CHANGES IN SUMMER TYPES IN RELATION TO DROUGHT OCCURRENCE IN THE ROMANIAN PLAIN REGION

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ABSTRACT Changes in summer types in relation to drought occurrence in the Romanian Plain region. This work aims at analysing the exposure of an important agricultural region of Romania (the Romanian Plain region) to hot summers and droughts over the 1961-2009 period, in response to the combined action of air temperature and precipitation. This study is focused on the changes of summer types, herein defined as four modes (warm/dry, warm/wet, cold/dry, cold/wet), based on the exceedence probabilities of the joint extreme quantiles (the 25th and the 75th) of mean daily temperature and precipitation, for a number of six weather stations located in the Romanian Plain region. The trends in the evolution of the four summer modes have been investigated in relation to the changes in the frequency, magnitude and duration of precipitation deficit and drought, as revealed by the Standardized Precipitation Index (SPI) and the maximum number of consecutive dry days. The changing behaviour of summer modes is strongly associated to the region wide signal of significant summer warming (both daytime and night-time) and less to the slight drying trend. The results show that most areas of the Romanian Plain region are subject to a greater exposure to heat stress in summer and also, to a slight intensification of dryness, more spatially extended since the mid 1980s to early 1990s. These findings are supported mainly by a significant increase of the frequency of the warm/dry summers and a slight lengthening of summer dry spells and less, by the long-term trends of summer SPI (at both 3- and 6-month time-scales), which suggest only a slight increase of the frequency of the moderately dry SPI values, yet not statistically significant.

Keywords: summer types, dry spells, SPI, drought, dryness**.**

1. INTRODUCTION

The southern plain regions of Romania are particularly subject to significant warming and decrease of available water resources necessary for crop development. These signals are mostly visible during the active vegetation season (with a peak in the summer months), affecting the stability of agricultural productivity and limiting the potential of crop yields.

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2. DATA AND METHODS

2.1. Data

The study was conducted using the non-blended daily mean, maximum temperature and precipitation data sets, available from the European Climate Assessment and Datasets project (ECAD), covering a 49-year period of observations (1961-2009), for six weather stations included in the network of the National Meteorological Administration: Bucureşti-Băneasa, Buzău, Călăraşi, Craiova, Galaţi and Roşiori de Vede. The temperature and precipitation time-series were quality-checked for inconsistencies in the records, using the RClimdex package. According to Raliţă (2005), most of the selected stations have open meteorological platforms and no/or no major nearby natural or anthropic obstacles were identified to add inhomogeneities to the *in situ* temperature and precipitation measurements (except for Bucureşti-Băneasa, located in a nearby forest and orchard area). No site relocations have been reported during the period surveyed in this study. After 2000, meteorological recordings have been made using automatic sensors at all the selected weather stations.

2.2. Methods

The analyses were carried out on the calendaristic summer months. Herein, the summer types were defined using an adapted concept based on joint quantiles of mean temperature (T_{mean}) and precipitation (R), previously described by Beniston and Goyette (2007) and applied by Beniston (2009a, b) and Morán-Tejeda et al. (2012). Quantile thresholds were calculated using the daily T_{mean} and R, for each summer month of the 49-year period. The joint exceedence of T_{mean}-R was obtained by counting the frequency of exceedence within each summer month, below or above distinct thresholds derived from the probability density functions of the two climatic variables. The levels of 25% and 75% quantiles, as intermediary thresholds towards the extreme domain, were considered reliable to assess the changes in summer types across the region. In order to reduce the large bias associated to the calculation of the 25% level from daily R, as result of the high frequency of 0 mm values, the 1.0 mm threshold was used for separating the dry days. The combinations between 25-75% quantile levels and R<1.0 mm were used to distinguish four summer modes: i.e. *dry-warm* (DW), when R<1.0 mm and $T_{mean}>T_{75\%}$; *dry-cold* (DC), when R<1.0 mm and $T_{mean}<T_{25\%}$; *wet-warm* (WW), when $R>R_{75\%}$ and $T_{mean}>T_{75\%}$; *wet-cold* (WC), when $R>R_{75\%}$ and $T_{mean}<T_{25\%}$. The estimation of $T_{25\%}$, $T_{75\%}$ and $R_{75\%}$ quantile levels was done using the best fitted distributions of T_{mean} and R summer time-series. The analysis of the change in the variability of the dry-warm summer mode was extended by introducing an additional index ($DW_{extreme}$), aimed to highlight the variation of summer temperature and precipitation within the 'extreme domain'. This index was expressed as the *tropical heat-dry spells* and was defined as consecutive days when maximum temperature reaching or exceeding 30°C and R<1.0 mm occurred simultaneously.

The characteristics of meteorological drought phenomenon (frequency, duration and magnitude) were studied using the *Standardized Precipitation Index* (SPI) and the *Consecutive Dry Days* (CDD). The SPI was calculated for intervals of 3 and 6 months (SPI3 and SPI6), aiming at quantifying the precipitation deficit in summer (in the value domain below -1). The dry spells were considered sequences of consecutive days when R<1.0 mm. The trends and the change signals in the variability of each variable were statistically estimated by using the non-parametric Mann-Kendall test and Sen's slope, relative to the 10% significance level.

3. RESULTS

3.1. Changes in summer types

The temperature rise in summer is highly significant, at a rate of 0.2-0.5°C/decade across the region, while precipitation change signal is rather weak and non-statistically significant at most sites: slightly negative at Bucureşti-Băneasa, Galaţi and Roşiori de Vede (up to 3.3 mm/decade) and slightly positive at Buzău, Călăraşi and Craiova (up to 9 mm/decade).

The trends in summer types in the Romanian Plain region as revealed by the average threshold exceedances for the four temperature-precipitation modes (CD, CW, WD and WW) are illustrated in figure 1. The behaviour of the joint quantiles over the 49-year period of meteorological observations is broadly similar across the region, where the "warm" and "dry" modes were already commonplace.

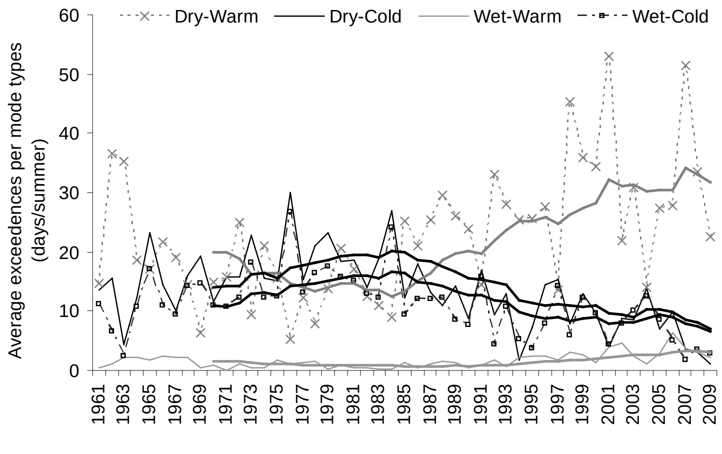

Fig. 1. Threshold exceedance of the four summer temperature-precipitation modes (DW, DC, WW, WC) in the Romanian Plain region. The solid lines indicate the 10-year running mean filter.

The comparison of the statistics depicting the changes in summer types (Table 1) shows a highly significant trend towards a prevalence of DW summer type across the region. This signal is mostly explained by the frequent and prolonged heat waves, associated with no/light rainfalls in the last two decades

(Sandu et al., 2010). Regionally wide, the change rates in the summer modes are in general the slowest or least/non-statistically significant at the Bucureşti-Băneasa site, due to the proximity of a large deciduous forest relative to its meteorological platform, which significantly moderates the local warming.

Table 1. Comparative statistics of change in the summer temperature-precipitation modes at six weather stations located in the Romanian Plain

Weather stations	Dry-Warm		Dry-Cold		Wet-Warm		Wet-Cold	
	a	b	a	b	a	b	a	b
Bucureşti-Băneasa	1.67	<0.1	-0.64	nss.	0.00	nss.	-0.49	nss.
Buzău	4.00	<0.01	-2.50	<0.001	0.00	nss.	-1.82	<0.01
Călăraşi	3.19	<0.01	-2.94	<0.001	0.40	<0.05	-1.74	<0.01
Craiova	4.00	<0.01	-2.00	<0.05	0.00	nss.	-1.56	<0.05
Galaţi	3.67	<0.01	-2.90	<0.001	0.00	nss.	-1.75	<0.01
Roşiori de Vede	4.13	<0.001	-2.14	<0.01	0.00	nss.	-1.60	<0.01

a. Change rate in days per summer/decade; b. Statistical significance (p-value), where nss. is non-statistically significant.

The evolution in the threshold of exceedence since 1961 at the six weather sites shows the large spread increase in the frequency of DW mode, at a rate of 2 to 4 days per summer/decade. This signal is closely related to the general shifts in the regime of summer temperature, as for five out of the six weather stations the change-point year was 1985 (p-value<0.001). The most outstanding summers corresponding to the DW mode were 2001 (51-62 days), for most of the weather stations located in the eastern half of the region (Buzău, Călăraşi, Galaţi) and 2007 (51-55 days), for some weather stations located in the central part of the Romanian Plain region (Bucureşti-Băneasa and Roşiori de Vede).

The $DW_{extreme}$ is a reliable indicator of summer temperature and precipitation variation within the extreme domain. The changes in the frequency and maximum duration of the tropical-dry summers are highly significant all over the region, since mid-1980s to-early-1990s. The strong upward trends in $DW_{extreme}$ variability over the 49-year period are mostly sustained by the intensification of summer tropical heat stress (as also emphasized by Micu et al., 2013) and less by the slight signal of drying (Fig. 2, Table 2).

Regionally wide, the duration of tropical heat-dry spells is dominantly short (up to 10 days), counting up 97% in the total number of cases recorded over the study period. The probability of longer duration (more than 11 days) is rather low (3.5%) at all the weather stations in the region. The summers when the tropical-dry spells exceeded 10 days, for at least four weather stations, were rather exceptional during the 1960s and 1970s (1962, 1971), their frequency has been notably increasing after 1984-1985 (1987, 1989, 1992, 1998, 2000-2001 and 2007-2008). Noteworthy, after 1990, the duration of these spells exceeded 20 days, particularly in 1994 (Buzău, Galaţi), 1998 (Călăraşi, Galaţi, Roşiori de Vede), 2000 (Călăraşi, Roşiori de Vede) and 2001 (Călăraşi).

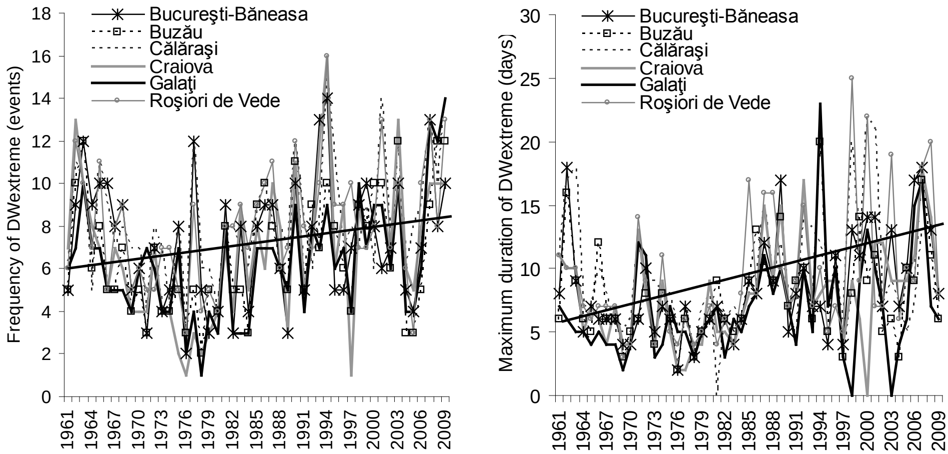

Fig. 2. Variability of the $\boldsymbol{DW_{extreme}}$ ***by the total number of events (left) and the maximum duration (right).***

Table 2. Statistics of changes in the evolution of $\boldsymbol{DW_{extreme}}$ ***over the 1961-2009 period***

Weather stations	Tropical heat-dry spells			
	Frequency		Maximum duration	
	No. events /decade	p-value	Days/decade	p-value
Bucureşti-Băneasa	0.50	.<0.05	1.18	.<0.01
Buzău	0.58	.<0.05	0.61	.<0.1
Călăraşi	0.51	.<0.05	0.20	n/a
Craiova	0.71	.<0.05	1.11	.<0.01
Galaţi	0.63	.<0.05	0.86	.<0.01
Roşiori de Vede	0.62	.<0.05	0.77	.<0.05

The frequency of DC mode started to decrease significantly (p-value<0.001) across the region during the mid-1980s or early-1990s: e.g. 1985 (Călăraşi), 1988 (Buzău, Galaţi and Roşiori de Vede) and 1990 (Craiova) at a rate of 2 to 3 days per summer/decade.

Even if the seasonal precipitation maintained essentially constant over the 1961-2009 interval across the region, the trend towards a drier summer climate observed in some areas could be partially connected to the slight shift detected in the occurrence of WW and WC modes. The WW is not a distinctive climatic feature of the region, as its frequency reached a maximum of only 17 days/summer at Călăraşi station (in 2006), while at the rest of the stations the frequency did not exceed 8 days/summer. The frequency of this is on increase only Călăraşi site, since 1996. The positive trends in the threshold exceedence, corresponding to the WW mode at this particular site, are statistically significant for the 95% level. The year associated to this shift is 1996. The WC mode showed a visible and statistically significant signal of change, with negative trends all over the region, particularly after 1988-1989.

Temperature trends alone could explain the shifts in the DW and DC modes across the region, which are reflecting most of seasonal average temperature over the studied 49-year interval. Beniston (2009) indicated that the higher summer temperatures associated light or no rainfalls, favouring a higher frequency of the DW mode, are in general the result of the positive feedback of drier land-surface conditions. Furthermore, Seneviratne et al. (2006) emphasized the key role of changing soil-moisture characteristics in explaining the positive feedback. The effects of this feedback are particularly visible in the Romanian Plan region which is subject to significant warming during summer.

3.2. Drought and dryness variability

The frequency and magnitude of drought phenomenon is highly variable at the spatial scale of the Romanian Plain region. The moderate droughts seem to prevail within the SPI deficitary domain, accounting 6 to 11% in the total number of cases over the period for SPI3 and 7 to 10% for SPI6 (Fig. 3). The extremely droughty intervals, depicted by SPI3 and SPI6 values lower than -2, have a very low probability over the 49-year period and are not affecting extended areas across the region:

-SPI3 (-2.3…-2.2): 1962 and 1965 (Călăraşi, Bucureşti-Băneasa and Galaţi);

-SPI6 (-2.3...-2.0): 1963 (Buzău), 1965 (Bucureşti-Băneasa), 1986 (Buzău), 1993 (Craiova), 2000 (Roşiori de Vede).

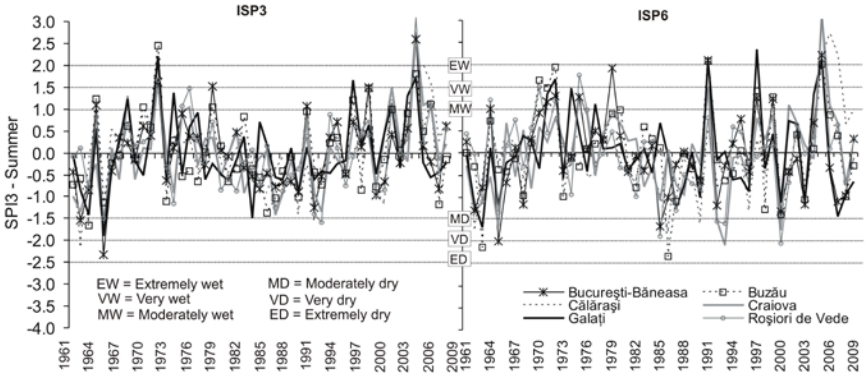

Fig. 3. Variability of ISP3 and ISP6 in summer for six weather stations located in the Romanian Plain region.

The analysis of changes in the variability drought intervals by SPI3 and SPI6 revealed no significant trends in the duration and intensity of the phenomenon across the region. These weak signals could be explained by the influence of summer rainfalls resulted from the high-intensity thermo-convective process in this period of the year, when also the main pluviometric maximum is reached (June). The torrential rainfalls are highly variable in time and amount and exhibit their effects on rather limited areas. However, summer convection is expected to ease significantly the drought condition in the region, as their frequency has increased over the 1965-2007 period, as suggested by Breza et al. (2013).

CDD was considered a reliable indicator of drought occurrence and persistence. The cumulated CDD duration in summer in the Romanian Plain ranges between 58 and 86 days, counting up to 63-94% in the summer length. Generally, the duration of dry spells is rather short across the region, most events reaching up to 10 consecutive days (above 80%) (Table 3). The maximum duration of individual dry spells are usually ranging between 20 and 40, while those exceeding 40 days are rather rare across the region, with up to 12% probability. The maximum CDD duration reached 50-51 days sparsely over the 1961-2009 period, during the 1960s (in 1963 and 1965 at Călăraşi and Craiova stations) and 1990s (in 1996 at Galaţi station).

Table 3. Frequency (%) of CDD duration in the Romanian Plain

CDD	Bucureşti-Băneasa	Buzău	Călăraşi	Craiova	Galaţi	Roşiori de Vede
<5 days	56.7	55.2	57.0	54.2	55.0	55.5
5-10 days	30.9	26.0	28.9	31.7	30.0	28.8
11-15 days	8.1	6.4	8.2	7.3	8.2	9.6
16-20 days	2.9	3.2	3.5	4.2	3.7	3.5
21-25 days	0.8	0.8	1.6	1.7	1.7	1.3
26-30 days	0.5	0.6	0.2	0.3	0.3	0.8
31-35 days	0.2	7.8	0.2	0.2	0.8	0.2
>35 days	0.0	0.0	0.5	0.5	0.3	0.3

Investigating the trends of CDD over the 49-year period, the Romanian Plain region appear as not being subject to significant changes in the variability of the parameter, suggesting rather a slight increase of dryness, particularly at Călăraşi and Roşiori de Vede stations. Moreover, the prevalence of dryness could be explained also by high frequency of very short (up to 5 days) and short dry spells (5-10 days) all over the region.

4. CONCLUSIONS

The paper has studied the changes in summer types using the quantile-based combined temperature-precipitation modes, aiming at explaining the changes in the frequency and duration of drought and dryness in a region, particularly subject to frequent heat waves and rainfall lack. Investigating the changes in summer modes in the Romanian Plain region, the DW and DC has showed the most significant signals, the behaviour of joint quantiles being broadly similar among the six weather stations. The results suggest an increasing prevalence of the DW mode, more spatially extended after 1985 and a strong decrease in the frequency of DC mode, mostly after 1988-1990. Summer temperature increasing trends are best explaining the changes in the DW and DC modes and only partially, the slight shifts detected in the occurrence of WW and WC modes. The frequency and duration of tropical heat-dry spells are on a significant increase all over the region, particularly due to the intensification of the tropical heat stress. This signal is mostly visible after 1990, when the occurrence probability of such events exceeded 20 days/summer. The Romanian Plain region is mostly affected by moderate drought (SPI between -2 and -1), while severe droughts (SPI<-2) occurred rarely over the 49-year period and did not affect extended areas across the study region. The long-term trends of seasonal SPI3 and SPI6 are not suggesting an increase of drought duration and intensity in the region. The findings could be explained by the summer convection. The behaviour of CDD showed that the Romanian Plain region is not particularly subject to significant changes in the occurrence and persistence of drought intervals, this indicator suggesting rather a slight increase of dryness.

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