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Article

Climatic Changes—A Challenge for the Bulgarian Farmers

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Abstract: Serious economic damages in many regions of the world were caused by the changes in agroclimatic resources during the last 2–3 decades. The Balkan Peninsula is much affected by the temperatures rising, changes in the distribution of precipitation, and the increasing frequency of extreme events—basically, droughts and frosts. Bulgarian agriculture is developed under various agrometeorological conditions. The climate of the country is characterized by the atmosphere and soil moisture deficit in the time of active crop vegetation and yield formation. The aim of this research is to assess the changes in agrometeorological conditions for the growth of the main grain crops and the possibilities for reaction through agro-technologies. Furthermore, the features of contemporary varieties and hybrids of spring and autumn cereals will be taken into account. The next important factor is the specific requirements for hydro-thermal conditions at different phenological phases of agricultural crop development, i.e., sums of the temperatures and precipitations. Agro-technologies react to tendencies in changing agrometeorological conditions. For the adaptation of agro-technologies, the maximum use of natural agroclimatic resources should be included in activities for overcoming unfavorable conditions, as well as the increased frequency of extreme events. A detailed assessment of the agrometeorological conditions is necessary to choose the suitable agro-technology activity. The analysis of the main meteorological elements—temperatures, precipitations, air humidity, wind speed, and solar radiation for thirty years (1986–2015) was used to assess the changes in agrometeorological conditions on agricultural lands in Bulgaria. Appropriate agro-technical activities for growing the main grain crops are proposed in accordance with the observed changes.

Keywords: climate change; temperatures deviation; rainfall deviation; aridity index; agro-technology recommendations

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1. Introduction

According to the World Bank of Development Report (WBDR), namely, The Changing Nature of Work published in early 2019, Bulgarian agriculture will be strongly influenced by climatic changes now and in the next 20–30 years. According to the experts, agriculture plays a key yet disproportionate role in the socioeconomic fabric of rural Bulgaria [1]. The agricultural sector generates 4.4 percent of the country's total gross value added (GVA) and provides employment to 5.8 percent of the labor force (the second highest rate in EU-28). More generally, the country remains predominantly rural. Therefore, climate change will be a significant factor in the future development of Bulgarian agriculture; according to the same report, the first negative impact is now a reality. The frequency and intensity of climatic adverse events have increased during the last decades: three distinct periods of drought were recorded; as well, more frequent floods caused by prolonged and intense rainfalls were regularly encountered, but they are not yet easy to predict. Over the last 50 years, the average temperature has risen by approximately 2 °C, and by the end of the 20th century, there were significant changes in the seasonal and monthly distribution of precipitation. Climate change scenarios for Bulgaria indicate an increased frequency of climatic adverse events, such as long droughts, heat waves, heavy rainfalls, and floods. Agriculture is the most vulnerable sector in the Bulgarian economy [1]. The agriculture sector, as a provider of quality food, a base for economic growth, a deliverer of ecosystem services, and a provider of a safe living environment for rural communities, is highly vulnerable to the impact of climate change. Bulgarian agriculture depends on climate variability, as three-quarters of agricultural outputs are from crop farming. Agricultural land occupies one-third of Bulgaria's total area, and 86 percent of the utilized agricultural area is used to grow cereals and industrial crops. The impact of extreme weather events and anomalies on agricultural productivity were best manifested in years with a drought, for example, in 2007, when the share of agriculture in the gross domestic product (GDP) dropped to 4.7 percent compared to 2006 (6.2 percent) and 2008 (6.0 percent). The most sensitive crops are the crops grown under irrigation conditions, traditionally in the summer seasons, such as maize, sunflower, fruits, and vegetables.

However, the impact of climate change is not equally distributed in the Bulgarian agriculture sector [1]. Overall, the livelihoods of the rural population will be affected by the changing climatic conditions. The impact of climate change may be positive or negative, but those currently encountered are predominantly negative. There are regional differences in the likelihood of negative impacts from drought and floods, as well as differences in the vulnerability, resilience, and adaptive capacity of rural populations to climate change. These differences are further accentuated by the pronounced dual farm structures and lopsided land distribution that clearly characterize the agriculture sector in Bulgaria. Furthermore, the bipolar farm structures are associated with substantial differences in resilience and adaptive capacity: (1) Large-scale commercial farms are mostly highly vulnerable to the impact of frequent and long periods of drought and floods. At the same time, large-scale farmers have better resources to adapt; (2) Smallholders practicing semi-subsistence farming are socially and economically vulnerable to adverse climate events. However, due to their more diversified production, smallholders tend to display more intrinsic resilience.

At the same time in the last 50 years, there were published a number of publications with results for climate change's impact on agriculture in Bulgaria and for the world. There is uncertainty about the impact of weather conditions on the yield. Chirkov [2] was one of the authors that researched statistical empirical models for forecasting yield. Later, during the 1970s and 1980s of the previous century, there appeared the investigations of Sirotenko [3], who proposed the model of weather yield; Gringof [4], with the statistical models for yield calculations; De Wit, et al. [5], De Wit [6], Tooming [7], and Ross [8], with the development of simulation modeling for yields. For the adaptation of these models to the conditions in Bulgaria and their adaptation, we should mention the investigations of Slavov et al. [9], Eitzinger et al. [10], Kazandjiev et al. [11–14].

The aim of this research is to assess the changes in agrometeorological conditions during the contemporary 30 years (1986–2015) in comparison with the referent period (1961–1990) for growing the main grain crops [15] and the possibilities for reaction through agro-technological measures.

2. Material and Methods

Over the last few decades, a steadily increasing frequency and intensity of climate anomalies have been observed, especially those related to the dynamics of daily temperatures and precipitation. The frequency of these fluctuations increases and is reflected in agricultural production because the entire cycle is under the open sky. The farmers cannot have much influence on the conditions for growth but their reaction should be related to changes in agro-technologies.

The study identifies areas affected by climatic changes and anomalies according to changes in agrometeorological conditions during the period 1986–2015. For this purpose, we used the daily values of the following meteorological elements: average, minimum, and maximum temperature; relative air humidity; wind speed; and sunshine duration measured in 65 meteorological and agrometeorological stations distributed evenly in the agricultural regions of the country, excluding mountainous farming areas. The stations list includes the meteorological and agrometeorological observation stations. Their decimal coordinates and elevations are present in Table 1 and spatial distribution in the territory of the country in Figure 1.

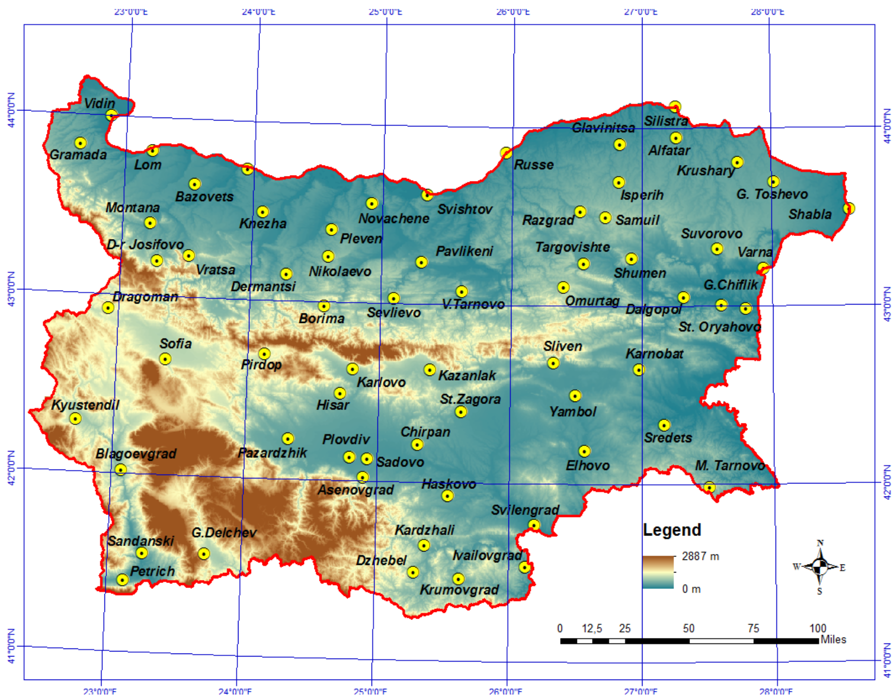


Figure 1. Meteorological stations distribution in the territory of Bulgaria using in the investigation.

To determine the areas with natural constraints—drought, a specialized database was set up with the measured daily values of mentioned meteorological elements. Data on the minimum and maximum temperature, relative air humidity, wind speed, and duration of solar radiation were used to calculate the values of potential evapotranspiration (PET) using the Penman–Monteith equation.

The annual sums of precipitation and potential evapotranspiration were calculated. By their ratio, we calculated the values of the aridity index (*AI*) (1).

$$AI = \sum r \;/\; \sum PET \tag{1}$$

where: $\Sigma\, r$ is annual rainfall (mm); $\Sigma\, PET$ is the annual sum of potential evapotranspiration (mm).

Table 1. Geographic coordinates—latitude, longitude, and elevation of 65 meteorological and agrometeor-ological stations subject of this study.

Station	Longitude	Latitude	Eelevation (m)	Station	Longitude	Latitude	Elevation (m)	Station	Longitude	Latitude	Elevation (m)	Station	Longitude	Latitude	Elevation (m)
Vidin	22.884	44.002	36	Razgrad	26.533	43.533	200	Asenovgrad	24.908	42.024	230	Pirdop	24.133	42.700	686
Vratsa	23.529	43.233	398	Silistra	27.273	44.121	35	Karlovo	24.808	42.627	453	M. Tarnovo	27.521	41.982	352
Bazovets	23.552	43.635	165	Shumen	26.933	43.267	211	Pazardzhik	24.338	42.227	208	Suvorovo	27.592	43.325	181
Montana	23.220	43.408	146	Shabla	28.609	43.539	22	Sofia	23.383	42.650	570	G.Chiflik	27.622	43.009	25
Lom	23.217	43.816	40	Varna	27.945	43.211	40	Blagoevgrad	23.086	42.015	390	Alfatar	27.280	43.946	140
Knezha	24.083	43.494	109	G. Toshevo	28.033	43.700	226	Kyustendil	22.722	42.290	523	Samuil	26.733	43.500	458
Oryahovo	23.959	43.734	150	Karnobat	26.991	42.646	203	Sandanski	23.270	41.554	297	Omurtag	26.412	43.105	502
Pavlikeni	25.320	43.239	121	Yambol	26.508	42.497	136	Petrich	23.133	41.400	178	Isperih	26.834	43.700	272
Pleven	24.618	43.409	126	Sliven	26.340	42.681	265	D-r Josifovo	23.283	43.197	202	Gramada	22.656	43.836	218
Novachene	24.926	43.562	333	Chirpan	25.310	42.211	185	Borima	24.577	42.977	484	Dalgopol	27.334	43.051	38
Nikolaevo	24.600	43.259	274	St.Zagora	25.642	42.402	205	Elhovo	26.580	42.186	111	Svilengrad	26.200	41.767	56
V.Tarnovo	25.628	43.077	215	Kazanlak	25.401	42.636	375	Dzhebel	25.301	41.500	325	Sredets	27.184	42.334	36
Svishtov	25.350	43.616	77	Haskovo	25.549	41.930	200	Krumovgrad	25.643	41.460	225	Dermantsi	24.283	43.150	199
Targovishte	26.566	43.240	191	Kardzhali	25.380	41.646	249	Ivailovgrad	26.134	41.533	86	Hisar	24.718	42.488	371
Russe	25.957	43.86	71	Plovdiv	24.802	42.134	162	Dragoman	22.932	42.922	734	Sevlievo	25.109	43.030	202
St. Oryahovo	27.804	42.986	14	Glavinitsa	26.838	43.910	109								

3. Results and Discussion

3.1. Changes in the Meteorological Conditions

The average monthly temperatures and monthly rainfall sum for the six agro-industrial regions of the country and for the 1986–2015 period were calculated. Their deviations compared to the period 1961–1990 were identified. The deviations in the monthly temperatures and precipitation sums are shown in Tables 2–7 and Figures 2 and 3.

Table 2. Average monthly temperatures deviations in northwestern Bulgaria in the period 1986–2015.

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Vidin	1.4	0.5	0.8	0.2	0.3	0.9	1.3	1.4	−0.1	0	−0.1	−0.5	1.7
Gramada	1.9	1.1	1.3	0.6	0.6	1.2	1.5	1.7	0.1	0.2	0.1	0.1	0.8
Montana	1.6	0.6	0.7	0.0	0.3	1.0	1.3	1.4	0.3	0.5	0.5	0.3	0.9
D-r Josifoo	1.5	1.0	1.0	0.3	0.5	1.4	1.5	1.6	0.5	0.4	0.4	0.0	0.4
Bazovs	1.6	1.3	1.3	0.2	0.4	1.1	1.4	1.7	0.6	0.9	0.6	0.3	0.6
Lom	1.5	0.9	1.1	0.5	0.8	1.3	1.5	1.6	0.3	0.4	0.3	−0.1	1.0
Vratsa	1.5	0.9	1.0	0.3	0.5	1.0	1.3	1.5	0.0	0.0	0.1	0.1	1.1
Knezha	1.1	0.5	0.7	0.1	0.2	0.7	1.1	1.4	0.2	0.2	0.1	−0.4	1.5
Oryahovo	1.3	0.8	0.9	0.1	0.4	0.8	1.2	1.4	0.1	0.2	0.1	−0.2	0.4

Table 3. Average monthly temperatures deviations in central north Bulgaria in the period 1986–2015.

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Pleven	1.5	0.9	0.9	0.2	0.3	0.8	1.2	1.6	0.3	0.3	0.1	0.0	0.7
Novachene	1.5	0.9	0.8	0.1	0.3	0.9	1.3	1.7	0.2	0.4	0.5	0.0	0.7
Nikolaevo	1.7	1.0	1.0	0.4	0.4	0.8	1.2	1.5	0.5	0.8	0.4	0.2	0.8
Borima	1.3	0.7	0.6	0.3	0.7	0.7	1.1	1.4	0.2	0.2	0.2	0.0	0.6
Dermatsi	1.7	0.8	0.9	0.4	0.6	1.0	1.1	1.5	0.4	0.4	0.2	−0.2	0.7
Sevlievo	1.1	0.5	0.7	0.4	0.8	1.1	1.3	1.6	0.6	0.9	0.4	−0.3	0.8
V.Tarnovo	1.2	0.6	0.5	0.3	0.6	1.1	1.6	1.8	0.3	0.3	0.0	−0.1	0.7
Pavlikeni	1.3	1.0	0.5	0.2	0.4	1.1	1.4	1.8	0.5	0.6	0.1	−0.1	0.7
Svitshov	1.2	0.7	0.8	0.0	0.4	0.7	1.3	1.6	0.2	0.0	−0.1	−0.4	0.5
Russe	1.2	0.5	0.7	0.1	0.3	0.7	1.2	1.5	0.2	0.0	0.0	−0.3	0.5
Obr. Chiflik	1.3	0.8	0.9	0.2	0.5	0.9	1.3	1.4	0.0	0.0	0.1	−0.1	0.6

Table 4. Average monthly temperatures deviations in northeastern Bulgaria in the period 1986–2015.

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Targovitshe	1.1	0.8	0.7	0.2	0.3	1	1.4	1.6	0.3	0.1	−0.2	−0.3	0.6
Razgrad	0.9	0.6	0.4	0	0	0.6	1.3	1.7	0.2	0.2	0.1	−0.2	0.5
Silistra	1.2	0.8	0.9	0.3	0.6	1.1	1.6	1.7	0.3	0.2	0.1	−0.3	0.7
Alfatar	1.0	0.7	0.1	0.2	0.5	0.9	1.1	1.3	−0.1	−0.3	−0.2	−0.4	0.4
Shumen	1.0	0.7	0.7	0.3	0.3	0.9	1.3	1.5	0.2	0.1	−0.2	−0.4	0.5
Shabla	0.9	0.5	0.7	0.1	0.1	0.5	1.0	1.6	0.6	0.6	0.1	−0.2	0.6
Krushari	0.9	0.5	0.7	0.1	0.1	0.5	1.0	1.6	0.6	0.6	0.1	−0.2	0.6
G. Toshevo	1.0	0.7	0.8	0.3	0.3	0.8	1.2	1.5	0.3	0.2	−0.2	−0.3	0.6
Varna	0.7	0.4	0.5	0.2	0.2	0.6	1.0	1.2	0.2	0	−0.3	−0.6	0.3

Table 4. *Cont.*

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
St. Oryahovo	0.7	0.6	0.6	0.2	0.2	0.8	1.2	1.4	0.4	0.4	−0.2	−0.6	0.6
G. Chiflik	0.7	0.2	0.5	0.2	0.3	0.9	1.4	1.6	0.5	0.4	−0.1	−0.6	0.5
Suvorovo	0.6	0.3	0.5	0.4	0.8	1.6	2.0	2.4	0.8	0.1	−0.4	−0.6	0.5
Dalgopol	0.7	0.6	0.7	0.5	0.6	1.2	1.5	2.2	1.1	0.5	0.2	−0.6	0.8

Table 5. Average monthly temperatures deviations in southeastern Bulgaria in the period 1986–2015.

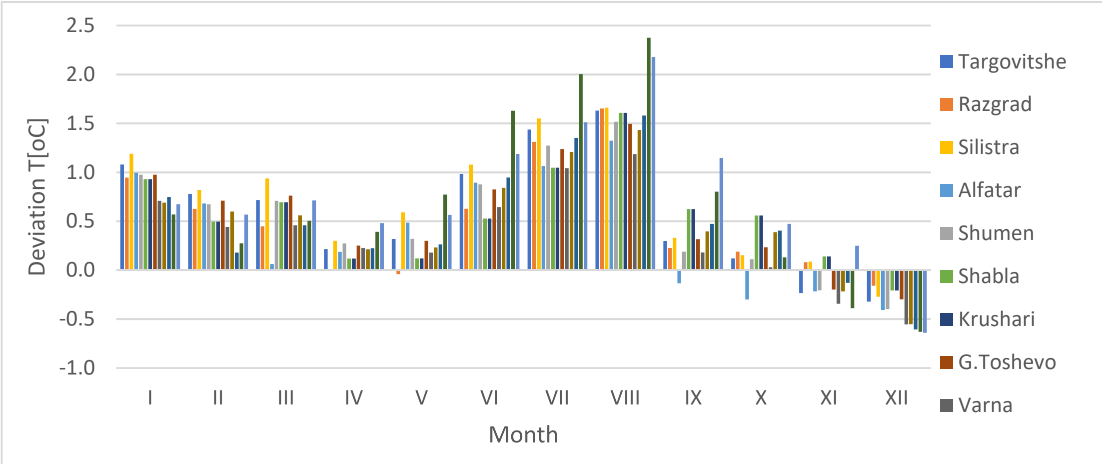
Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Karnobat	0.7	0.5	0.6	0.3	0.4	0.9	1.4	1.5	0.4	0.5	0.0	−0.4	0.6
M. Tarnovo	1.3	1.0	1.1	0.5	0.6	0.9	1.2	1.5	0.8	0.8	0.2	0.2	0.8
Yambol	0.4	0.4	0.5	0.1	0.4	1.0	1.5	1.9	0.6	0.5	0.3	−0.6	0.6
Elhovo	0.7	0.4	0.4	0.1	0.2	0.8	1.1	1.3	0.3	0.5	−0.1	−0.4	0.4
Sliven	0.9	0.6	0.6	0.3	0.5	1.0	1.4	1.6	0.4	0.4	0.0	−0.3	0.6

Table 6. Average monthly temperatures deviations in central south Bulgaria in the period 1986–2015.

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
St. Zagora	0.4	0.2	0.2	0.1	0.2	0.9	1.4	1.7	0.4	0.2	−0.2	−0.6	0.4
Chirpan	0.5	0.2	0.4	0.3	0.3	0.3	1.3	1.7	0.4	0.3	−0.1	−0.4	0.4
Kazanlak	0.9	0.4	0.5	0.2	0.5	1.0	1.7	1.9	0.7	0.6	0.1	−0.4	0.7
Haskovo	0.6	0.4	0.4	0.1	0.4	1.0	1.6	1.9	0.5	0.3	−0.2	−0.5	0.6
Kardzhali	0.6	0.2	0.1	−0.3	−0.2	0.3	0.8	1.2	0.2	0.2	−0.4	−0.6	0.2
Krumovgrad	0.3	0.0	0.1	−0.3	−0.1	0.3	0.7	0.6	0.1	0.2	−0.5	−0.6	0.1
Ivaylovgrad	0.6	0.3	0.2	−0.2	−0.3	0.4	0.6	0.9	−0.1	0.1	−0.3	−0.6	0.2
Plovdiv	0.9	0.3	0.6	0.3	0.5	1.0	1.4	1.8	0.6	0.5	0.1	−0.3	0.6
Sadovo	0.8	0.3	0.6	0.3	0.5	1.0	1.3	1.6	0.4	0.4	0.1	−0.3	0.6
Asenovgrad	0.6	0.4	0.5	0.3	0.6	0.9	1.4	1.9	0.3	−0.1	−0.2	−0.4	0.5
Karlovo	0.9	0.5	0.6	0.0	0.2	0.7	0.9	1.4	0.1	0.1	0.0	−0.3	0.6
Pazardzhik	0.9	0.2	0.4	0.1	0.3	0.8	1.2	1.5	0.5	0.5	0.0	−0.3	0.5

Table 7. Average monthly temperatures deviations in southwestern Bulgaria in the period 1986–2015.

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Blagoevgrad	0.7	0.3	0.4	0.2	0.4	1	1.4	1.7	0.3	0.5	0.3	−0.2	0.6
Sandanski	0.7	0.5	0.5	0.2	0.4	1.1	1.4	1.6	0.3	0.3	0.3	−0.1	0.6
Petrich	0.4	0.2	0.2	−0.1	0.0	0.5	0.6	1.1	0.0	0.2	0.0	−0.3	0.2
Kyustendil	0.3	0.0	0.1	0.0	0.2	0.6	1.1	1.4	0.2	0.3	−0.1	−0.4	0.3
Sofia	1.1	0.6	0.8	0.5	0.7	1.3	1.8	2.0	0.5	0.4	0.4	−0.1	0.8



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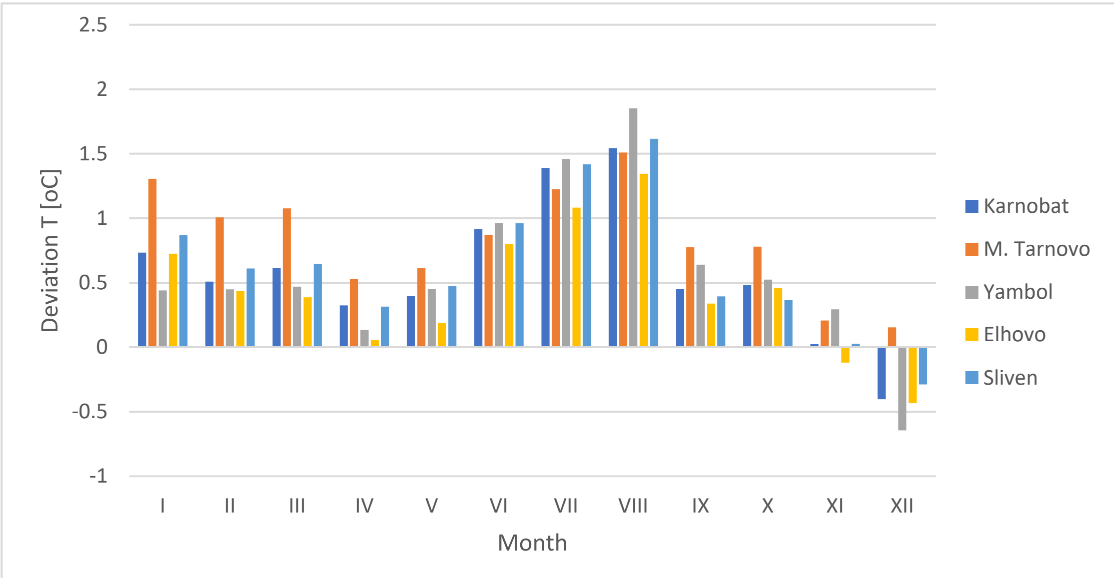

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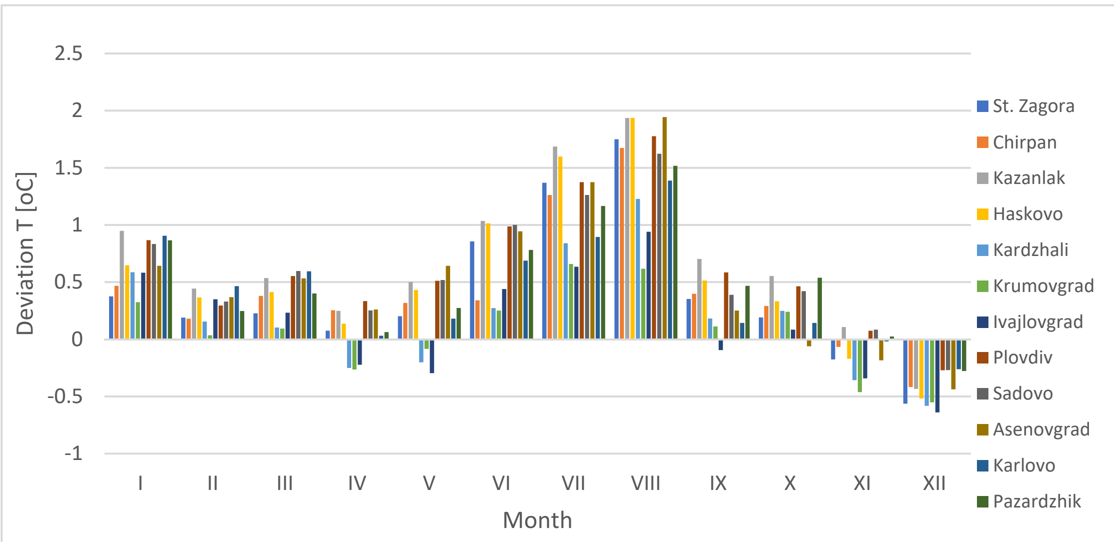
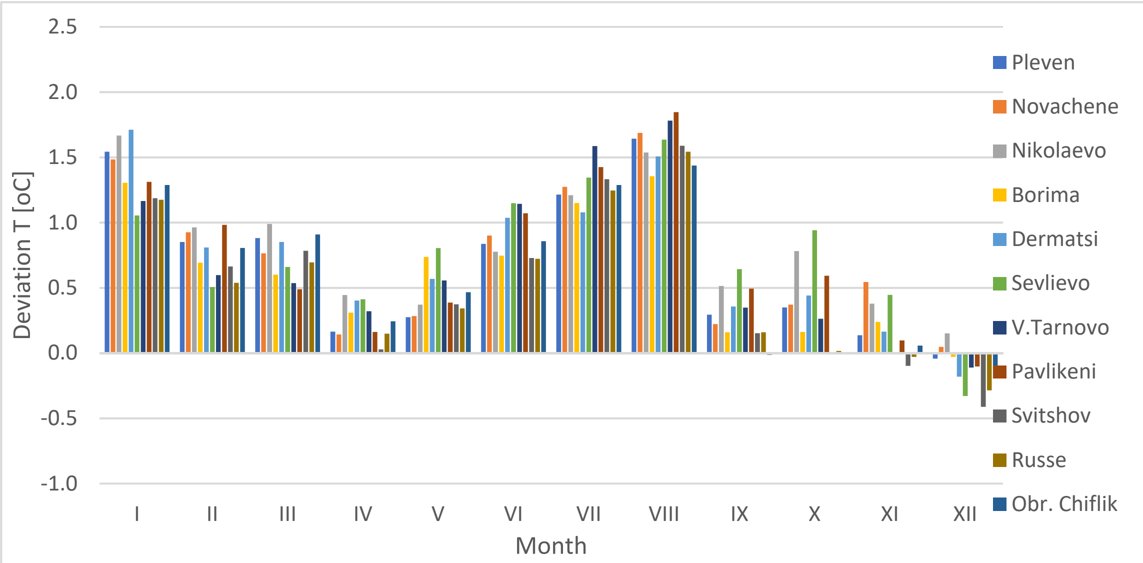


(**c**)

Figure 2. *Cont.*



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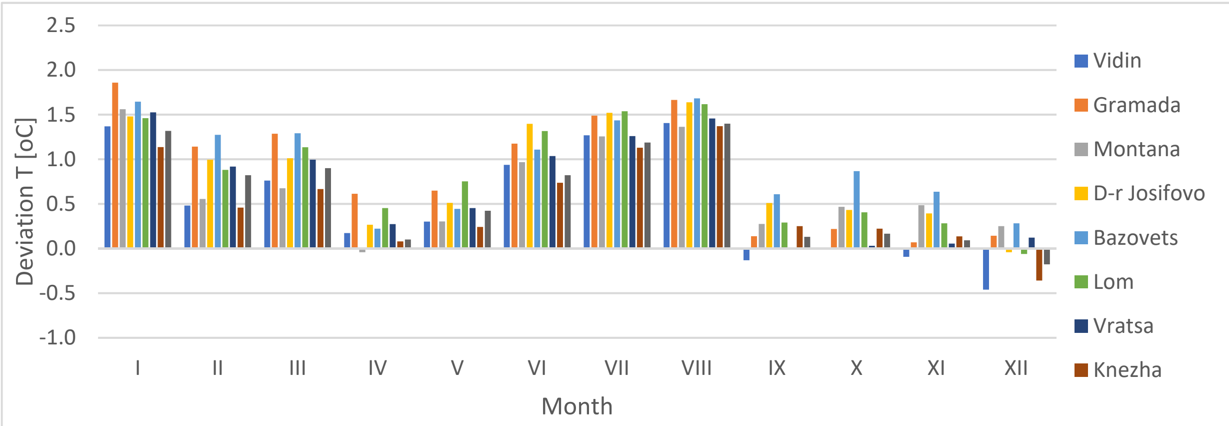

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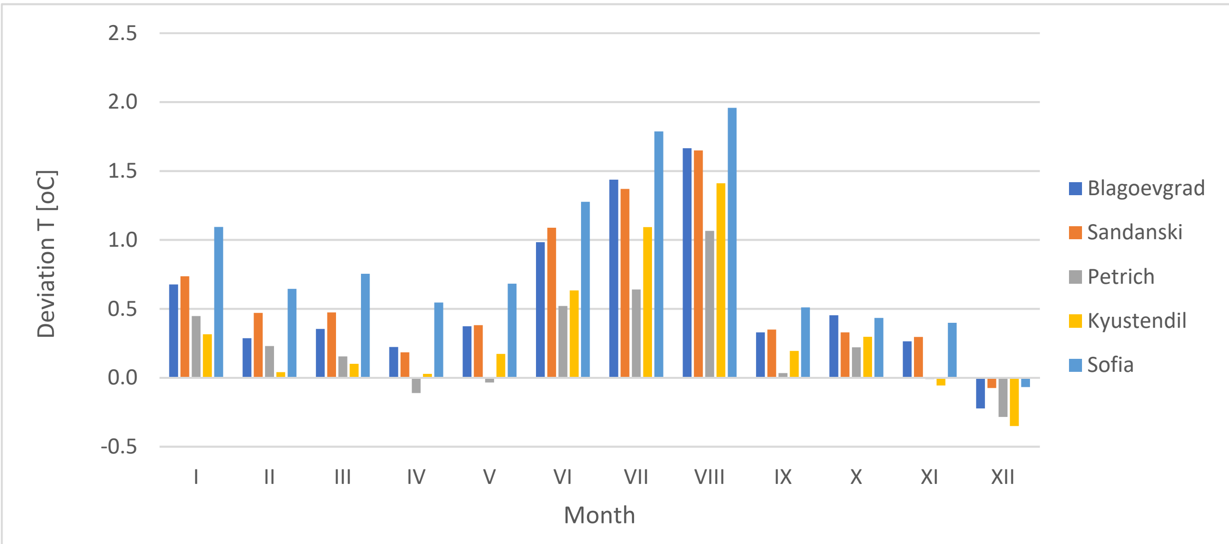
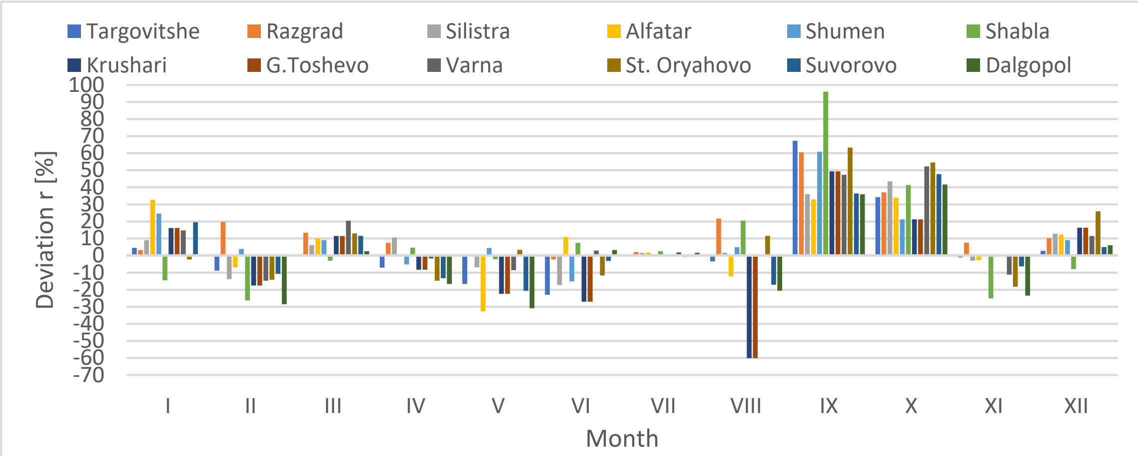


(**f**)

Figure 2. Deviations in average monthly temperatures for the period 1986–2015 in (**a**) northeast, (**b**) southeast, (**c**) central south, (**d**) central north, (**e**) northwest, and (**f**) southwestern Bulgaria compared to 1961–1990.



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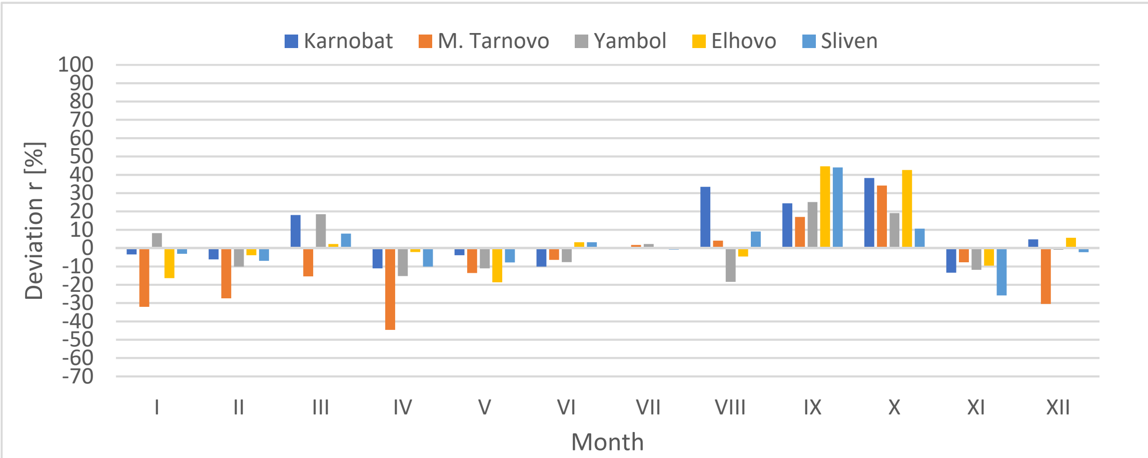

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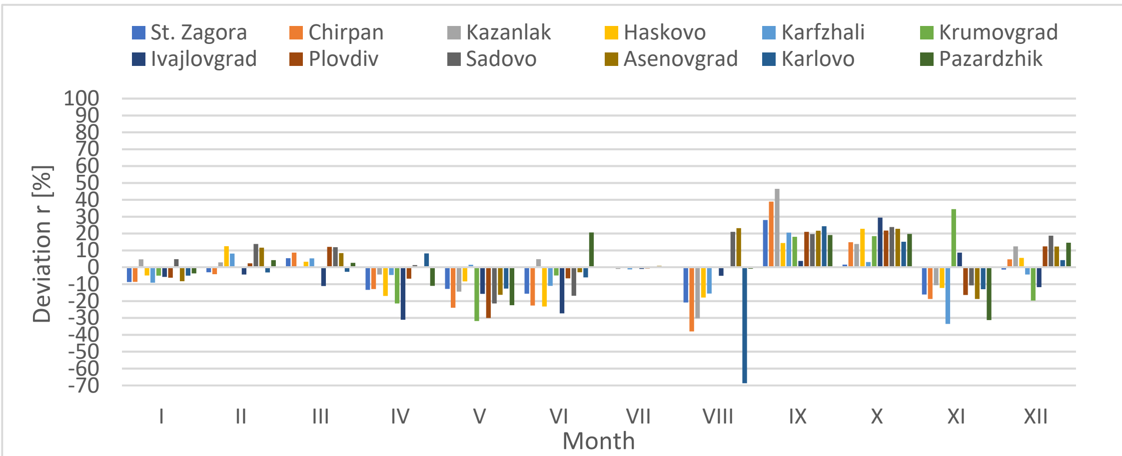
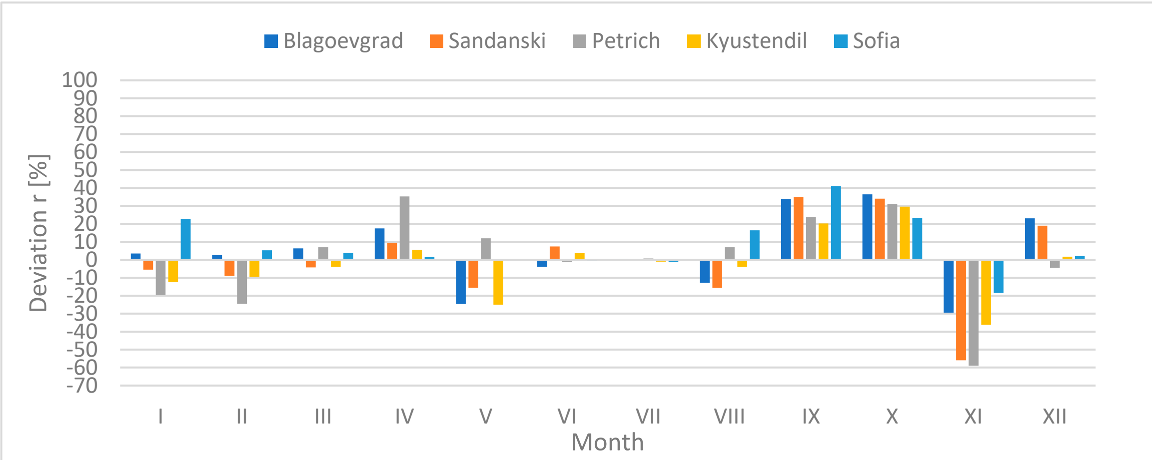


(**c**)

Figure 3. *Cont.*



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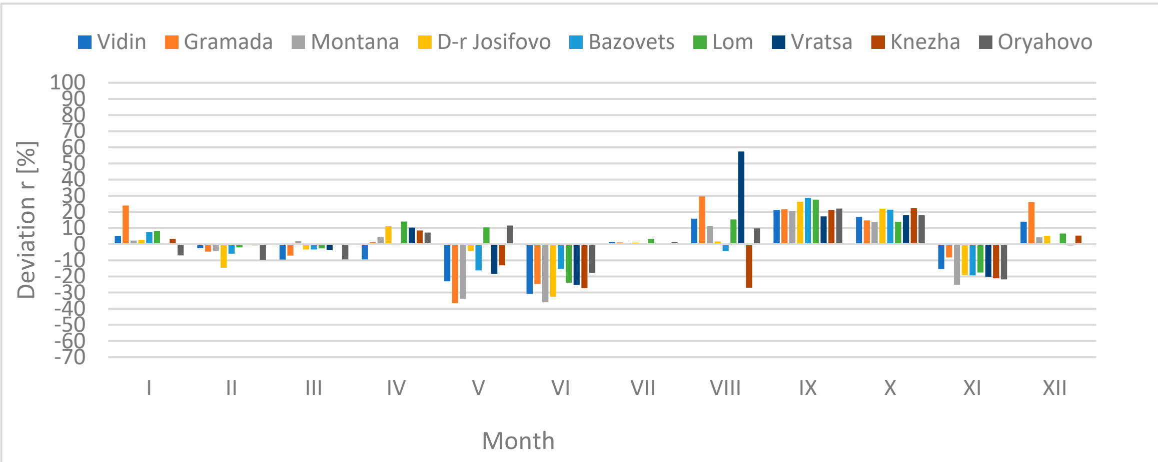
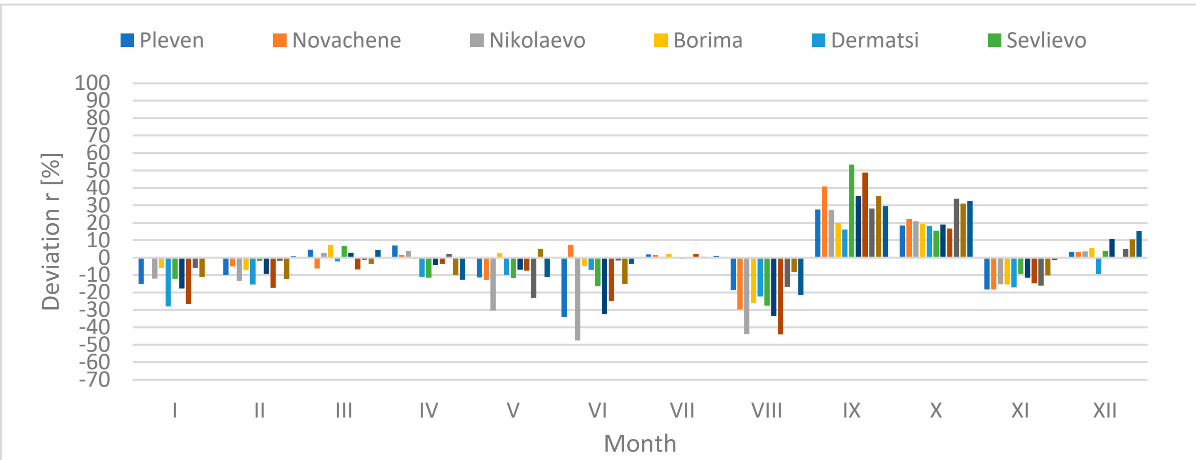


(**e**)



(**f**)

Figure 3. Deviations in the monthly sum of rainfall for the period 1986–2015 in (**a**) northeast, (**b**) southeast, (**c**) central south, (**d**) southwestern, (**e**) northwest and (**f**) central north Bulgaria compared to 1961–1990.

The average monthly temperatures rose in all the regions of the country during the period 1986–2015 from January to September compared with the reference period. The biggest deviations were observed in January, July, and August. During the coldest month of the year—January—the average deviation varied between 0.5–1.5 °C. In northwest and north central Bulgaria this increase was within 1–1.5 °C. August was the month with the biggest deviations for all regions, between 1.5 and 1.6 °C. In most parts of the country, except the southwestern and part of the northwestern region, December was colder in comparison with the reference period. The negative temperature deviation averaged 0.5 °C (Figure 2).

The deviations in the monthly sums of rainfall during the investigated period showed a significant increase during September and October and insignificant changes during July in all agro-industrial regions (Figure 3 and Tables 8–13). The most significant was the increasing percentage during September in northeastern Bulgaria—50–90%. In the remaining regions, the deviations varied between 20 and 40%. The lowest was in northwestern Bulgaria—28% (meteor station Lom). A decrease in the monthly precipitation sum during April, May, and June—30–45% (M. Tarnovo)—was observed all over the field regions of the country, except in the two western regions. Significant increases were detected in southwestern Bulgaria—35% (Sandanski)—and they were insignificant in northwestern Bulgaria. They made an impression with the negative deviation during August in the central part of the country and some eastern regions—G. Toshevo, Krushary, and Yambol. At the same time, in the other eastern areas, the monthly rainfall sums increased to 33% (Karnobat). Only in the northwestern part of the country in most stations were the deviations positive. Taking into account the prevailing negative variations in monthly precipitation totals and the positive deviations in average monthly values of temperatures in four of the six districts, agrometeorological conditions were largely unfavorable. The exceptions in this regard were northwest and central south Bulgaria.

Table 8. Average monthly sums of rainfall deviations in northeastern Bulgaria in the period 1986–2015.

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Targovitshe	2.0	−4.2	0.4	−4.6	−6.8	−11.9	2.6	−1.6	32.2	22.3	−0.8	2.0	31.7
Razgrad	1.2	6.9	8.8	4.1	−0.1	−1.0	11.2	8.4	26.6	24.4	5.0	6.8	102.4
Silistra	3.0	−4.9	3.0	4.7	−2.5	−7.2	7.2	0.6	13.7	19.9	−1.6	6.3	42.2
Alfatar	10.2	−2.5	6.6	−0.2	−13.7	5.0	9.1	−5.1	14.2	17.5	−1.5	6.9	46.5
Shumen	8.9	1.5	5.8	−2.6	1.6	−7.4	4.3	2.2	27.6	14.1	0.3	5.7	62.0
Shabla	−5.1	−7.7	−1.0	1.4	−0.7	3.7	10.7	6.1	27.2	13.2	−10.2	−4.9	32.7
Krushari	5.0	−6.0	6.7	−4.0	−7.4	−10.9	2.5	−21.6	20.0	10.9	−0.1	8.6	3.8
G. Toshevo	4.9	−7.3	4.1	−1.3	2.0	−2.6	8.6	−6.8	23.5	17.3	−5.7	3.9	40.7
Varna	5.2	−4.6	7.9	−0.7	−2.9	1.5	8.8	−0.1	18.4	18.9	−5.1	5.9	53.3
St. Oryahovo	−1.2	−6.0	6.4	−6.6	1.2	−7.8	−4.7	5.7	30.9	27.6	−7.3	17.5	55.9
G. Chiflik	−1.2	−12.9	2.2	−3.8	−2.8	−0.2	0.8	2.3	15.3	18.4	−5.5	9.8	22.4
Suvorovo	6.6	−3.7	6.5	−6.7	−7.6	−1.5	−3.7	−6.9	14.7	23.3	−3.0	2.6	20.5
Dalgopol	0.1	−13.5	1.7	−7.6	−10.2	2.0	9.5	−9.7	17.6	23.5	−12.9	3.0	3.3

Table 9. Average monthly sums of rainfall deviations in southeastern Bulgaria for the period 1986–2015.

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Karnobat	−1.3	−2.2	10.7	−5.3	−1.7	−5.5	1.0	12.1	11.2	22.1	−6.6	2.6	37.2
M. Tarnovo	−35.9	−21.3	−10.1	−16.2	−6.8	−6.4	15.4	3.1	11.5	20.0	−4.0	−18.9	−69.7
Yambol	2.9	−3.6	10.0	−7.0	−4.3	−4.0	12.0	−7.2	11.3	9.5	−6.8	−0.5	12.4
Elhovo	−6.9	−1.6	1.2	−0.9	−5.6	1.7	1.0	−1.6	18.7	20.1	−3.9	2.7	24.8
Sliven	−1.1	−2.3	5.1	−5.0	−2.8	1.8	−4.7	3.2	16.9	6.6	−11.5	−1.2	5.0

Table 10. Average monthly sums of rainfall deviations in central south Bulgaria in the period 1986–2015.

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
St. Zagora	−3.6	−1.1	3.1	−6.5	−4.3	−7.2	−0.5	−7.8	11.4	0.8	−7.7	−0.6	−24.0
Chirpan	−4.0	−1.7	5.5	−6.6	−7.6	−11.7	3.3	−15.9	18.0	8.2	−10.2	2.4	−20.3
Kazanlak	1.5	1.0	0.3	−2.5	−5.0	2.2	−5.5	−9.8	16.3	9.1	−5.7	6.2	8.0
Haskovo	−2.8	7.1	2.1	−7.4	−3.1	−13.6	0.0	−10.0	8.5	13.9	−5.4	2.5	−8.2
Karfzhali	−5.1	4.3	3.2	−1.8	0.5	−7.5	−8.6	−8.0	11.4	1.9	−10.5	−1.9	−22.1
Krumovgrad	−3.8	−0.2	−0.2	−8.2	−11.6	−3.4	−3.2	−0.3	12.8	9.8	12.0	−9.8	−6.1
Ivajlovgrad	−3.9	−2.8	−6.4	−9.7	−5.7	−18.6	−6.9	−3.2	2.2	15.2	2.1	−4.5	−42.3
Plovdiv	−2.5	0.9	7.8	−3.4	−9.6	−2.9	−3.8	−0.2	9.9	12.0	−7.6	5.1	6.0
Sadovo	1.9	5.6	7.0	0.6	−7.3	−7.6	0.4	8.8	9.4	12.5	−5.0	8.1	34.5
Asenovgrad	−3.3	5.6	5.5	0.1	−6.0	−1.5	4.6	8.4	11.7	13.6	−10.1	5.9	34.7
Karlovo	−2.0	−1.4	−2.2	5.5	−5.2	−3.1	−1.6	−27.0	10.4	11.2	−8.6	2.2	−21.9
Pazardzhik	−1.4	1.7	1.7	−4.8	−6.8	9.8	−1.3	−0.3	8.2	11.6	−13.3	5.6	10.7

Table 11. Average monthly sums of rainfall deviations in southwestern Bulgaria in the period 1986–2015.

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Blagoevgrad	1.3	1.0	3.9	6.9	−8.4	−2.4	2.3	−4.9	15.0	19.3	−12.2	11.3	33.1
Sandanski	−2.1	−3.5	−2.0	3.2	−3.6	4.7	−0.1	−5.5	12.8	14.8	−18.6	6.8	6.9
Petrich	−10.7	−12.3	3.6	12.7	3.7	−0.9	4.3	3.0	12.8	17.1	−23.7	−1.9	7.8
Kyustendil	−4.8	−4.1	−2.5	2.9	−9.8	2.3	−6.1	−1.4	8.2	16.1	−16.6	0.8	−15.0
Sofia	6.4	2.0	2.8	1.0	−0.1	−0.4	−7.5	5.7	16.7	17.0	−10.3	1.2	34.4

Table 12. Average monthly sums of rainfall deviations in northwestern Bulgaria in the period 1986–2015.

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Vidin	1.9	−1.1	−5.9	−4.3	−8.5	−16.0	7.7	6.1	8.1	9.1	−8.2	6.3	−4.8
Gramada	7.8	−2.2	−5.1	0.6	−15.0	−13.0	6.1	11.9	9.1	8.4	−4.5	13.0	17.0
Montana	0.8	−1.7	1.4	2.4	−13.5	−18.8	4.5	3.9	8.7	9.2	−14.6	2.0	−15.6
D-r Josifovo	1.1	−7.0	−2.5	6.0	−1.6	−18.0	5.8	0.6	11.9	16.6	−11.4	2.7	4.1
Bazovets	2.6	−2.4	−2.1	−0.2	−6.0	−7.6	2.3	−1.6	10.8	12.6	−9.7	0.1	−1.1
Lom	3.1	−0.9	−1.5	5.8	3.4	−12.2	18.2	6.3	12.0	8.4	−10.4	3.0	35.2
Vratsa	−0.2	−0.1	−3.8	7.5	−10.0	−15.6	−0.3	25.7	9.9	16.7	−14.7	−0.5	14.7
Knezha	1.2	−0.3	−0.4	4.8	−5.6	−13.2	3.4	−9.8	8.8	13.5	−12.8	2.7	−7.6
Oryahovo	−2.7	−4.4	−5.0	3.3	3.7	−8.6	6.3	3.5	8.8	10.2	−11.5	0.0	3.6

Rainfall across the country showed a visible negative trend in November. The highest values of this deviation were in northwestern and southwestern Bulgaria.

The significant increase in the yearly rainfall sums was observed in the northeastern part of the country—Razgrad, Shumen, and Varna of approximately 10–18%, Figure 4. An insignificant decrease was detected in some of the meteorological stations in central and western Bulgaria.

Table 13. Average monthly sums of rainfall deviations in central north Bulgaria in the period 1986–2015.

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Pleven	−6.4	−3.7	3.0	4.2	−4.6	−16.7	10.6	−6.7	11.3	11.4	−12.9	1.7	−8.9
Novachene	0.2	−1.8	−4.0	0.8	−5.1	3.4	7.1	−11.1	13.1	13.1	−10.7	1.7	6.7
Nikolaevo	−5.4	−5.7	2.3	2.5	−12.1	−23.0	3.3	−17.4	12.3	14.6	−10.4	1.8	−37.2
Borima	−2.8	−3.8	7.1	−0.6	1.4	−2.7	15.9	−11.7	12.1	19.2	−14.2	4.0	24.0
Dermatsi	−12.9	−7.1	−1.8	−6.2	−4.2	−3.7	1.8	−7.4	7.1	13.6	−10.0	−4.7	−35.4
Sevlievo	−4.7	−0.7	5.6	−8.6	−4.9	−7.2	−3.6	−9.3	23.8	12.3	−6.7	2.4	−1.7
V.Tarnovo	−9.2	−4.8	2.3	−2.8	−2.9	−16.9	−1.9	−14.4	19.1	15.0	−7.4	6.6	−17.4
Pavlikeni	−10.8	−7.1	−4.6	−1.8	−2.8	−11.0	12.3	−13.1	17.8	10.7	−9.3	−0.1	−19.7
Svitshov	−2.5	−0.8	−0.8	0.9	−9.0	−0.8	3.0	−6.8	11.8	18.2	−8.0	2.6	7.8
Russe	−5.6	−5.7	−2.3	−6.0	2.0	−7.8	0.4	−3.7	15.4	20.6	−6.1	5.9	7.1
Obr. Chiflik	0.2	0.3	3.1	−7.1	−5.0	−1.8	6.5	−8.3	12.7	20.9	−0.9	8.9	29.6

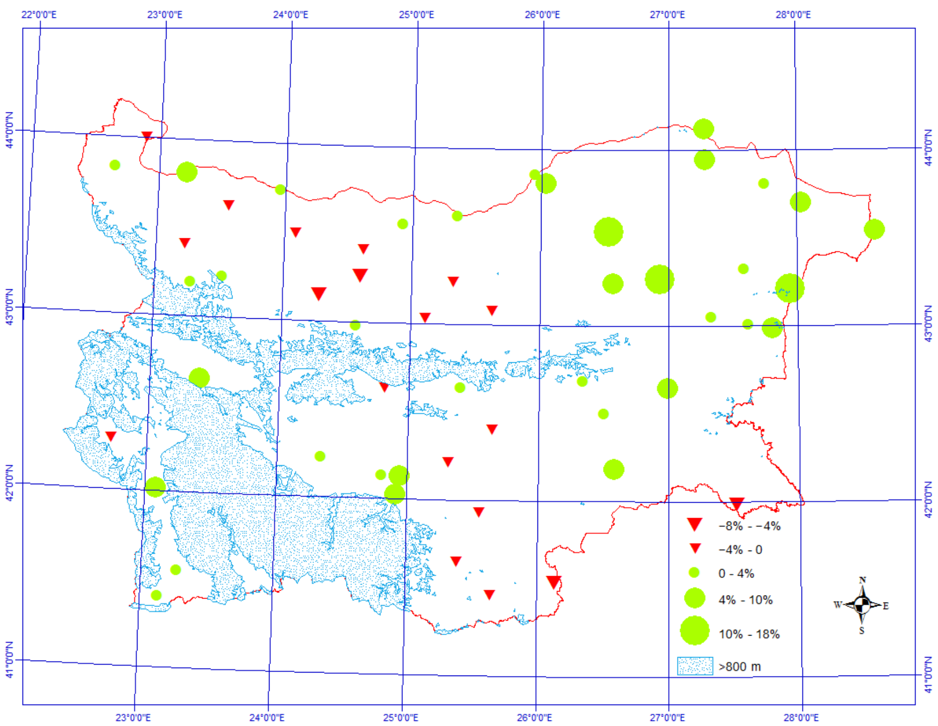


Figure 4. Deviations in yearly rainfall sums [mm]. Triangles shows decrease (−), and circles increase of rainfall sums.

3.2. Changes in Agrometeorological Conditions

Agrometeorological conditions, characterized through the temperature conditions, are defined by the dates of the transition in daily temperature across 5 and 10 °C at spring and autumn, as well as the temperature sums for the periods with higher temperatures.

3.2.1. Transition in Average Daily Temperatures across Biological Thresholds 5 °C and 10 °C

The length of the period limited by the temperature transition at 5 °C in spring and autumn determines the potential growing season for autumn crops, and the sum of temperatures above this threshold is the sum of effective temperatures above 5 °C. The case concerning the transition in temperatures through 10 °C is similar. This transition defines the onset of spring and autumn as seasons. The permanent retention of temperatures above 10 °C is associated with the transition to active vegetation of autumn crops and sowing and vegetation of spring crops; therefore, this period appropriately characterizes the duration of the actual growing season. The longer period with an average daily air temperature above 10 °C, and the higher the sum of temperatures above this threshold. An earlier transition across 5 °C of 3–9 days was detected in northern Bulgaria. In south Bulgaria, the deviation was 3 days (Figure 5a). The deviations at the transition across 5 °C during autumn were insignificant and varied between −4–4 days (Figure 5b). The latest date of transitions was observed in the Eastern part of the country, but in the Western part the transition began earlier by 4 days.

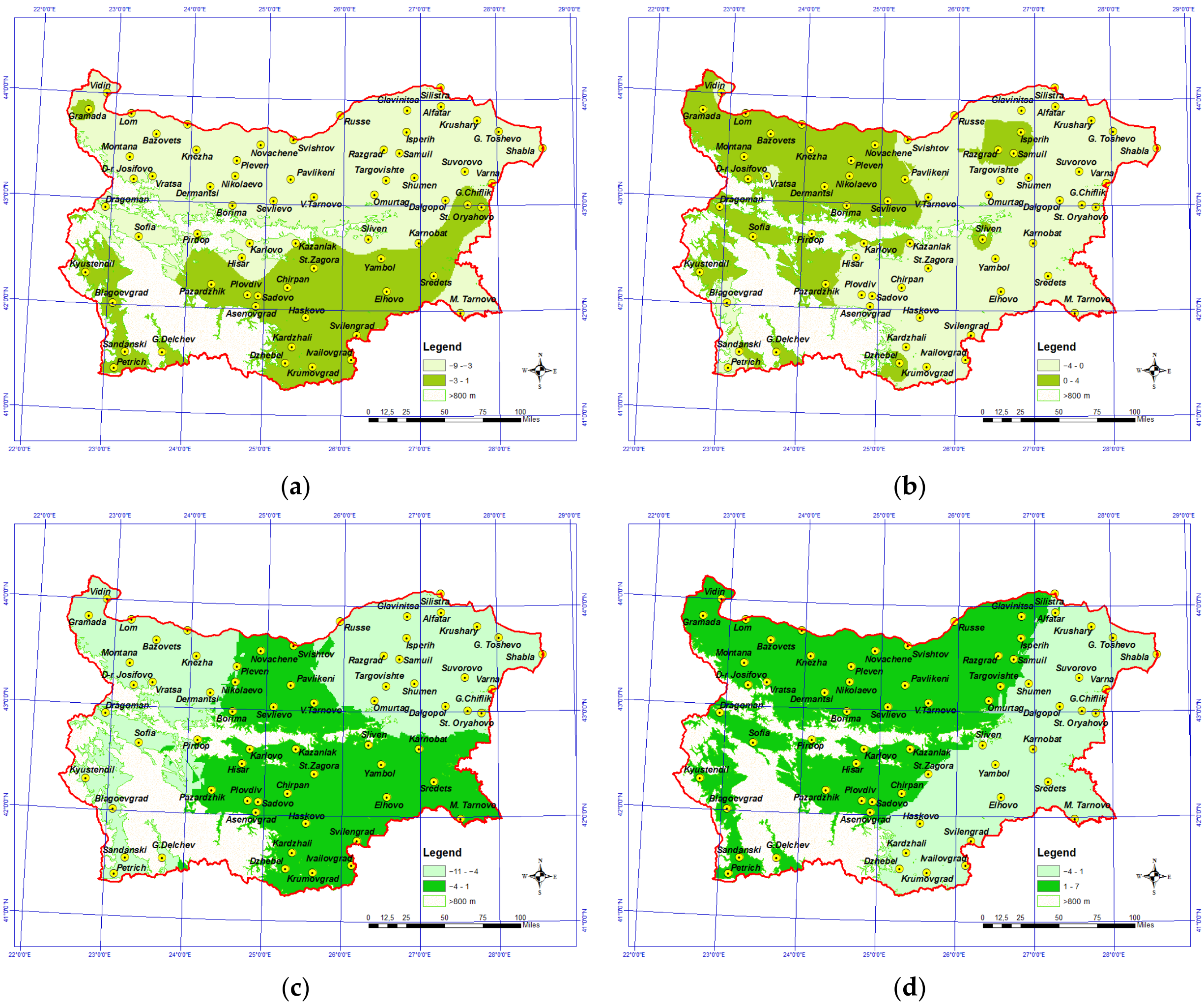


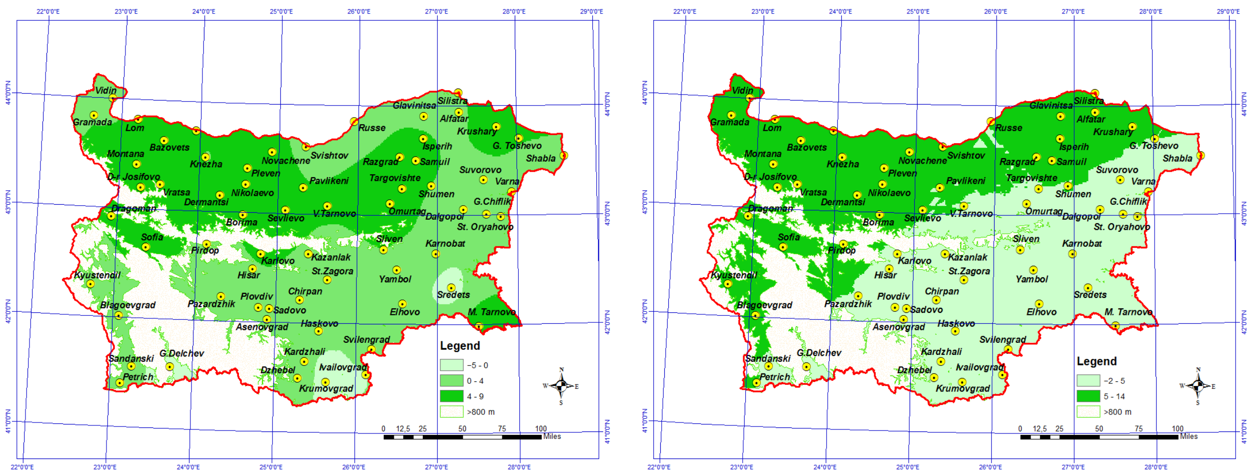
Figure 5. Deviations in the dates of transition the air temperature above and below 5 and 10 °C during the spring and autumn: (**a**) spring 5 °C; (**b**) autumn 5 °C; (**c**) spring 10 °C; and (**d**) autumn 10 °C.

The tendencies to overtake the beginning of the vegetation season in relation to the previous period were confirmed in the transition across 10 °C. The beginning of the vegetation season in the western and northeastern parts of the country was 4 to 11 days earlier, Figure 5c. In central and southeastern Bulgaria, the negative deviation was insignificant. The date of the daily air temperature transition across 10 °C in the autumn was earlier than the previous period by 4 days in the eastern part of the country and later by 1 to 7 days in the western part, Figure 5d.

3.2.2. Duration of the Period with Daily Temperature above 5 °C and 10 °C

The period with daily temperature above 5 °C in the field regions varied between 235 and 300 days.

The shortest was period in the region of Dragoman and in the western part of the Pre-Balkan area and in the western part of the Sofia field. The longest period was in south Bulgaria, except in the western part of the Thracian valley. The deviation from the previous period, as seen in Figure 6a, shows an increase of 9 days, except in the areas around Yambol, Ivaylovgrad, and Krumovgrad, where a decrease of 5 days was observed.



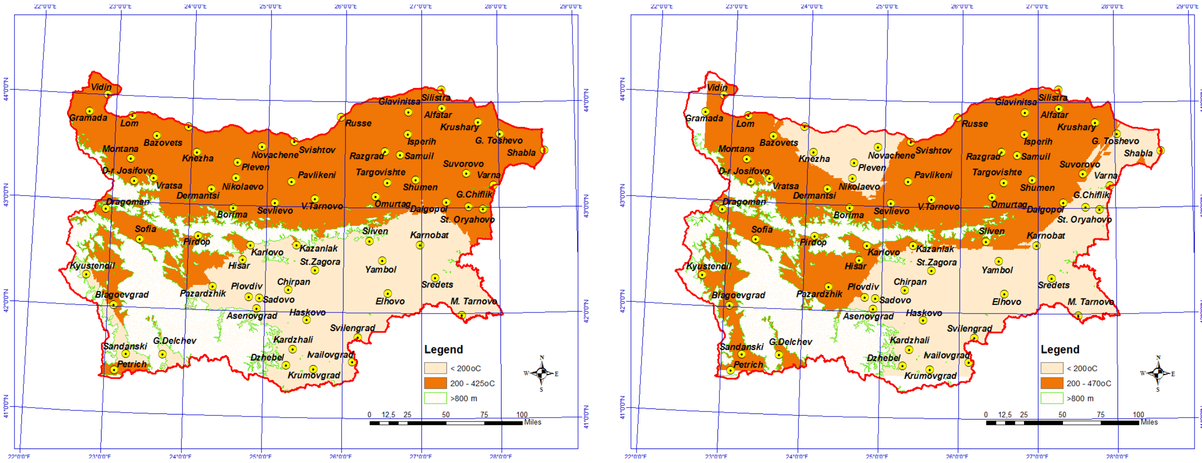
(**a**) (**b**)

Figure 6. Deviations in the duration of the period with temperatures above 5 °C (**a**) and 10 °C (**b**).

The period with temperatures higher than 10 °C varied between 191 and 263 days. Between 200–220 days is the duration of the growing season in northwestern and northeastern Bulgaria, and between 230 and 240 days in the southern parts of the country. The deviations in comparison with the previous period separate the territory of the country into two parts: first, in the northern and southwestern areas where the changes are insignificantly decreasing, and second, in the rest of the country where the period is prolonged by one week. As can be seen from the results of the transitions in air temperature across biological thresholds, the extension of the vegetation season due to earlier spring temperature raising, Figure 6b.

3.2.3. Active and Effective Temperature Sums for the Period with Temperatures above 5 °C and 10 °C

In the recent research, the heat resources are expressed through the total temperature during the growing season. These are the temperature sums with different initial and final air temperatures. The rate of the accumulation of these amounts, the frequency with which different temperature sums occur, the start and end dates of occurrence of favorable temperatures for vegetation, and the average temperatures of the warmest month are presented as a deviation of the sum of temperatures for the investigated period with average air temperatures above 5 °C and 10 °C in the above-mentioned reference period, Figure 7. An increase between 200 and 420 °C of the temperatures sums during the period with temperatures higher than 5 °C was observed in the northern and southwestern part of the country. The deviation was similar in the temperature sums during the period with temperatures higher than 10 °C, Figure 7a,b.



(**a**) (**b**)

Figure 7. Deviations in sums of temperature during the period with temperatures above 5 °C (**a**) and 10 °C (**b**).

3.3. Changes in Rainfall Sums during the Vegetation Season

There are three periods for characterizing the moisturizing conditions for agrometeorological aims. During October–March, a significant increase (above 10%) was detected in northeastern Bulgaria, Figure 8a. This tendency is favorable because the region is characterized with smaller rainfall and soil water deficit during the period of accumulation. A decrease was observed in central north Bulgaria, eastern Bulgaria, and Sandanski. This period is connected to the accumulation of the soil water supply, and the quantities of supplies determine crop development of spring vegetation or of winter wheat. The previous investigations for the period 1971–2000 show that at the end of the soil water accumulation period in the central north Danube plain, the rooting depth reached field capacity (FC). The decrease in precipitation by 10% could cause a 5–7% decrease in the soil water supplies.

The second period is April–June when vegetation is restored at winter wheat and the vegetation stages of spring crops begin, Figure 8b. The deviations during this period are negative. The decrease seen in central and northeastern Bulgaria varied between 10% and 15%. The biggest decrease was observed in the ending western station Vidin 16% and in the ending south station Ivaylovgrad—20%. The significant positive deviations were detected in the most southern station Petrich.

The third period VI–VIII is characterized by the conditions of the vegetation of spring crops, Figure 8c. A significant decrease was detected in central south and part of the central Danube plain. The deviation varied between 7–25%. The significant increase (above 10%) in rainfall during VI–VIII was observed in two stations in northeastern Bulgaria—Razgrad and Shabla. In this region the tendencies were different—there were negative and positive deviations.

3.4. Potential Evapotranspiration (ETo) Dynamics

The potential evapotranspiration is the complex agrometeorological index and content changes in the main meteorological parameters. Long term values of ETo for the period of investigation were studied. They were compared with those of the referent period, and deviations were analyzed. The investigation was made for three periods—March–October, April–June, and July–August, Figure 9.

During the first period, March–October, the deviations were mostly positive. The significant increase in the values of ETo were observed in the western and central part of the Danube plain and in the Thracian valley, Sadovo, Pazardzhik, and Karlovo. The negative deviations were insignificant.

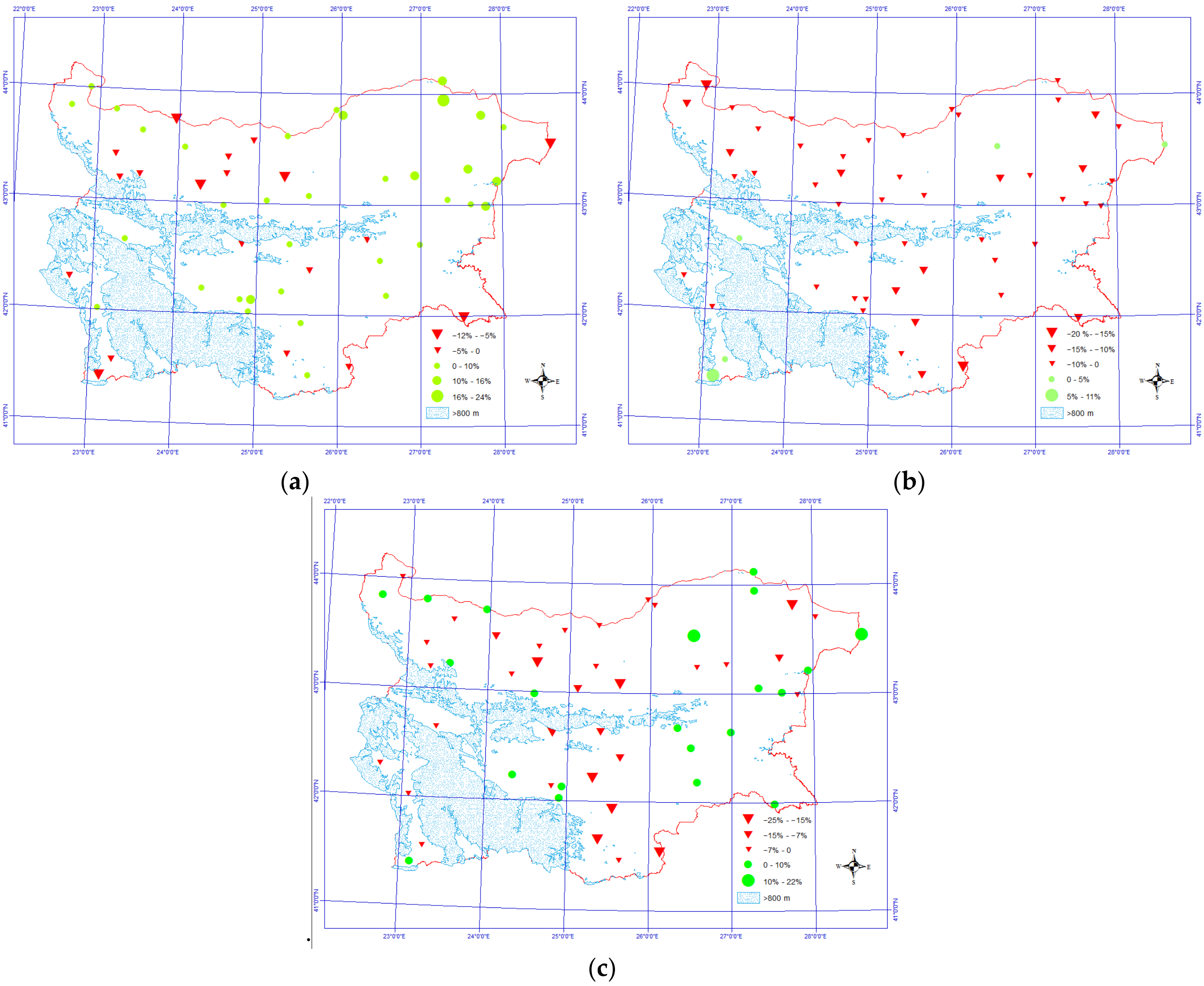
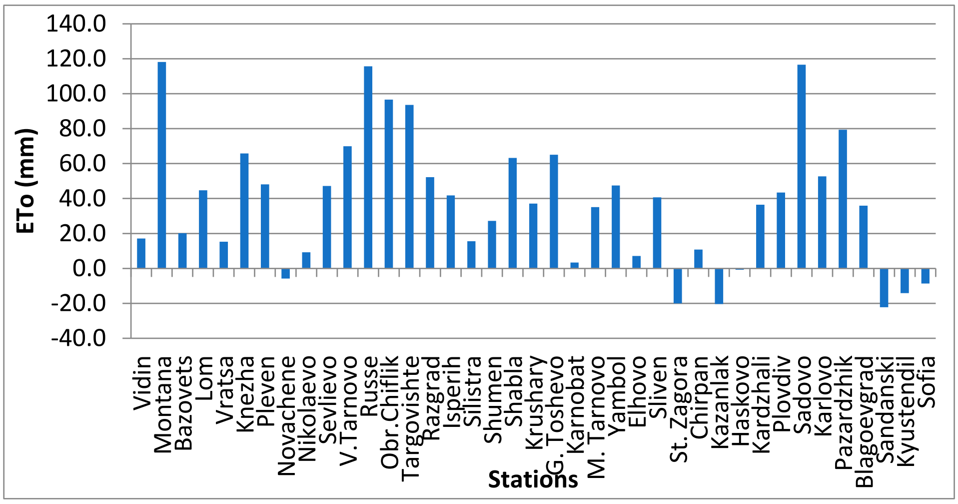
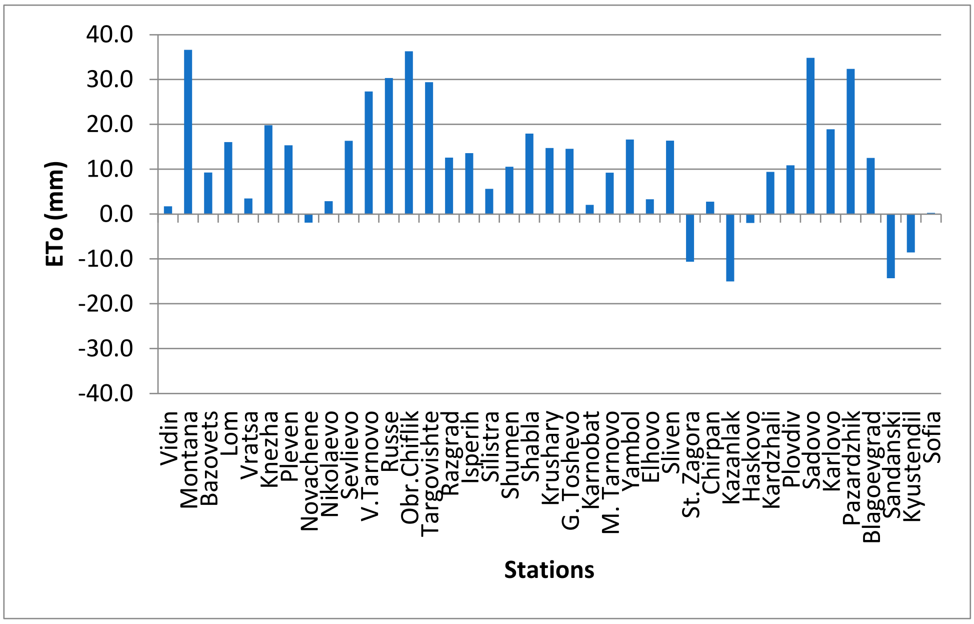


Figure 8. Deviations of rainfall sums during the periods: (**a**) October–March; (**b**) April–June; (**c**) June–August.

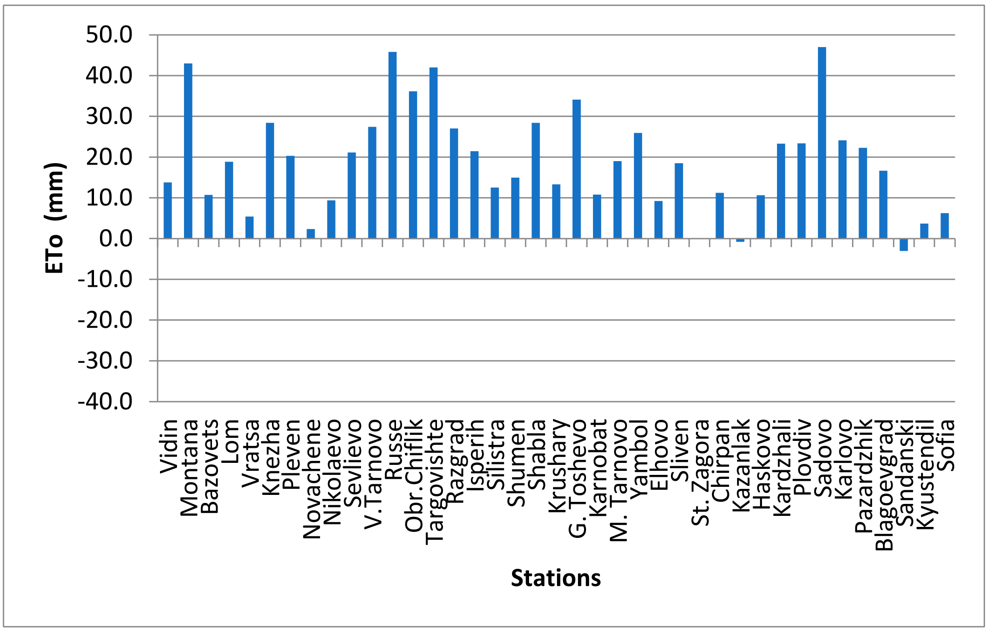


(**a**)

Figure 9. *Cont.*



(**b**)



(**c**)

Figure 9. Deviation in the sum of ETo (mm) for the periods: (**a**) March–October; (**b**) April–June; (**c**) July–August. During the second period IV–VI the tendencies in the changes are the same, Figure 9b. The biggest increase in the water deficit was observed during the third period VI–VIII with values between 20–40 mm.

Using the annual values for precipitation and the values for the potential evapotranspiration for each year of the study period calculated by the Penman-Monteith equation, through their ratio, we obtained the values of the drought index (AI). According to the value of AI, the years are classified as dry, normal, or humid.

When summarizing the results of this research, it should be noted that there is a permanent trend of increasing average monthly temperatures, with the exception of the month of December. Regardless of the increase in the annual amount of precipitation by up to 10–18%, the tendency for the occurrence of long dry periods is maintained. In some of the main grain-producing regions in eastern and central south Bulgaria, their distribution during the growing season shows deterioration in moisture conditions.

The changes in conditions put agricultural producers in Bulgaria to the test. The consequences are different for every group of crops—wintering, spring crops, and orchards. The increase in summer temperatures by up to 2.4 °C and the increase in the sum of the ballast temperatures caused by this (above the optimum for growth processes) add stress and affect the fertility of pollen during the generative stage—pollination and fertilization. In combination with a deficit in precipitation observed in central and part of northeastern Bulgaria, the increase in summer temperatures causes prolonged dry periods, which often turn into autumn droughts. This worsens the agrometeorological conditions in the last stages of the development of spring crops—maize, sunflower, cotton—and in the initial stages of the development of winter crops—wheat and rape.

The increase in average monthly temperatures in January by up to 1.9 °C, February by up to 1.1 °C, and March by 1.3 °C shift the permanent transition through 5 °C to an earlier date, extending the period with temperatures higher than 5 °C. This, however, cannot be assessed as a positive effect of climate changes. Higher temperatures allow slow crop development during this period as well but increase the risk of frost damages due to loss of cold hardiness. In the case of fruit trees, the earlier development of early flowering crops—almonds, plums, cherries, peaches and apricots—is also provoked, which increases the risk of frost damages. Despite this, the threat of critical cold temperatures in winter remains, regardless of the lower probability of occurrence.

4. Conclusions

The outlined trends in the change in hydro-thermal conditions imply undertaking appropriate changes in technology, in crop zoning, and creation of varieties and hybrids with high plasticity for maximum use of the natural agroclimatic resources in each of the regions in the country. This will help to:

1. Draw up precise and highly reliable and sufficiently advanced forecasts for agrometeorological conditions, for the growth and development of crops and expected yields;
2. Guide breeders when creating new varieties and hybrids;
3. Update agroclimatic zoning of agricultural crops
4. Optimize the varietal and hybrid composition of cultivated crops for the maximum use of agroclimatic resources;

The application of the obtained scientific results in programs for managing agriculture with a view to their multiplication and they can be realized by:

- Shifting the sowing dates to adapt crops to rising temperatures. This will allow the crops to develop during a period with temperature closer to most favorable, optimizing the growing duration, especially the grain filling period on the grain crops;
- Growing varieties of autumn crops with an appropriate period of development, which will allow them to use the maximum accumulated soil water and the temperatures above 5 °C in the months of December, January, and February.
- Using cultivars and hybrids with a shorter growing season as spring crops in the areas with summer droughts and ones with a longer growing season in the regions with drought during the winter;
- Focusing on early and mid-early varieties during the growing season from April to October in conditions of dry spell and drought with tendencies for rising temperatures, which would allow the crops to complete their development earlier and exclude the loss of yields by extreme agrometeorological conditions;
- Seeking the advice and competence of experts for the deployment of precision agriculture in the context of dynamically changing agroclimatic conditions, which will minimize expenses and increase competitiveness of production.

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