PROJECTIONS OF CHANGES IN AGROCLIMATIC CONDITIONS IN THE REPUBLIC OF MOLDOVA ACCORDING TO AN ENSEMBLE FROM 10 GSMS FOR SRES A2, A1B AND B1 EMISSION SCENARIOS IN THE XXI CENTURY

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Abstract: A set of agroclimatic indices: frost, frost free period; length of growing season; active growing degree days, effective growing degree days; potential evaporation; Ivanov's Aridity Index; Hydro-thermal coefficient and Index of biological effectiveness of the climate representing the heat and humidity conditions during the growing season was computed from 30-yr daily climatic observed data for a baseline period 1961-1990 and three future 30-yr time periods (2020s, 2050s and 2080s) based on an ensemble of 10 GCMs for SRES A2, A1B and B1 emission scenarios. Due to climate change is expected a significant increase in the length of the growing season and associated available heat. For all three SRES emission scenarios are expected worsening of the humidity conditions throughout the Republic of Moldova's Agro-Ecological Zones. Reduced rainfall in the summer and autumn period against a background of rising temperatures will cause the strong moisture deficit and sequential increase of the potential evaporation and accelerate considerably climate aridization process during the growing season in the XXI century. IBEC clearly shows the latitude-zonal pattern of climate variability and gradual worsening of optimal ecological-climatic characteristics for plant growing, including the northern areas by 2080s.

Key words: *Agroclimatic indices, climate change, frost free period, length of growing season, growing degree days*

1. INTRODUCTION

Climate change is expected to affect both regional and global food production through changes in overall agroclimatic conditions [1; 2]. To date, there have been a limited number of reports [3; 4] dealing with the changes expected in agroclimatic parameters at the pan-European scale, and many of these are review articles [5-7]. Most studies of climate change impacts on crop yields apply either statistical models [8] or process-based crop simulation models [9-11]. Most process-based models are also capable of simulating, in addition, effects of enhanced CO2 concentration and management practices on biomass, seed yields and water use of crops [12-14]. However, even the more complex process based crop simulation models cannot take all important interactions between the environment and management into account, such as effects of heavy rainfall on harvested yield. Neither do they include all interactions between genotype and environment such as yield reduction due to weather-induced pest and/or disease occurrence. On the other hand, crop growth simulation is the only meaningful practical way for analysing the interactions between the many options of combining different crop cultivars with diverse management practices under a wide range of possible new environmental conditions [15-17; 9;]. Usually, crop-climate models do not cover all important crops and soils in a region. For this reason, agroclimatic indices approaches are sometimes applied to provide a more comprehensive picture of the agroclimatic conditions for larger areas and its shifts under climate change [18; 19; 1; 4; 20]. The main objective of this work was: (i) to develop a set of agroclimatic indices that will be used for assessment of temporal and spatial changes in the Republic of Moldova's agroclimatic conditions due to climate change; and (ii) to evaluate how the temperature – based and humidity agroclimatic indices is likely to change in time (by the 2020s, 2050s, 2080s) and space (Northern, Central and Southern Agro - Ecological Zones) under an ensemble of 10 GCM for three SRES A2 (high), A1B (medium) and B1 (low) emission scenarios.

2. DATA AND METHODS

2.1. Climate change scenarios

The model simulations for precipitation and temperature used in this study stem from 10 of the global coupled atmosphere ocean general circulation models (AOGCMs) made available by the World Climate Research Program (WCRP) Coupled Models Intercomparison Program Phase 3 (CMIP3) [21]: **CSIROMk3** (Australia's Commonwealth Scientific and Industrial Research Organisation, Australia), **ECHAM5-OM** (Max-Planck-Institute for Meteorology, Germany), **HadCM3** (UK Met. Office, UK), **BCCR_BCM2.0** (Bjerknes Centre for Climate Research, Norway), **CCCma_CGCM3_T63** (Canadian Center for Climate Modeling and Analysis, Canada), **NIES_MIROC3.2_medres, NIES_MIROC3.2_hires** (National Institute for Environmental Studies; Japan), **MRI_CGCM2.3.2** (Meteorological Research Institute, Japan), **NCAR_CCSM3** (National Centre for Atmospheric Research, USA), **GFDL_CM2.1** (Geophysical Fluid Dynamics Laboratory, USA) model experiments for SRES A2, A1B and B1 were downloaded from: (http://www.ipcc-data.org/gcm/monthly/SRES_AR4/index.html). Totally, 37 simulations for 10 global coupled atmosphere ocean general circulation models (GCMs) were downloaded and assessed. The GCM simulations were grouped into three multi-model ensembles depending on the different IPCC emission scenarios SRES A2, A1B and B1[22] and the climatic changes over the RM AEZs were computed for tree different future periods (2020s, 2050s and 2080s) with respect to the baseline 1961-1990 [23].

2.2. Agroclimatic indices

In this study, thermal and humidity agroclimatic indices were calculated from 30-yr daily climatic observed data for a baseline period 1961-1990, current climate 1991-2010 and for three future 30-yr time periods (2020s, 2050s and 2080s) based on projections of changes in temperature received by regionalization of global experiments the most reliable in the Republic of Moldova (RM) 10 GCMs for three SRES A2, A1B and B1 emission scenarios of greenhouse gases and aerosols. Producers traditionally determine the actual length of a growing season and the suitable dates for planting and harvesting field crops by the number of frost-free days (FFP), which include period between the date of the last spring frost (LFD), and the date of the first fall frost (FFD), respectively. A day with average temperature above than 0ºC is considered a frost-free day, as frost often occurs when daily average temperature is below 0ºC. The length of the growing season (LGS) is another widely used index. In our study, LGS $_{5,\,10,\,15\,°C}$ is defined as the period from the growing season start (GSS $_{5,\,10,\,15\,°C}$) to the growing season end (GSE). The GSS $_{5,\,10,\,15\,°C}$ is the earliest date of series of days with the mean daily air temperature of $\geq$ 5, 10 and 15 ºC that is the beginning of such cumulated series of daily mean temperature deviations from the threshold value of 5, 10 and 15 ºC that do not have negative values up to the end of the first 6 month of the year. The GSE $_{5,\,10,\,15°C}$ in a given year is a day directly preceding the earliest date after the beginning of GSE $_{5,\,10,\,15°C}$ of a series of days with the mean daily air temperature of $\leq$ 5, 10 and 15 ºC that is the beginning of such cumulated series of daily mean temperature deviations from the threshold value of 5, 10 and 15 ºC that do not have positive values up to the end of a year. The definition of LGS $_{5,\,10,\,15\,°C}$ is particularly relevant for measuring change of agricultural environment.

Crops grow when the daily T_{avg} is above a given temperature threshold, varying according to the specie and its phenological state. The active growing degree day (AGDD $_{5,\,10°C}$) and effective growing degree day (EGDD $_{5,\,10\,°C}$) has been used to assist in selections of crops and hybrids to assure the selected crops will achieve maximum growth at the time they reach maturity and potential yield. The AGDD $_{T\,b}$ for two different temperature thresholds (5 and 10 ºC) was computed according to: $AGDD_{T_b} = \sum_{k=1}^{n} \mathrm{T_{avg}}$ (1), where n is the number of days in a given growing season, T_{avg} is the daily average temperature from the start (GSS $_{5,\,10°C}$) to the end (GSE $_{5,\,10°C}$) of the growing season and T $_b$ is the cardinal temperature (5, 10°C) for initiation and termination of growth for different crop types.

The EGDD T $_b$ for three different temperature thresholds or base temperature T_b (5 and 10 ºC) was computed according to: $EGDD_{T_b} = \sum_{k=1}^{n}\left(T_{avg} - T_b\right)$ (2), where n is the number of days in a given growing season, T_{avg} is the daily average temperature from the start GSS $_{5,\,10°C}$) to the end (GSE $_{5,\,10°C}$) of the growing season and T $_b$ is the cardinal temperature 5 and 10°C for initiation and termination of growth for different crop types. There is no accumulation in EGDD if T_{avg} < T $_b$.

Ivanov's aridity index (AI) was used to perform analysis of the temperature/humidity ratio development: $E = 0.001825{+}T2(100{-}a)$ (3); $AI{=}P/E$ (4), where E - the potential evaporation (mm), T - is average monthly air temperature (°C), a – relative humidity (%), and P - the sum of precipitation values (mm). The indicator allows assessing the development of the climate aridity rate throughout the year or during certain periods which are crucial for certain crops or species. The aridity rate was assessed using the following assessment scale: AI ≤ *0.05 – hyper-arid climate;* AI = *(0.05 – 0.20) – arid climate;* AI = *(0.21 – 0.50) – semi-arid climate;* AI = *(0.51 – 0.65) – dry-sub-humid climate; and* AI ≥ *0.65 – sub-humid and humid climate.*

In addition to AI to assess climate AEZs of the region was used another integral Ivanov's Index of the Biological Effectiveness of the Climate (IBEC), IBEC is a product of the sum of active temperatures above 10°C in hundreds of degrees: $\mathrm{IBEC} = 0.01 \sum \mathrm{T}_{>10°C}\, AI$ (5). IBEC synthesizes the most important climatic variables: precipitation, temperature and relative humidity of the air covered in their annual cycle, as well as the annual heat supply; and well expresses the general ecological background.

An assessment of the Hydro-thermal coefficient (HTC) was performed to identify the climate change patterns during the plant vegetation period. HTC is a relative empirical index, which reflects the humidity rate and which is calculated as the ratio between the sum precipitation level (R) expressed in millimeters for the period with the average daily air temperatures above 10°C and the sum of daily average temperatures above 10°C ($\sum T$) for the same period of time divided by 10: $HTC = R/0.1\sum T_{>10°C}$ (6), when the value of that index is 1.0 it means that the amount of the precipitations is equal to the amount of the evaporated moisture. HTC is frequently used for monitoring drought conditions during growing period, where: HTC> *1 - sufficient humidity;* HTC $\leq$ *0.7 - drought conditions;* HTC = *0.6 - medium drought;* HTC $\leq$ *0.5 - strong drought* [24].

3. RESULTS AND DISCUSSIONS

3.1. Temperature based agroclimatic indices

3.1.1. Frost indices

In the future RM's climate due to the FFD delay and earliest occurrence of LFD can be expected a substantial decrease in the FP. The duration of the FP with temperatures below 0ºC for baseline climate have been varied from 105 days in the north of the country to 83 days in the south. As a result of climate change by the 2020s the duration of the FP may decrease from 14 days (according to the scenario B1) to 17 days (under A2) to in the Northern AEZ. In the Central and Southern AEZs the duration of the FP will decrease in both scenarios for 9-11 days, respectively. By the end of 2080s, duration of the FP in the Central and Southern AEZs will decrease significantly from 44-56 days (B1) to 71-75 days (A2). The lowest decrease is expected in the Northern AEZ from 33 to 68 days (Table 1).

Table 1: Projected Ensemble Changes of the FFD $_{0°C}$, LFD $_{0°C}$ Dates and FP when Average Daily Air Temperature is below 0ºC (Days) for SRES A2, A1B and B1 Emission Scenarios to the 1961-1990 Climatological Baseline Period in XXI Century

AEZ	**A2**			**A1B**			**B1**		
	FFD	**LFD**	**FP (+/-)**	**FFD**	**LFD**	**FP (+/-)**	**FFD**	**LFD**	**FP (+/-)**
				2020s					
Northern	10/12	08/03	**-17**	06/12	07/03	**-14**	06/12	07/03	**-14**
Central	15/12	01/03	**-9**	18/12	29/02	**-12**	17/12	01/03	**-11**
Southern	14/12	27/02	**-9**	16/12	26/02	**-11**	14/12	27/02	**-10**
				2050s					
Northern	15/12	01/03	**-41**	15/12	27/02	**-31**	08/12	05/03	**-21**
Central	31/12	18/02	**-36**	01/01	13/02	**-42**	24/03	15/02	**-30**
Southern	31/12	07/02	**-45**	30/12	06/02	**-44**	25/12	14/02	**-32**
				2050s					
Northern	04/01	15/02	**-68**	24/12	17/02	**-57**	16/12	27/02	**-33**
Central	07/01	24/01	**-75**	06/01	28/01	**-71**	01/01	15/02	**-44**
Southern	07/01	23/01	**-71**	07/01	31/01	**-67**	01/01	15/02	**-56**

Note. *The observed mean for baseline period 1961-1990: the FFD $_{0°C}$, date - Briceni (30/11); Chisinau (10/12); Cahul (09/12); the LFD $_{0°C}$, date Briceni (16/03); Chisinau (06/03); Cahul (03/03); FP length of the period with the average daily air temperature is below 0°C, days - Briceni (105); Chisinau (85); Cahul (83).*

3.1.2. Growing season and frost free period

In the future RM's climate due to the earlier start of spring and autumn elongation can be expected a substantial increase in the FFP. The duration of the FFP with temperatures above 0ºC for baseline climate have been varied from 260 days in the north of the country to 282 days in the south. As a result of climate change by the 2020s the duration of the FFP may increase from 14 days (according to the scenario B1) to 17 days (under A2) to in the Northern AEZ. In the Central and Southern AEZs the duration of the FFP will increase in both scenarios for 9-11 days, respectively. By the end of 2080s, duration of the FFP in the Central and Southern AEZs will increase significantly from 44-56 days (B1) to 71-75 days (A2). The lowest growth is expected in the Northern AEZ from 33 to 68 days (Table 2).

Table 2: Projected Ensemble Changes of the LSF $_{0°C}$, FFD $_{0°C}$, (Dates) and FFP (Days) for SRES A2, A1B and B1 Emission Scenarios to the 1961-1990 Climatological Baseline Period in XXI Century

AEZ	A2			A1B			B1		
	LSF $_{0°C}$	**FFD $_{0°C}$**	**FFP (+/-)**	**LSF $_{0°C}$**	**FFD $_{0°C}$**	**FFP(+/-)**	**LSF $_{0°C}$**	**FFD $_{0°C}$**	**FFP(+/-)**
2020s									
Northern	08/03	10/12	**+17**	07/03	06/12	**+15**	07/03	06/12	**+14**
Central	01/03	15/12	**+9**	29/02	18/12	**+12**	01/03	17/12	**+11**
Southern	27/02	14/12	**+9**	26/02	16/12	**+11**	27/02	14/12	**+10**
2050s									
Northern	01/03	15/12	**+41**	27/02	15/12	**+31**	05/03	08/12	**+21**
Central	18/02	31/12	**+36**	13/02	01/01	**+42**	15/02	24/03	**+30**
Southern	07/02	31/12	**+45**	06/02	30/12	**+44**	14/02	25/12	**+32**
2080s									
Northern	15/02	04/01	**+68**	17/02	24/12	**+57**	27/02	16/12	**+33**
Central	24/01	07/01	**+75**	28/01	06/01	**+71**	15/02	01/01	**+44**
Southern	23/01	07/01	**+71**	31/01	07/01	**+67**	15/02	01/01	**+56**

Note. *The observed mean for baseline period 1961-1990: the LFD $_{0°C}$, date - Briceni (16/03); Chisinau (06/03); Cahul (03/03); the FFD $_{0°C}$, date - Briceni (30/11); Chisinau (10/12); Cahul (09/12); FFP length of the period with the average daily air temperature is above 0°C, days - Briceni (260); Chisinau (280); Cahul (282).*

The LGS $_{5°C}$ for basic climate varies from 222 days in the north of the country up to 236 days in the south. Analysis of the data presented in the Table 4, shows that the LGS $_{5°C}$ will elongate, and its increase in the 2020s for the Northern and Southern AEZs can be from a week (A2) up to 5-9 days (B1), respectively. In the central region the duration of the growing season will increase in both scenarios, by 12 days. The tendency to maximum increase of the LGS $_{5°C}$ in the Central region will persist, and by the 2080's is expected that such periods will be 24-36 days longer. For all agro-ecological zones by the end of the century the LGS $_{5°C}$ will increase, mainly due to a late finish in the autumn (from 7 to 20[1] days in the Northern; 14 to 23 days in Central; and 14 to 20 days later in Southern AEZs), while the spring vegetation will start earlier than usual from 7 to 12 days in the Northern; from 9 to 13 days in Central; and from 7 to 10 days before in Southern AEZs (Table 3).

Table 3: Projected Ensemble Changes of the GSS $_{5°C}$, GSE $_{5°C}$ (Dates) and LGS $_{5°C}$ (Days) for SRES A2, A1B and B1 Emission Scenarios to the 1961-1990 Climatological Baseline Period in XXI Century

AEZ	A2			A1B			B1		
	GSS $_{5°C}$	**GSE $_{5°C}$**	(+/-)	**GSS $_{5°C}$**	**GSE $_{5°C}$**	(+/-)	**GSS $_{5°C}$**	**GSE $_{5°C}$**	(+/-)
2020s									
Northern	25/03	08/11	**+7**	25/03	07/11	**+6**	26/03	07/11	**+5**
Central	22/03	18/11	**+12**	21/03	18/11	**+13**	20/03	17/11	**+12**
Southern	21/03	18/11	**+7**	19/03	20/11	**+11**	20/03	18/11	**+9**
2050s									
Northern	22/03	14/11	**+16**	22/03	13/11	**+16**	23/03	10/11	**+11**
Central	19/03	23/11	**+19**	16/03	25/11	**+24**	19/03	21/11	**+19**
Southern	17/03	25/11	**+13**	14/03	27/11	**+22**	17/03	23/11	**+16**
2080s									
Northern	17/03	25/11	**+32**	18/03	18/11	**+25**	22/03	12/11	**+14**
Central	13/03	04/12	**+36**	08/03	30/11	**+37**	17/03	25/11	**+24**
Southern	12/03	02/12	**+30**	10/03	28/11	**+28**	15/03	26/11	**+21**

Note. *The observed mean for baseline period 1961-1990: the GSS $_{5°C}$, dates - Briceni (29/03); Chisinau (26/03); Cahul (22/03); the GSE $_{5°C}$, dates - Briceni (05/11); Chisinau (11/11); Cahul (12/11); LGS $_{5°C}$, days - Briceni (222); Chisinau (231); Cahul (236).*

The LGS $_{10°C}$ for the baseline climate varies from 172 days in the North of the country up to 182 days in the South. In connection to climate change is expected that the LGS $_{10°C}$ will increase by 2020s from 21 to 22-23 days in the Southern and Central AEZ. The lowest growth by 7-10 days is possible in the Northern AEZ. The tendency to minimum increase of the LGS $_{10°C}$ in the Northern areas will persist, and by the 2080s would be expected that such periods will be only 25-37 days longer (Table 4).

[1] Here and throughout the text the first number corresponds to the B1 scenario, the second to A2 scenario.

Table 4: Projected Ensemble Changes of the GSS $_{10°C}$, GSE $_{10°C}$ (Dates) and LGS $_{10°C}$ (Days) for SRES A2, A1B and B1 Emission Scenarios Relative to the 1961-1990 Climatological Baseline Period in XXI Century

AEZ	A2			A1B			B1		
	GSS $_{10°C}$	**GSE $_{10°C}$**	**(+/-)**	**GSS $_{10°C}$**	**GSE $_{10°C}$**	**(+/-)**	**GSS $_{10°C}$**	**GSE $_{10°C}$**	**(+/-)**
2020s									
Northern	18/04	16/10	**+10**	20/04	15/10	**+7**	20/04	15/10	**+7**
Central	04/04	21/10	**+21**	02/04	22/10	**+23**	03/04	21/10	**+23**
Southern	05/04	23/10	**+21**	04/04	23/10	**+21**	03/04	23/10	**+22**
2050s									
Northern	11/04	20/10	**+20**	08/04	19/10	**+24**	13/04	17/10	**+16**
Central	31/03	25/10	**+28**	30/03	27/10	**+33**	31/03	25/10	**+29**
Southern	31/03	29/10	**+31**	29/03	29/10	**+33**	31/03	28/10	**+30**
2080s									
Northern	01/04	27/10	**+37**	04/04	23/10	**+31**	07/04	19/10	**+25**
Central	28/03	04/11	**+42**	26/03	31/10	**+40**	30/03	27/10	**+32**
Southern	27/03	05/11	**+41**	27/03	02/11	**+40**	30/03	30/10	**+34**

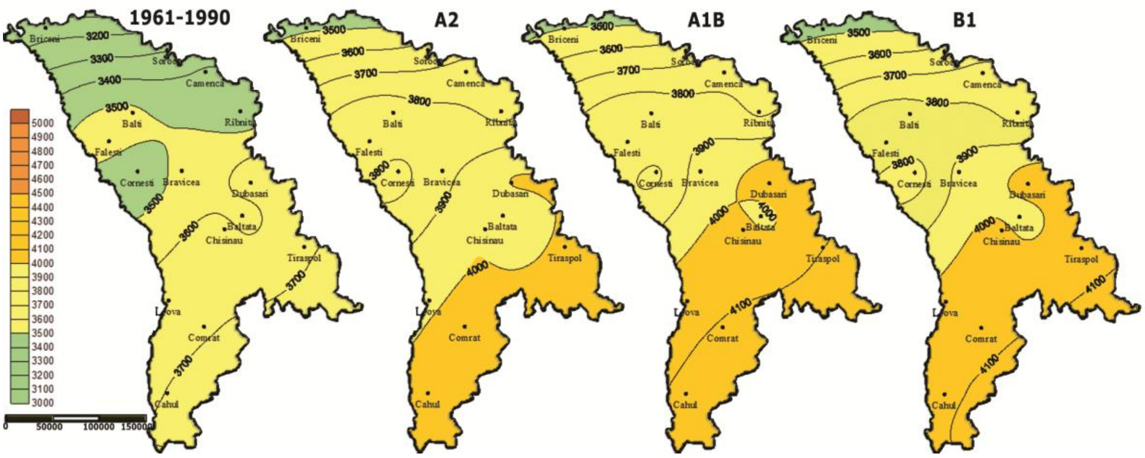
Note. *The observed mean for baseline period 1961-1990: the GSS $_{10°C}$, dates - Briceni (22/04); Chisinau (20/04); Cahul (21/04); the GSE $_{10°C}$ - Briceni (10/10); Chisinau (16/10); Cahul (19/10); LGS$_{10°C}$, days - Briceni (172); Chisinau (180); Cahul (182).*

According to [25; 26] a longer LGS could add more flexibility to some agricultural practices which could lead to maximize yields. The sowing date for summer crops is usually delayed due to high probabilities of occurrence of the last frost; therefore an earlier start of the growing season would allowed for an earlier sowing date of summer crops which would increase the possibility for example planting of double-cropping corn in the RM [27]. Much of the relevant data in literature suggests the necessity of distinguishing between the potential and the actual vegetation periods. A consequence of the higher daily mean temperatures is that the potential vegetation period will be longer. At the same time the higher temperature leads to accelerated growth and this in turn shortens the crop lifecycle, and thus the duration of the actual vegetation period is also shortened. Under such circumstances it is reasonable to either grow varieties having a longer growth season (these usually produce higher yields than varieties with a shorter growth season, and can also be stored better), or to grow after crops. In this latter case the same area can be harvested twice within the same year [27].

3.1.2. Growing Degree Days

The AGDD $_{5°C}$ and/or EGDD $_{5°C}$ for the baseline climate vary from 3105 and/or 1995 ^{o}C in the North up to 3652 and/or 2472 ^{o}C in the South of the country. The AGDD $_{5°C}$ and/or EGDD $_{5°C}$ temperatures (lower limit of the grain crops development) will increase consistently on the territory of the Republic of Moldova. According to all three scenarios in the 2020s is expected a small increase in the AGDD $_{5°C}$ and/or EGDD $_{5°C}$ about 9-11% and/or 12-16%[2], with maximum increase in Northern AEZ. By the end of 2080s the AGDD $_{5°C}$ and/or EGDD $_{5°C}$ would increase significantly under high emission scenario A2 by 34-37%, respectively by 45-50%, and will make from 4267 and 2996^{o}C for the Northern to 4911 and 3575^{o}C for the Southern AEZs; slightly lower growth is expected according to low emission scenario B1 by 21-23% and respectively by 28-30%, varying from 3779 and 2599^{o}C for the Northern, to 4434 and 3155^{o}C for the Southern AEZs, relative to the baseline climate (Figure 1).

2020s



[2] Here and throughout the text the first pair of numbers corresponds to AGDD $_{5°C}$, the second one EGDD $_{5°C}$.

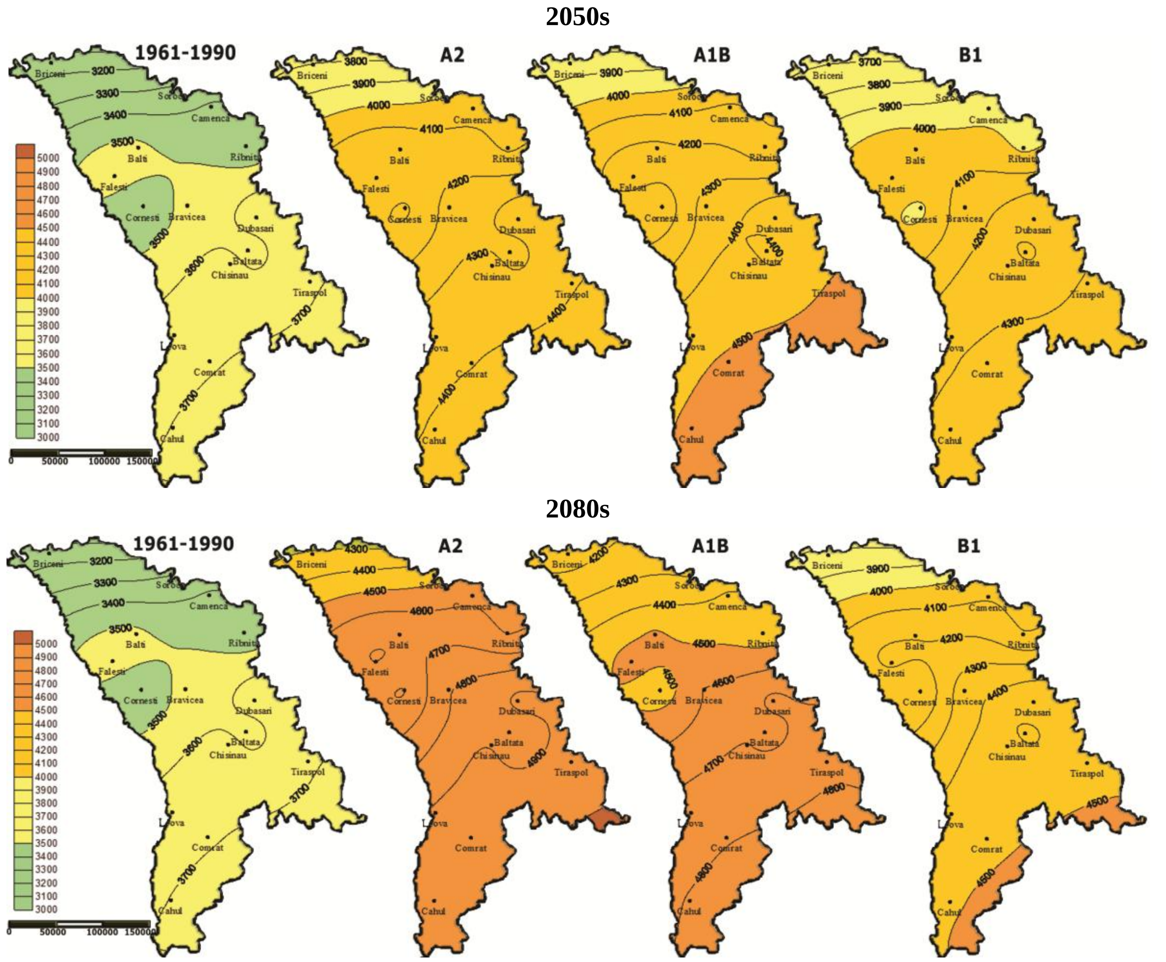
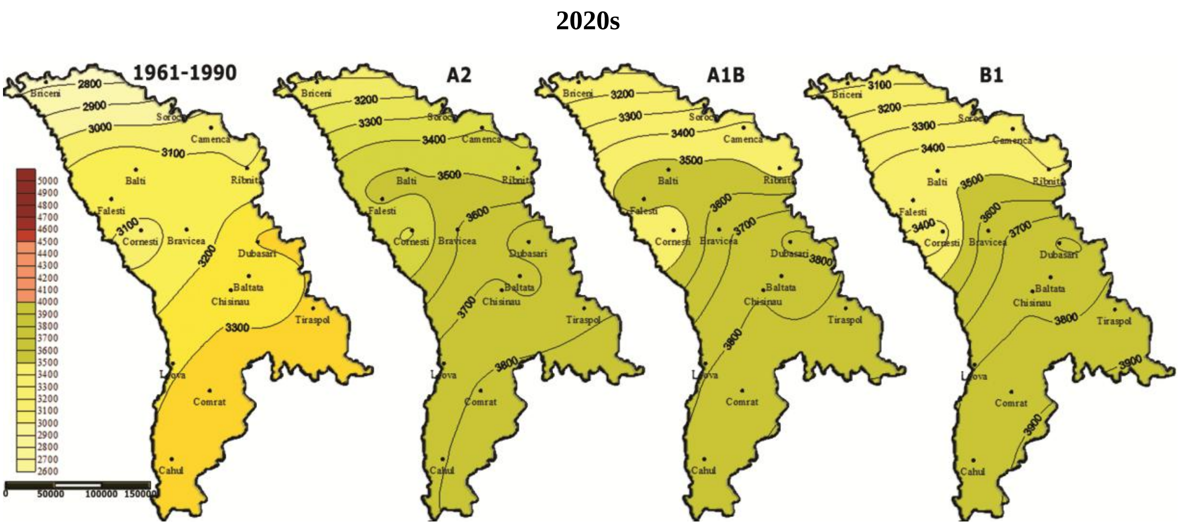
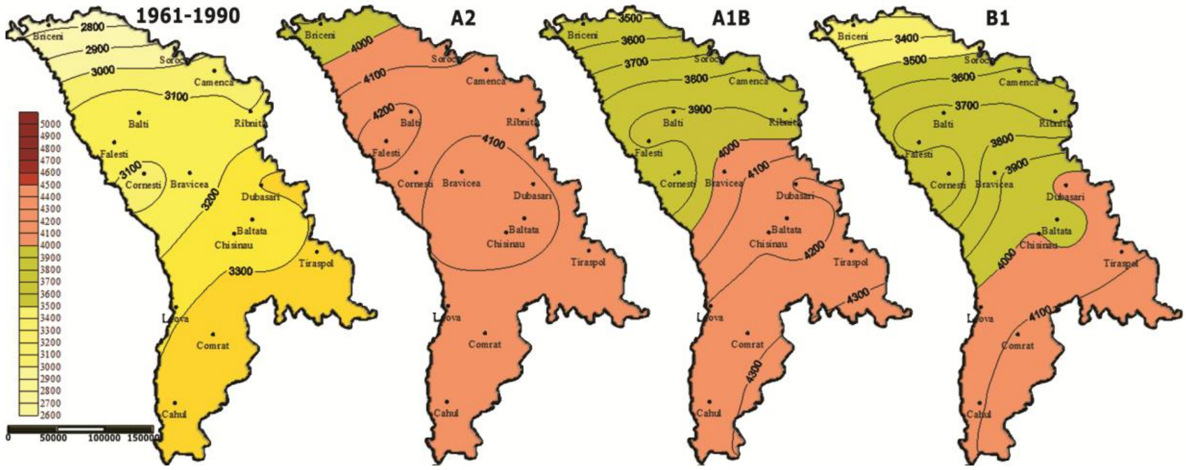


Figure 1: Projected Multi - Model Ensemble AGDD $_{5°C}$, (°C) Spatial Development throughout the Republic of Moldova

For the majority of the cultivated plant species in the Republic of Moldova the biologically active air temperatures mean the AGDD $_{10°C}$ or/and EGDD $_{10°C}$. In the Figure 2 is presented the multi-model ensemble estimation of spatial distribution of the Republic of Moldova's AGDD $_{10°C}$ development for SRES A2, A1B and B1emission scenarios relative to the baseline climate 1961-1990 in the XXI century. If in the baseline climate the AGDD $_{10°C}$ varies across the territory from 2800 to 3300°C then by the end of 2080s these values could rise according to the high emission scenario A2 from 4000 to 4700°C and/or from 3500 to 4300°C under the low emission scenario B1.



2050s



2080s

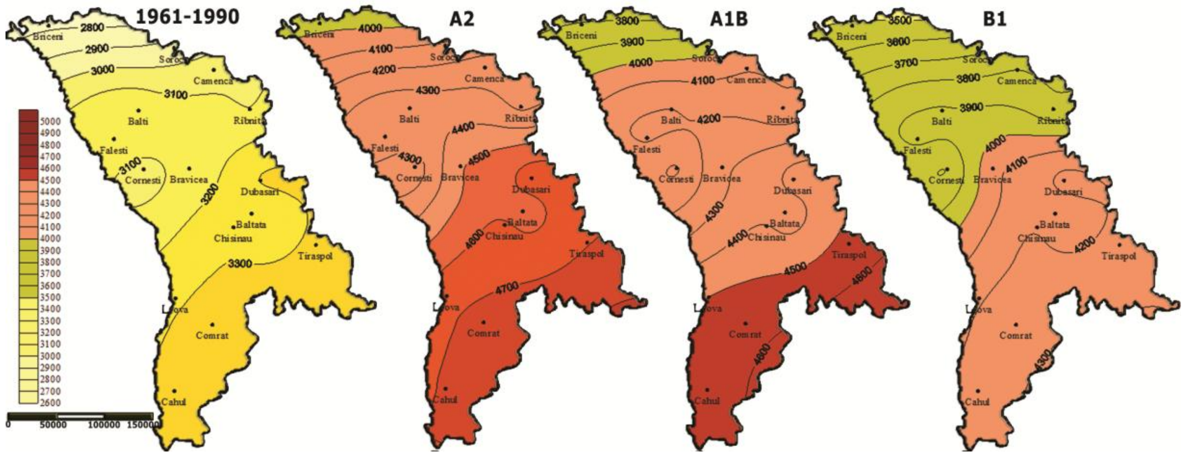


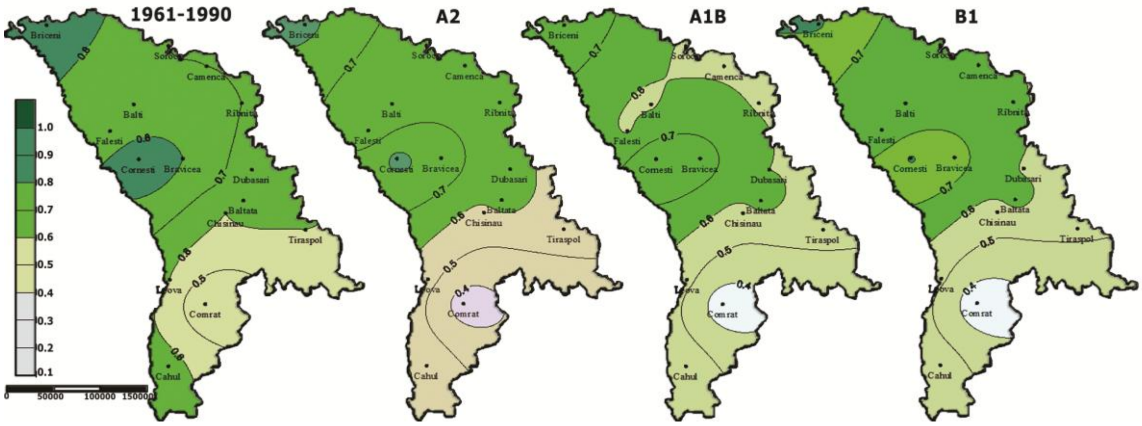
Figure 2: Projected Multi - Model Ensemble AGDD $_{10°C}$, °C Development throughout the Republic of Moldova

3.2. Humidity agroclimatic indices

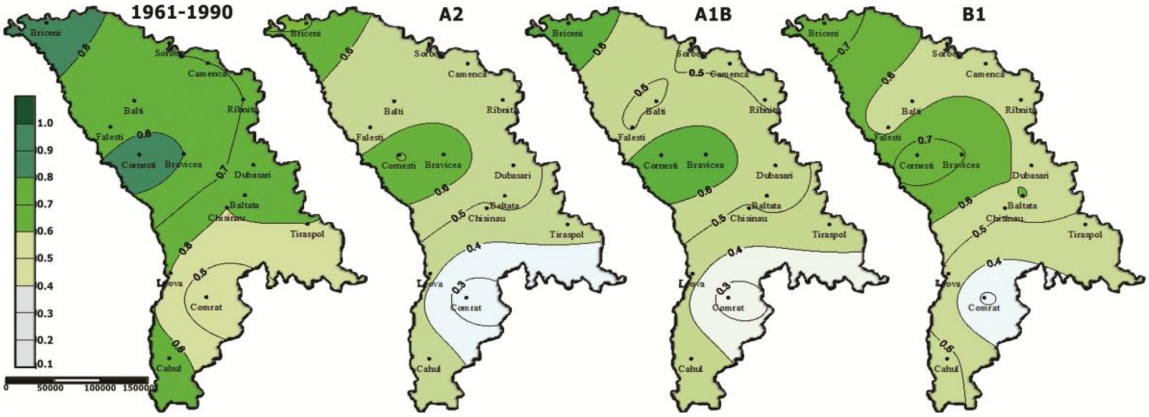
3.2.1. Aridity Index (AI) and Potential Evaporation (E)

According to the above classification, most of the Republic of Moldova's territory is characterized currently with dry or sub-humid climate ($0.50 \geq AI \leq 0.65$). Certain areas in the South-East have semi-arid climate ($AI \geq 0.48$), and Northern AEZ and the areas with altitudes above 350-400 meters above sea level have sub-humid and humid climate ($AI \geq 0.65$). The dynamic of changes in humidity conditions over the century, expressed in annual *AI* is shown in Figure 3, it is evident that the Republic of Moldova is moving towards a dryer climate, from dry or sub-humid climate to dry sub-humid and semi-arid climate.

2020s



2050s



2080s

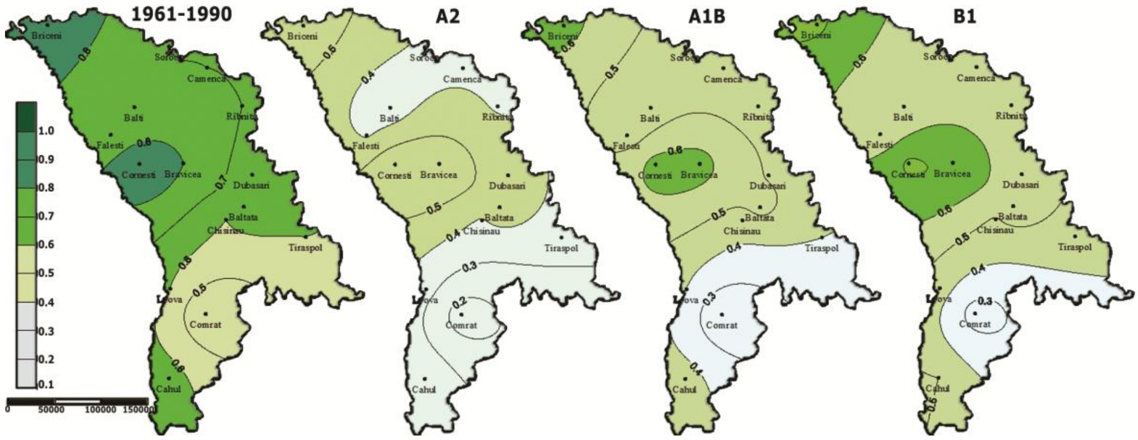


Figure 3: Projected Multi - Model Ensemble Annual Aridity Index (*AI*) Development throughout the Republic of Moldova

Potential evaporation is likely will increase by 9-13 per cent during the growing season over the 2020s, and run up to 40-45 per cent by the 2080s and make from 810 mm for Northern to 1074 mm in Southern AEZs under the high emission scenario A2; slightly lower growth is projected according to the low emission scenario B1, by 22-27 per cent, from 713 mm for Northern, to 942 mm in Southern AEZs, relative to the baseline climate (Table 5).

Table 5: Projected Ensemble Changes in the Potential Evaporation (*E*) and Ivanov's Aridity Index (*AI*) during the growing season for SRES A2, A1B and B1 Emission Scenarios Relative to the 1961-1990 Climatological Baseline Period in XXI Century

AEZ	**A2**				**A1B**				**B1**			
	PE		**AI**		**PE**		**AI**		**PE**		**AI**	
	mm	**%**	**Index**	**%**	**mm**	**%**	**Index**	**%**	**mm**	**%**	**Index**	**%**
					2020s							
Northern	633	+13	0.69	-9	644	+15	0.66	-13	637	+13	0.69	-9
Central	843	+9	0.42	-9	856	+11	0.41	-11	853	+11	0.42	-9
Southern	831	+12	0.44	-12	845	+14	0.44	-12	842	+13	0.44	-12
					2050s							
Northern	704	+25	0.60	-21	644	+29	0.57	-25	679	+21	0.66	-13
Central	948	+23	0.35	-24	856	+24	0.35	-24	904	+17	0.39	-15
Southern	935	+26	0.35	-30	845	+28	0.36	-28	900	+21	0.40	-20
					2080s							
Northern	810	+44	0.48	-37	782	+39	0.53	-30	713	+27	0.60	-21
Central	1080	+40	0.28	-39	1014	+32	0.33	-28	942	+22	0.37	-20
Southern	1074	+45	0.28	-44	1024	+38	0.34	-32	942	+27	0.38	-24

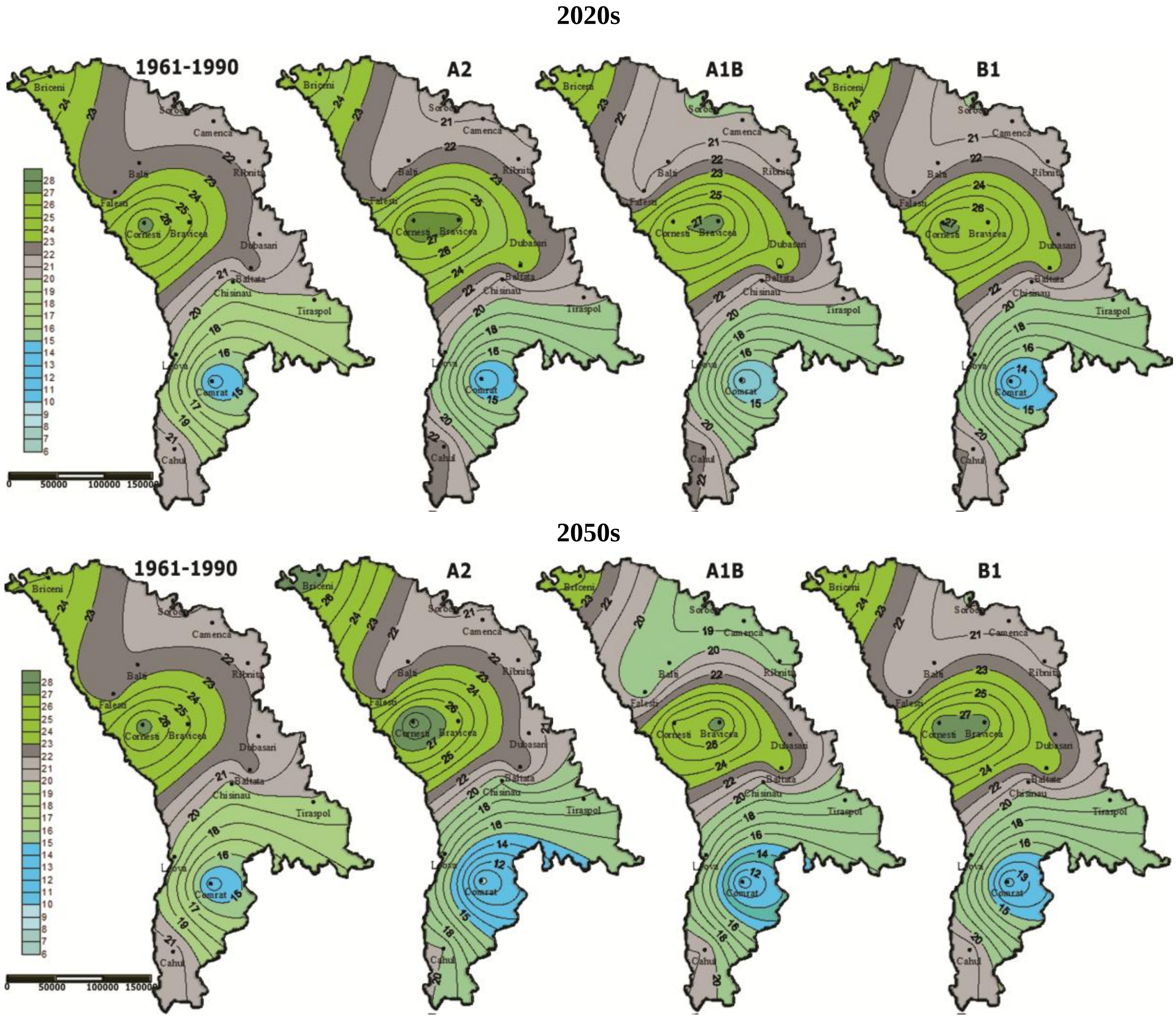
Note: *The observed mean E and AI during the growing season for reference period (1961-1990) were as following: PE - Briceni (562mm); Chisinau (770mm); Cahul (742mm); AI – Briceni (0.76); Chisinau (0.46); Cahul (0.50)*

The obtained results allow conclude that in the future the climate aridization process during the growing season may accelerate considerably on the territory of the Republic of Moldova. Thus, already in the early 2020s that process would intensify noticeably as compared to the reference period of 1961-1990. That phenomenon will be more pronounced during July to October. By the 2080s the climate aridization will be felt during the whole vegetation period (April to October); it will be much more pronounced and may result in values characteristic to the semi-arid climate (AI = 0.21-0.50). Compared to reference period (1961-1990), all climatic scenarios applied for the assessment purposes, have demonstrated that the aridity would be higher in August (in the case of A2 scenario, also in July, August and September), achieving in respective periods values characteristic to arid climate conditions (AI = 0.05-0.20) [24].

3.2.2. Ivanov's Index of the Biological Effectiveness of the Climate (IBEC)

It is estimated that the area of ecological optimum corresponds to IBEC - 22. The area with the corresponding value of IBEC is a kind of environmental axis or core, of which the natural habitat conditions deteriorate, on the one hand, to the north (due to the general reduction of the heat supply), on the other hand, to the south (due to reduced natural moisture availability of the territory and at the same time enhance of thermal discomfort due to excessive heat).

IBEC shows the latitude-zonal pattern of climate variability. The national projections clearly demonstrate the gradual worsening of optimal ecological-climatic characteristics for plant growing of the Republic of Moldova's territory, including Northern areas by the 2080s (Figure 4).



2080s

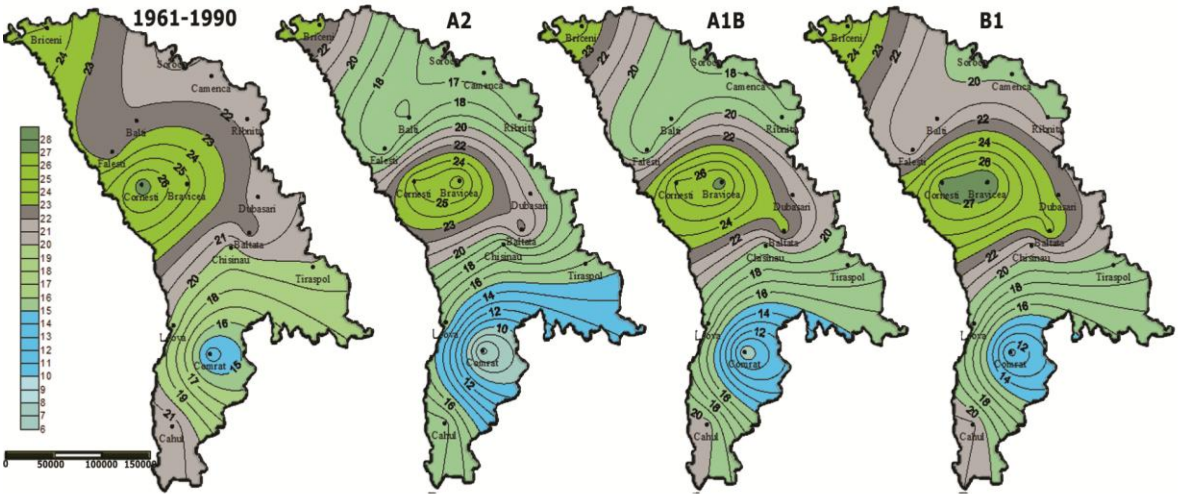
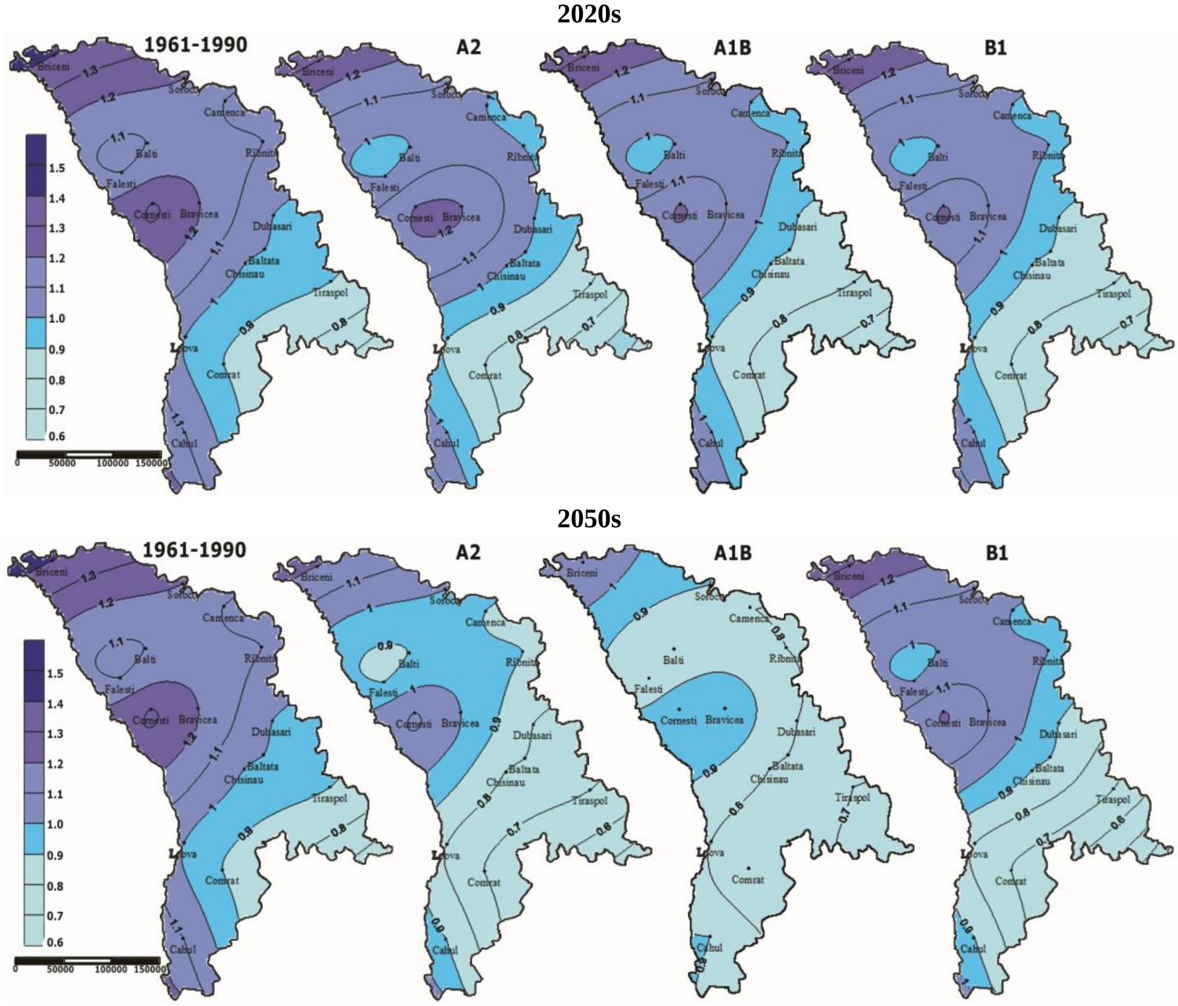


Figure 4: Projected Multi - Model Ensemble Ivanov Index of the Biological Effectiveness of Climate (*IBEC*) Development throughout the Republic of Moldova

3.2.3. Selianinov Hydro-thermal coefficient (HTC)

In the Republic of Moldova's the baseline climatic conditions HTC index ranges from 1.4 in the North to 0.7 in the South-East of the country, i.e. registers the values characteristic of the moderately dry climate in the former case and of the dry climate in the latter case (Figure 5).



2080s

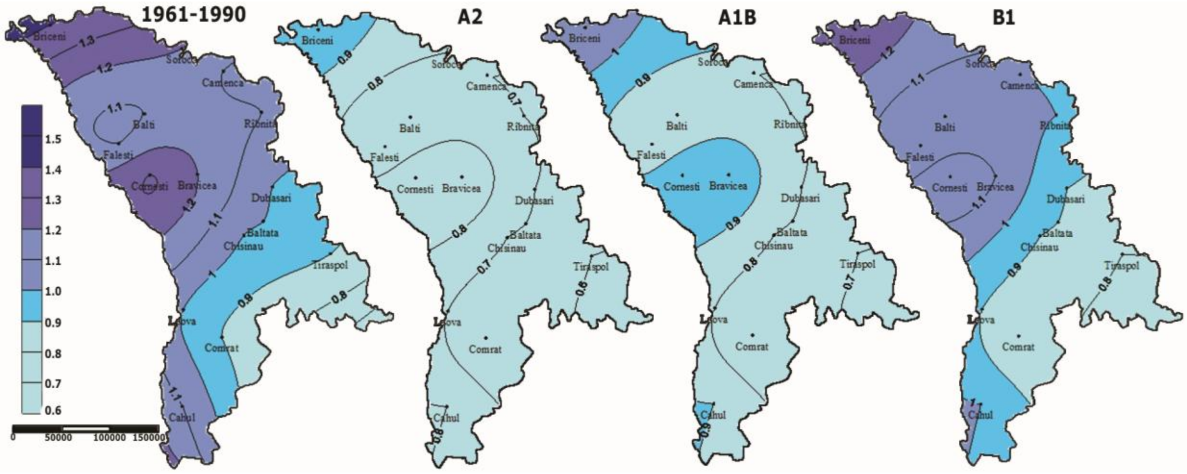


Figure 5: Projected Multi - Model Ensemble *HTC* Index Development for the Vegetation Period throughout the Republic of Moldova

The assessment of HTC index has shown that the insufficiency of moisture would become more pronounced in the future as compared to the climate of the reference period, Figure 4 clearly demonstrates the gradual aridization of the Republic of Moldova territory, including Northern areas, which today are still sufficiently wet. Analysis of data shows that by 2080 the drought conditions of HTC $\leq$ 0.7 will be observed on the whole territory of Moldova including the Northern AEZ and what is more in the Central and Southern AEZs under A2 high emission scenario in July, August, September, and October those levels can achieve even the values characteristic of the medium drought (HTC = 0.6) and strong drought (HTC $\leq$ 0.5) [24].

4. CONCLUSIONS

A set of agroclimatic indices: last (LFD), first (FFD) frost day; frost (FP), frost free (FFP) period; start (GSS $_{5,\,10^{\circ}C}$), end (GSE $_{5,\,10^{\circ}C}$), length (LGS $_{5,\,10^{\circ}C}$) of growing season with T_{avg} above 5ºC and 10ºC; active growing degree days *(*AGDD $_{5,\,10^{\circ}C}$*)*; effective growing degree days *(*EGDD $_{5,\,10^{\circ}C}$); potential evaporation (PE); Ivanov's Aridity Index (AI); Hydro-thermal coefficient (HTC) and biological effectiveness of the climate (IBEC) representing the heat and humidity conditions, during the growing season for cool season, warm season, and very warm season agricultural crops across the Republic of Moldova (RM) Agro-Ecological Zones (AEZs) were computed from 30-yr daily climatic observed data for a baseline period 1961-1990, current climate 1991-2010 and for three future 30-yr time periods (2020s, 2050s and 2080s) based on an ensemble of 10 GCMs for three SRES A2, A1B and B1 emission scenarios.

Due to climate change is expected a significant increase in the length of the growing season and in the associated available heat. The winter temperature will be less damaging and the frost-free periods longer. For all three SRES emission scenarios are expected worsening of the humidity conditions throughout the territory of the RM's AEZs. Reduced rainfall in the summer and autumn period (not compensated by a slight increase in winter and spring precipitation) against a background of rising temperatures will cause the strong moisture deficit and sequential increase of the potential evaporation and accelerate considerably climate aridization process during the growing season in the XXI century. IBEC clearly shows the latitude-zonal pattern of climate variability and clearly demonstrates the gradual worsening of optimal ecological-climatic characteristics for plant growing on the Republic of Moldova's territory, including the northern areas by 2080s.

Our results may be useful in further developing of national and regional adaptation strategies and plans specific to the Republic of Moldova's agriculture sector, which is currently underway. Farmers and policymakers may use such information to choose climate adaptation measures such as for example agricultural crop selections. For example, an increasing trend in heat accumulations may be more favorable for vine and fruit production, but less favorable for cereal crop production, a sharp decrease in grain corn and winter wheat yield is excepted to more districts in the Republic of Moldova, especially in the central and southern areas of existing agricultural regions (Taranu, unpublished). A balance should be reached by taking advantage of the increases in growing season length and heat accumulations and managing the risks associated with seasonal water deficits.

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