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New trends for reference evapotranspiration and climatic water deficit

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A b s t r a c t. The paper deals with the trend for Penman-Monteith reference evapotranspiration and climatic water deficit during the first decade of the 21st century in Southern Romania *vs* the 20th century. For the first half of the year the monthly evapotranspiration values were higher for the first decade of the 21st century *vs* the means of the 20th century. However, the trend reverses for the second half of the year, but for the whole year the totals were higher for the first decade of the 21st century *vs* the totals of the 20th century. The yearly temperature means in the first decade of the XXI century showed an increase in the three locations studied, respectively, *vs* century XX. This warming is responsible to a great extent for the increase in evapotranspiration, and the relationship between evapotranspiration and temperature was highly significant. Water deficit decreased in Constanta and Pitesti, but there was a slight increase in water deficit in the same period in Bucharest-Baneasa. Water deficit increased in the first half of the year and decreased in the second half during the first decade of century XXI in all the three locations investigated *vs* century XX.

K e y w o r d s: arid conditions, dryland, global warming

INTRODUCTION

Aridity has been defined in various ways, often using factors based on reference evapotranspiration (ET_o) and precipitation (*P*), either as the difference (P- ET_o) giving the climatic water deficit (*WD*), or as the P/ET_o ratio (UNESCO Aridity Index, 1979). All these terms have some value for evaluating water resources of regions and for devising practical measures to control drought by applying irrigation. An increase in aridity is predicted in some areas in some model scenarios evaluating the impact of global changes in Romania (Marica and Busuioc, 2004); they showed that aridity would increase especially during the crop growing season in the southern parts of Romania. In the same context, Paltineanu *et al*. (2007a, b; 2009) among others have reported data on arid or drought-affected areas, including water-crop response and irrigation water requirements (*IWRs*) for various regions of Romania.

However, global warming is only a hypothesis, and the increase in temperature in recent years is controversial. Peterson and Baringer (2009) documented that the global temperature had not risen in the past decade. Between January 1999 to December 2008 the HadCRUT3 dataset showed that the temperature change was +0.07±0.07°C decade^{-1} (Knight *et al*., 2009). HadCRUT3 stands for the ‘Hadley Centre/CRU gridded monthly temperatures dataset’, and CRU stands for ‘Climate Research Unit’. The Hadley Centre is located in Exeter, Devon, UK. Notwithstanding, regionally or locally *ie* in Romania the temperature still increased in the first decade of century XXI (Busuioc *et al*., 2010, Sandu and Mateescu, 2009; Sandu *et al*., 2010). In this context, a possible increase in air temperature due to global warming would influence ET_o (Marica and Busuioc, 2004). However, some authors have predicted that little or no change in ET_o is likely due to increasing temperature (Snyder *et al*., 2010), and this would be caused by increasing air humidity and higher CO_2 concentrations which both tend to reduce transpiration and counteract the higher temperature effects on ET_o.

The purpose of this paper is to show the new trends for reference evapotranspiration and climatic water deficit during the first decade of the 21st century in some areas of Southern Romania.

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MATERIAL AND METHODS

Mean daily, monthly and annual weather statistics were calculated for three weather stations in various relief regions of southern Romania: Pitesti, Bucharest-Baneasa and Constanta. Constanta is representative for the south-eastern part of the country – the Dobrogea Plateau region with most of its territory between 100 and 300 m altitude – whereas Bucharest-Baneasa and Pitesti are representative for the central part of the Romanian Danube Plain (altitude mainly between 60 and 100 m) and the northern part of the same Plain (the High Plain of Pitesti, with an altitude mainly around 300 m), respectively. The southern part of Romania was chosen for this study due to the fact that it is the most arid of this country. The data set used in this paper consisted of mean daily data for temperature and precipitation sum, as well as for other climatic parameters needed in calculating the FAO recommended Penman-Monteith reference evapotranspiration (ET_o) like: sunshine hours, air humidity, as well as wind speed at 10 or 2 m height. Wind speed measured at a height of 10 m was transformed into wind speed values at 2 m height using regressions equations given by Paltineanu *et al*. (1999 and 2000) for these regions. The period of investigation was one decade, mainly from 2000 to 2010, and the data recorded in this period was compared to data obtained in century XX, previously published (Paltineanu *et al*., 2007b). This latter period was not complete *eg* there were 8 years missing for Constanta, 19 years for Pitesti and 6 years for Bucharest, all of them occurring in the first half of century XX; nevertheless the quality of data set was reliable because they were recorded in the national network, and standard quality control methods were applied to the data set used.

The only accurate method to get ET_o is by measurement in weighing lysimeters (Tanner, 1967). More recently, Allen *et al*. (1998) and Jensen *et al*. (1990) documented that the best theoretical model to fit to weighing lysimeter results is the Penman-Monteith model (Monteith, 1965). This latter was used to calculate daily and monthly values of ET_o, and *WD* was calculated with means of monthly sum of precipitation data, by difference:

$$WD = P - ET_o \,, \qquad (1)$$

where: P is the precipitation sum (mm) and ET_o is the Penman-Monteith reference evapotranspiration (mm), which was calculated using the combined equation based on daily data of mean temperature, sunshine duration, air humidity and wind speed at 2-m height:

$$ET_o = (0.408\Delta(Rn - G) + 900\gamma\, U(e_a - e_d)/(T+273))/ (\Delta + \gamma(1+0.34U)) \,, \qquad (2)$$

where: Rn is the net radiation at grass surface (MJ m^{-2} d^{-1}), G is the soil heat flux (MJ m^{-2} d^{-1}), T is average temperature (°C), U is wind speed at 2 m height (m s^{-1}), (e_a-e_d) is vapour pressure deficit (kPa), Δ is slope of the vapour pressure curve (kPa C^{-1}), γ is psychrometric constant (kPa C^{-1}). The other terms needed to calculate ET_o were taken from Allen *et al.* (1998) and Jensen *et al.* (1990).

Relationship between ET_o and temperature (T) data was calculated by help of the least squares method, using regression made by the Microsoft Office Excel (MS Office Excel) program. In order to assess the significance of R (the correlation coefficient or correlation ratio) for both linear and nonlinear regression equations, respectively, the *t*-test was calculated and utilized in comparisons with tabulated values at the desired significance level, using a two-sided *t*-test and (n-2) degrees of freedom (Aïvazian, 1970):

$$t = R\ sqrt\ (n-2)/\ sqrt\ (1-R^2)\,, \qquad (3)$$

where n is the number of points used in the calculation.

SPSS 14.0 for Windows was used to calculate various statistics parameters, while means of ET_o data for the three locations studied were compared by help of test *t*.

RESULTS AND DISCUSSIONS

The probability distribution of ET_o is almost normal, but strongly skewed, for both the growing season and summer time in the three locations investigated (Fig. 1). The mean values ranged between 3.34 and 3.39 mm day^{-1} during the

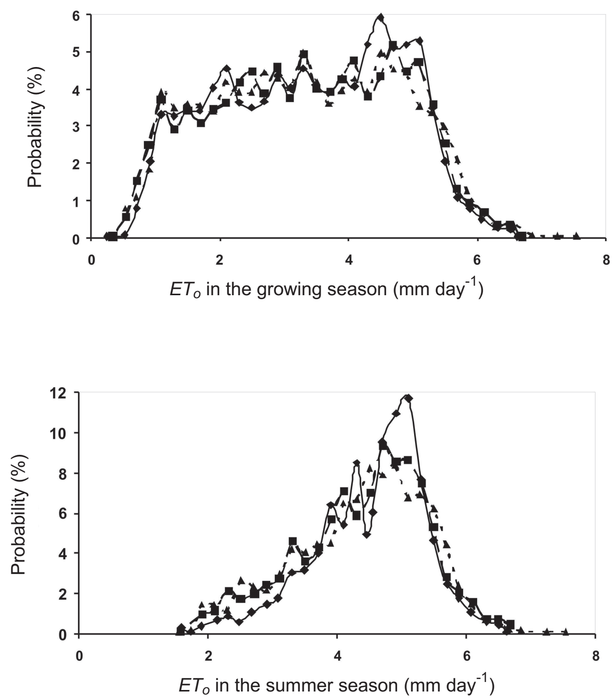

Fig. 1. Probability distribution of Penman-Monteith ET_o during both growing season and summer time for the three locations studied in the southern part of Romania, the first decade of the 21st century; ◆ Constanta, ■ Bucharest-Baneasa, ▲ Pitesti.

growing season and between 4.38 and 4.52 mm day^{-1} in the summer time (Table 1), the highest mean values occurred in Constanta, due to sunshine hours and wind speed alike. Median values were close to the average values, slightly lower for the growing season and slightly higher for the summer time. However, the modal values were considerably higher than the respective means. Test *t* analysis revealed no significant differences between the ET_o means in the case of the growing season in spite of the fact that their altitudes and relief positions are quite different, and highly significant differences between Constanta on the one hand and the other two locations on the other hand in the case of summer time.Skewness and kurtosis are shown in Table 2. Both the standard error of kurtosis and the standard error of skewness were used to check normality (SPSS 14.0). As seen in Table 2, these values ranged between -2 and +2 which justified acceptance of normality for ET_0 distribution.

Monthly distribution of ET_o for the three locations studied and the comparison between the mean values of the first decade of the 21st century and the ones of the 20th century are shown in Fig. 2. For all the three stations studied, for the first half the year it can be noted that the monthly values are higher for the first decade of the 21st century *vs* the means of the 20th century. However, the trend reverses for the second half of the year, but for the whole year the totals are higher for the first decade of the 21st century *vs* the totals of the 20th century (Table 3). Averaged over the year, this shows that the ET_o trend was to increase. Hence, for the first decade of

T a b l e 3. Percentage of the increase in Penman-Monteith ET_o for the first decade of the 21st century *vs* the 20th century, monthly values, annual means, summer means and growing season means, respectively, for the three locations investigated, southern Romania

Month/ Location	Constanta	Bucharest-Baneasa	Pitesti
I	89.8	111.0	109.0
II	112.1	167.5	180.9
III	127.3	185.7	180.8
IV	119.1	131.0	137.5
V	116.7	120.6	126.6
VI	112.3	107.6	117.3
VII	111.0	105.0	116.0
VIII	103.2	101.0	105.8
IX	91.9	84.2	87.0
X	83.3	71.3	79.3
XI	76.5	61.4	72.6
XII	72.2	67.9	69.5
Annual total	105.7	105.7	112.9
Summer	108.9	104.5	113.1
Growing season	106.7	103.9	111.3

T a b l e 1. Statistical values of the probability distribution of ET_o for the three locations studied in the southern part of Romania, the first decade of the 21st century

Weather station	Growing season (mm day^{-1})					Summer time (mm day^{-1})				
	Mean	ST	CV (%)	Median	Mode	Mean	ST	CV (%)	Median	Mode
Constanta	3.39 a	1.38	40.80	3.34	4.45	4.52 a	0.85	18.71	4.55	5.10
Bucharest-Baneasa	3.35 a	1.44	42.93	3.30	4.70	4.39 b	1.00	22.85	4.50	4.70
Pitesti	3.34 a	1.44	43.23	3.30	4.50	4.38 b	1.04	23.85	4.42	4.90

ST – standard deviation, *CV* – coefficient of variation, the same letter – no significant difference, different letters – significant differences at 5% probability.

T a b l e 2. Skewness and kurtosis values of the probability distribution of ET_o for the three locations studied in the southern part of Romania, the first decade of the 21st century

Weather station	Growing season					Summer time				
	SK	*ST-SK*	*KS*	*ST-KS*	*RN*	*SK*	*ST-SK*	*KS*	*ST-KS*	*RN*
Constanta	-0.120	0.051	-1.05	0.102	6.38	-0.67	0.077	0.678	0.154	5.07
Bucharest-Baneasa	-0.055	0.051	-0.98	0.102	6.46	-0.40	0.077	-0.27	0.154	5.23
Pitesti	0.006	0.051	-0.98	0.102	7.10	-0.39	0.077	-0.27	0.154	6.01

SK – skewness, *ST-SK* – standard error of skewness, *KS* – kurtosis, *ST-KS* – standard error of kurtosis, *RN* – range.

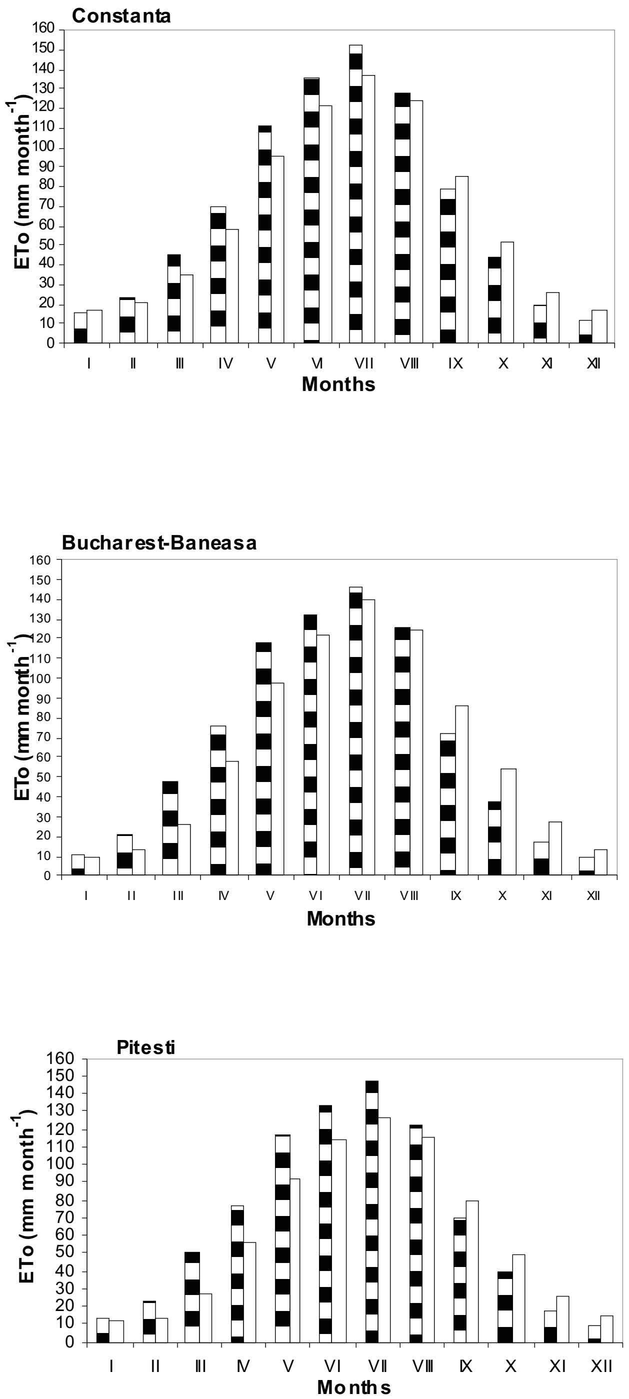

Fig. 2. Monthly distribution of Penman-Monteith *ETo* for the three locations studied, comparison between the mean values of the first decade of the 21st century and the ones for the 20th century as presented by Paltineanu *et al*. (2007b). Columns in square – years 2000-2010, empty columns – century XX.

the 21st century ET_o increased as a yearly total *vs* the last century, and this increase ranged from about 6% in Constanta and Bucharest-Baneasa to 13% in Pitesti (Table 3). The increase also occurred for summer time and growing season.

The magnitude of the highest ET_o values, namely those exceeding 6.0 mm day^{-1}, their number and the years of occurrence are shown in Table 4. Surprisingly, the maximum value (7.54 mm day^{-1}) occurred in Pitesti which had the minimum average ET_o (Table 4) and minimum temperature (Table 5), respectively. The months when maximum ET_o values occurred was July (78%, mainly due to the highest temperature) and then June (22%, mainly due to largest sunshine hours or global solar radiation). Table 4 also shows that the highest ET_o values from the 1st decade of the 21st century occurred in years 2007 and 2000, with more than 50% from the total of these high ET_o values, and combined with 2002 and 2003 these four years totalized 68% for Constanta and over 80% for the other two locations studied.

With regard to July temperature (Table 5), one might say that the highest increase occurred at Pitesti: 1.96°C in 2000 and 4.32°C in 2007, then in Bucharest-Baneasa: 1.21 and 3.43°C, followed by Constanta with 1.27 and 3.15°C, respectively. However, the yearly means in the first decade of the XXI century showed an increase of 1.32ºC for Constanta, 0.23ºC for Bucharest-Baneasa and 1.28ºC for Pitesti, respectively (Table 6), *vs* century XX. Considering parts of century XX in calculating these differences *vs* decade 1 of century XXI, one might say that they decreased gradually and reached as much as 1.09, 0.00, and 1.20ºC, respectively, for the three locations from above, period 1941-2000. This might be interpreted in the sense that the temperature in century XX increased in its last part, even if the measurement devices or procedures could have involved some inherent experimental errors enlarging these differences. So, even if the temperature had not globally risen in the past decade, local or regional increases in temperature could have occurred. This warming is responsible to a great extent for the increase in ET_o in the region studied, and the regression equation obtained with these mean daily data of ET_o and temperature -T (Fig. 3) had a determination coefficient (R^2) that was highly significant; this relationship was very close to that obtained with mean monthly data of the same variables over century XX (Paltineanu *et al*., 2007b):

$$ET_o = 0.0048\,T^2 + 0.0678\,T + 0.4888,\ R^2 = 0.93^{***}. \quad (4)$$

However, because two variables are correlated, this does not necessarily mean that one entirely causes the other ($R^2<1$). One of the consequences of the increase in ET_o is represented by higher plant water uptakes. It is also interesting to see what happened with the climatic water deficit under such circumstances.

Table 4. Highest ET_o values (exceeding 6.0 mm day^{-1}), their number and the years of occurrence for the three locations studied

Weather station	Maximum value (mm day^{-1})	Number of values over 6.0 mm day^{-1}	Years of occurrence and percentage (%)				Total (%)
			2007	2000	2002	2003	
Constanta	6.63	23	31.8	22.7	4.5	9.1	68.1
Bucharest-Baneasa	6.79	37	32.4	27.0	13.5	8.1	81.0
Pitesti	7.54	35	48.6	17.1	14.3	5.7	85.7

Table 5. Temperature values during July of the years 2007 and 2000 and the means for the whole period investigated (°C)

Year/Period	Constanta	Bucharest-Baneasa	Pitesti
2000	23.33	23.98	22.32
2007	25.21	26.19	24.68
2000-2010	24.15	23.33	22.15
Century XX	22.06	22.77	20.36
Differences: year 2000 minus century XX	1.27	1.21	1.96
Differences: year 2007 minus century XX	3.15	3.43	4.32
Differences: period 2000 to 2010 minus century XX	2.09	0.45	1.79

Table 6. Mean annual temperature differences (°C) between century XX or parts of this period and the first decade of century XXI in the three locations studied

Periods	Constanta	Bucharest-Baneasa	Pitesti
Century XX	1.32	0.23	1.28
1941-2001	1.28	0.12	1.23
1961-2001	1.09	0.01	1.20

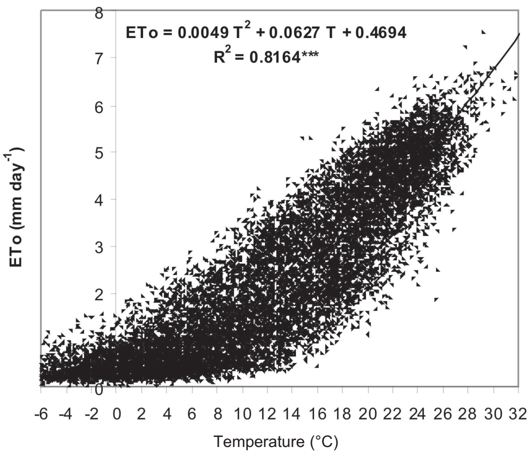

Fig. 3. Relationship between mean daily temperature and Penman-Monteith reference evapotranspiration ET_o during the first decade of the XXI century in the three locations studied.

Water deficit decreased in magnitude from Constanta to Pitesti (Fig. 4). There was not a clear trend regarding *WD* in the areas studied. For instance, during the first decade of century XXI *WD* generally decreased in both Constanta and Pitesti *vs* century XX, except for summer time. However, there was a slight increase in *WD* in the same period in Bucharest-Baneasa. Time distribution of monthly *WD* data did not show a clear pattern either (Fig. 5). What can be surely said for the first decade of century XXI *vs* century XX is that *WD* increased in the first half of the year and decreased in the second half in all the three locations investigated (Table 7).The consequences are not necessarily negative, because the soil is usually wetter in the first half of the year and drier in the second half.

There are no many published papers on the dynamics of air humidity on the region for these periods, but from our previous data (Paltineanu *et al.*, 2007b) the annual means of relative air humidity (*RH*) decreased during the first decade of the XXI century by 1-3% (from about 81 to 79% in Constanta, from 77 to 74% in Bucharest and from 75 to 73% in Pitesti) *vs* century XX, and this decrease also enhanced ET_o. However, as Snyder *et al.* (2010) reported, if an increasing trend in *RH* and in CO_2 concentration will be noted in the future, then these will tend to somewhat reduce ET_o. So, the present data show simultaneous increase in temperature and decrease in *RH*, and this contradicts Snyder pattern for the period investigated.

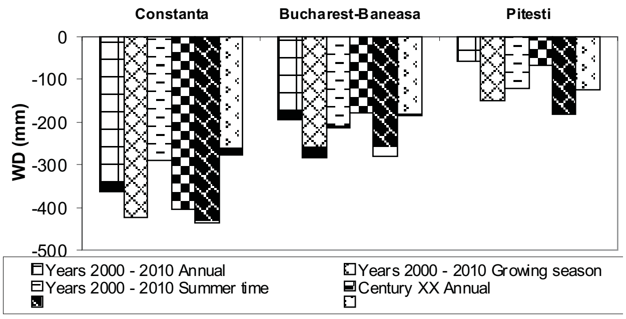

Fig. 4. Climatic water deficit (*WD*, mm), values for various periods, the 2000 through 2010 period *vs* century XX (Paltineanu *et al.*, 2007b) in the three locations studied.

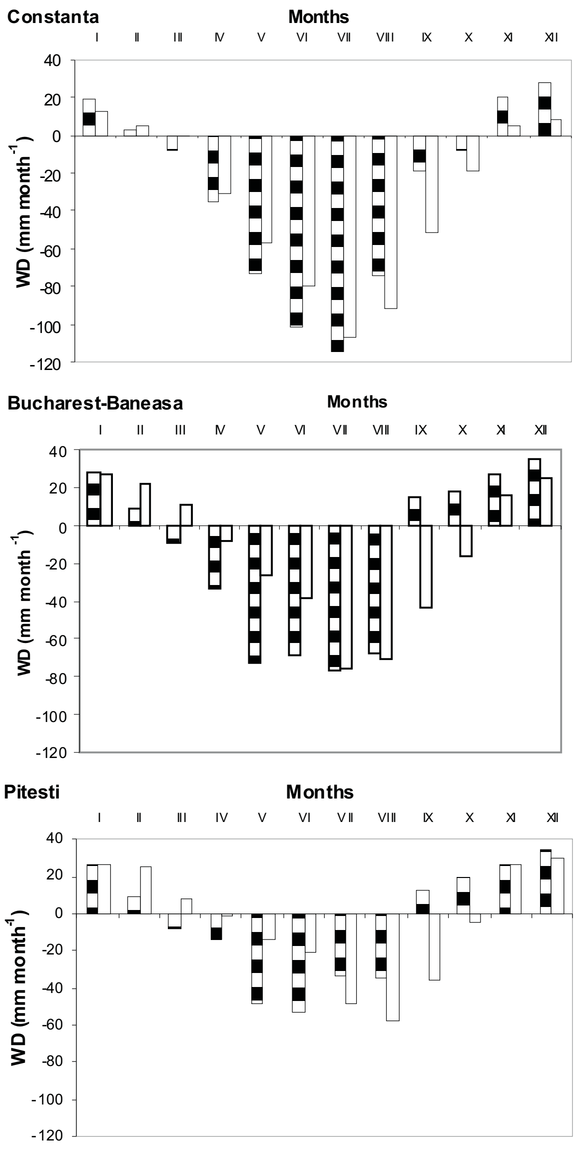

Fig. 5. Climatic water deficit (WD), monthly values, for the 2000 through 2010 period *vs* century XX (Paltineanu *et al.*, 2007b) in the three locations studied; Legend: columns in square – years 2000-2010, empty columns – century XX.

T a b l e 7. Percentage of the WD ratio between the first decade of the 21st century and the 20th century, monthly values, annual means, summer means and growing season means, respectively, for the three locations investigated, southern Romania. Note: negative values from autumn (September and October) and spring (March) show a climatic water deficit in a period and climatic water excess in the other period studied

Month/ Period	Constanta	Bucharest-Baneasa	Pitesti
I	145.1	103.8	102.0
II	52.1	40.5	36.3
III	1 505.9	-83.3	-91.4
IV	113.7	407.9	974.7
V	128.6	268.7	340.6
VI	126.7	176.9	250.5
VII	107.0	101.8	70.4
VIII	80.7	95.5	59.7
IX	37.6	-34.1	-37.1
X	40.1	-113.5	-447.7
XI	397.2	162.7	104.0
XII	327.8	137.1	115.4
Annual total	89.5	109.4	89.7
Summer	97.2	101.6	82.2
Growing season	104.0	115.1	95.6

One also could infer from our data, that the extreme SE part of the country located near the Black Sea (Constanta) maintained large ET_0 differences *vs* the central part of the Danube Plain (Bucharest) and the High Plain of Pitesti. However, ET_0 means of the last two regions tend to equalize even if there were large differences in the past.

CONCLUSIONS

1. For all the three stations studied, for the first half the year the monthly ET_0 values were higher for the first decade of the 21st century *vs* the means of the 20th century. However, the trend reverses for the second half of the year, but for the whole year the totals are higher for the first decade of the 21st century *vs* the totals of the 20th century.

2. The highest ET_0 values (exceeding 6.0 mm day^{-1}) occurred in July. Years 2007 and 2000 had more than 50% highest ET_0 values, and combined with 2002 and 2003 these four years totalized 68% of the total of such high ET_0 values for Constanta, and over 80% for the other two locations studied.

3. The yearly temperature means in the first decade of the XXI century showed an increase in the three locations studied, respectively, *vs* century XX.

4. This warming is responsible to a great extent for the increase in ET_o, and the regression equation obtained with the mean daily data of ET_o and temperature had a determination coefficient that was highly significant.

5. Climatic water deficit (*WD*) decreased in Constanta and Pitesti, but there was a slight increase in *WD* in the same period in Bucharest-Baneasa. Consequently, there was not a clear trend regarding *WD* in the areas studied. *WD* increased in the first half of the year and decreased in the second half during the first decade of century XXI in all the three locations investigated *vs* century XX.

6. The extreme south-eastern part of the country located near the Black Sea (Constanta) maintained large ET_o differences *vs* the central part of the Danube Plain (Bucharest) and the High Plain of Pitesti. However, ET_o means of the last two regions tend to equalize even if there were large differences in the past. Future studies with more weather stations should be carried out in order to find out if this trend is kept for the entire region.

7. Because this study only refers to one decade from a new century, and this decade showed high dynamics in global temperature, this temporal trend of increasing in ET_o in the southern part of Romania could also have either a cyclic or a permanent character. We will be able to respond to this dilemma only after another past decade of this century. The conclusions drawn from this study could be used for regions with similar conditions.

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