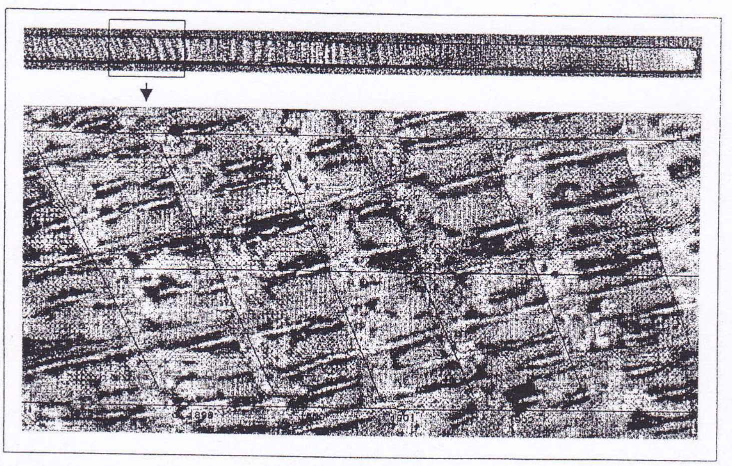

Figure 9. Scannogram of the selected tree core of the pedunculate oak (*Quercus robur* L.): up – entire tree core, down – enlarged part of the tree core in the measurement scale (tree ring tangents and years are superimposed).

Slika 9. Skanogram odabranog izvrtka hrasta lužnjaka (*Quercus robur* L.): gore – cijeli izvrtak, dolje – povećani dio izvrtka u mjerilu izmjere (prikazane su i tangente na god, te godine).

difference between precipitation and evapotranspiration is also included in figure 8 as an indication of the water deficit for the tree species, which has to be compensated by groundwater.

4. DENDROECOLOGICAL EXAMPLE

The tree that was selected as an example of dendroecological analysis is a specimen of the pedunculate oak (*Quercus robur* L.) from the Repaš forest (the tree is coded as REP335 in the Oikon Ltd. dendrochronological database). It is 36.0 m tall with a diameter of 147.6 cm and is over 400 years old. This tree was drilled at standard height from the ground (1.3 m) using a motorised tree corer. The obtained tree core was polished, scanned by a specially calibrated and rectified high-resolution scanner (Fig. 9) and analysed using special dendrochronological software. The analysis included measurements of the tree ring width and tree ring tangent angle (for the correction of the tree ring width due to the tree core eccentricity). The obtained time series of the radial increment was used as a dependent variable.

The monthly values of the four climatic variables were used for the calculation of the average, minimum, maximum and standard deviation of the vegetation period (from April to October) for each year from 1899 to 1997 and for each climatic variable. This resulted in 16 independent variables used for the explanation of the radial increment (ring width) of the selected tree. The year related to the respective tree ring was also included as an independent variable to describe the expected negative trend of the radial increment due to the age of the tree (see e.g. Levaković 1935, 1938). It was assumed that this trend is approximately linear at this point of life of the tree (400 years old).

The tested regression model was:

$$\Delta = c_0 + \Sigma\, c_i\, v_i \qquad (11)$$

where Δ is the radial increment (mm) of the selected tree, v_i is the i-th independent variable and c_0 and c_i are empirical parameters. General linear modelling and a forward stepwise procedure (Ott, 1993) were used for the selection of the independent variables of the final model (Tab. 5). The relation between es-

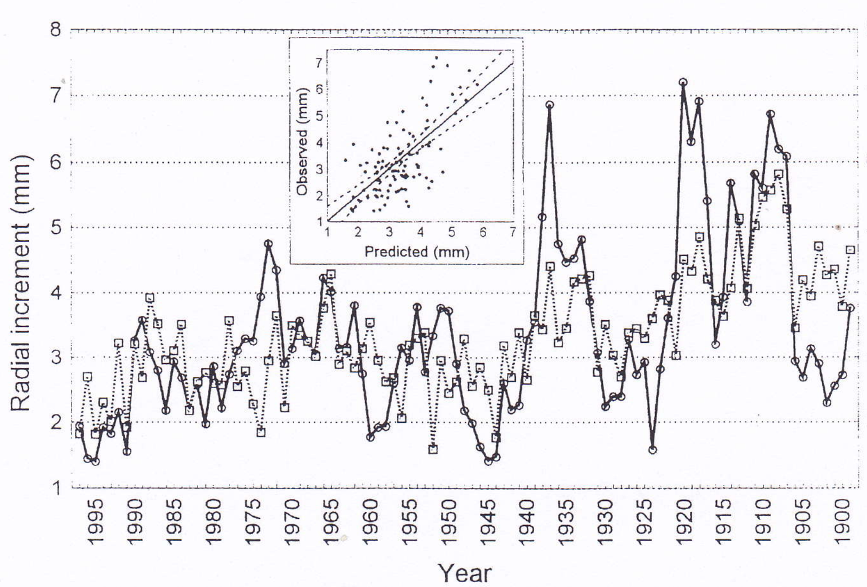

Figure 10. The time series of observed (thin line with circles) and estimated (thick line with squares) values of the radial increment of the selected tree (scatterplot of observed and predicted values shown in the frame).

Slika 10. Vremenski nizovi opaženih (tanka linija s kružićima) i procijenjenih (debela linija s kvadratićima) vrijednostima radijalnog prirasta odabranog stabla (grafički prikaz opaženih i procijenjenih vrijednosti dan je na manjoj slici).

Table 5. Parameters and statistics of the finally selected model of radial increment of the selected tree. The regression coefficient is R = 0.664. The ratio between regression mean square and residual mean square is $F(12, 85)$ = 5.57 with $p(F)$ = 0.000. The parameters are denoted by c_i. *MMAT* – monthly mean air temperature, *MP* – monthly precipitation, *MMSI* – monthly mean solar irradiation, *MPE* – monthly potential evapotranspiration, *AVR* – average, *MIN* – minimum, *MAX* – maximum, *STD* – standard deviation (statistics relates to the vegetation period).

Tablica 5. Parametri i statistika konačno odabranog modela radijalnog prirasta odabranog stabla. Regresijski koeficijent jest R = 0.664. Omjer srednjeg kvadrata regresije i srednjeg kvadrata reziduala $F(12, 85)$ = 5.57 s vjerojatnošću $p(F)$ = 0.000. Parametri su označeni s c_i. *MMAT* – mjesečni srednjak temeprature zraka, *MP* – mjesečna oborina, *MMSI* – mjesečna dozračena sunčana energija, *MPE* – mjesečna potencijalna evapotranspiracija, *AVR* – prosjek, *MIN* – minimum, *MAX* – maksimum, *STD* – standardna devijacija (statistika odgovara vegetacijskom razdoblju).

i	Variable	c_i
0	Intercept	41.74937
1	YEAR	-0.01948
2	MMAT_MAX	-0.16357
3	MMSI_MAX	-0.00155
4	MP_MIN	0.02132
5	MPE_AVR	0.15251
6	MP_MAX	0.00973
7	MMSI_MIN	0.00898
8	MMSI_STD	0.03139
9	MPE_STD	-0.32190
10	MMAT_AVR	-0.62299
11	MMSI_AVR	-0.00782
12	MMAT_STD	0.47898

timated and observed values is presented on figure 10.

It is obvious that climatic variables significantly influenced the radial increment of the selected tree during the examined period (1899–1997). The unexplained variability of the radial increment can be explained by the influence other ecological factors (groundwater level dynamics, hydropedological parameters, pests and disease population dynamics, forest management, see also Antonić *et al.*, 1999).

5. INSTEAD OF A CONCLUSION

The tree ring width can be considered to be the consequence of cumulative ecological conditions during the related vegetation season. Thus, dendrochronological data could be the basis for a number of ecological studies, which can be oriented toward the past. Climatic variables are unavoidable in the dendroecological analysis, due to the importance of climatic influences on tree growth. When a meteorological station is near to the analysed trees, a simple extrapolation based on distant stations could be used for the lengthening of the time series of the relevant climatic variable. The problem that has to be solved in the future is how to ensure reliable climatic data for a sufficiently long period at locations, which are remarkably distant from the nearest meteorological station.

REFERENCES

Antonić, O., 1996: Application of the spatial modelling in the karst bioclimatology. *Croatian Meteorological Journal*, **31**, 95–102.

Antonić, O., 1998: Modelling daily topographic solar radiation without site-specific hourly radiation data. *Ecol. Modelling*, **113**, 31–40.

Antonić, O., D. Hatić, J. Križan i D. Bukovec, 1999: HE Novo Virje: Prihvatljivi režim podzemnih voda sa stajališta održanja šumskih ekosustava. Glavni izvještaj, Oikon, Zagreb, 220 str.

Bonan, G.A., 1989: A computer model of the solar radiation, soil moisture and soil thermal regimes in boreal forests. *Ecol. Modelling*, **45**, 275–306.

Campbell, G.S., 1977: An introduction to environmental biophysics. Springer, New York, 159 str.

Denffer, D. i H. Ziegler, 1988: Botanika: Morfologija i fiziologija. Školska knjiga, Zagreb, 595 str.

Dubayah, R. and P.M. Rich, 1995: Topographic solar radiation models for GIS. *Int. J. Geographical information systems*, **9**, 405–419.

Jensen, M.E., 1973: Consumptive use of water and irrigation water requirements. American society of civil engineers, New York, 215 str.

Jensen, M.E. and H.R. Haise, 1963: Estimating evapotranspiration from solar radiation. *J. Irrig. Drain. Div. Am. Soc. Civ. Eng.*, **89**, 15–41.

Klein, S.A., 1977: Calculation of monthly average insolation on tilted surface. *Solar Energy*, **19**, 325–329.

Leváković, A., 1935: Analitički oblik zakona rastenja. *Glas. šum. pokuse,* **4**, 189–282.

Leváković, A., 1938: Fiziološko-dinamički osnovi funkcija rastenja. *Glas. šum. pokuse,* **6**, 374–389.

Nikolov, N.T. and K.F. Zeller, 1992: A solar radiation algorithm for ecosystem dynamic models. *Ecol. Modelling,* **61**, 149–168.

Ott, R.L., 1993: An introduction to statistical methods and data analysis. Duxbury press, Belmont, 1051 str.

Pandžić, K., 1989: Faktorska analiza lokalnih klimatskih polja unutar globalnog strujanja. *Doktorska disertacija*, Prirodoslovno-matematski fakultet Sveučilišta u Zagrebu, 156 str.

Penzar, B., 1976: Klima makroregionalnih gradova SR Hrvatske. Centralna naselja i gradovi SR Hrvatske, Školska knjiga, Zagreb, 163–191.

Penzar, I. i B. Penzar, 1989: Agroklimatologija. II. izdanje. Školska knjiga, Zagreb, 274 str.

Pranjić, A. i N. Lukić, 1989: Prirast stabala hrasta lužnjaka kao indikator stanišnih promjena. *Glas. šum. pokuse,* **25**, 79–94.

Priestley, C.H.B. and R.J. Taylor, 1972: On the assessment of surface heat flux and evaporation using large-scale parameters. *Mont. Weather Rev.*, **100**, 81–92.

Prpić, B., A. Vranković, Đ. Rauš, S. Matić, A. Pranjić i Š. Meštrović, 1994: Utjecaj ekoloških i gospodarskih činilaca na sušenje hrasta lužnjaka u gospodarskoj jedinici Kalje Šumskog gospodarstva Sisak. *Glas. šum. pokuse,* **30**, 361–420.

Sraka, M., 1996: Lizimetrijsko mjerenje i metode proračuna bilance vode u tlu. *Magistarski rad,* Agronomski fakultet Sveučilišta u Zagrebu, 72 str.

Vidaček, Ž., F. Tomić i D. Romić, 1993: Bilanca vode u tlu. Priručnik za hidrotehničke melioracije – Kolo II, Knjiga 2. Građevinski fakultet, Rijeka, 159–174.