CLIMATE CHANGE AND AGROCLIMATIC CONDITIONS IN THE REPUBLIC OF MOLDOVA. COMMUNICATION I: TEMPERATURE – BASED INDICES

Lilia Țăranu
PhD in Biological Sciences, Senior Consultant in the Area of Adaptation and Vulnerability to Climate Change, Climate Change Office, Ministry of Environment of the Republic of Moldova
#156A, Mitropolit Dosoftei St., Office 37, MD 2004, Chişinău, Republic of Moldova
E-mails: l.taranu@yahoo.com and clima@mediu.gov.md

Rezumat: *În articol este prezentat un set de indici agroclimatici, precum: prima (FFD) şi ultima (LFD) zi cu îngheț; perioadele cu îngheț (FP) şi fără îngheț (FFP); începutul (GSS $_{5,\ 10,\ 15\ °C}$), sfârşitul (LGS $_{5,\ 10,\ 15\ °C}$) şi durata sezonului de vegetație (GSE $_{5,\ 10,\ 15\ °C}$) cu temperaturi medii ale aerului (T_{avg}) peste 5ºC, 10ºC şi 15ºC; zile cu temperaturi active (AGDD $_{5,\ 10°C}$) şi efective (EGDD $_{5,\ 10°C}$), caracterizând condițiile termice ale perioadei de vegetație a diferitelor grupuri de culturilor agricole pe teritoriul Republicii Moldova pentru trei zone agroecologice (ZAE); calculați în baza datelor climaterice zilnice, pentru perioada de referință (1961-1990) şi perioada de climă recentă (1991-2010), precum şi pentru prospecțiunile de viitor: perioade a câte 30 ani din secolul XXI (anii 2020': perioada temporală 2010-2039; anii 2050': perioada temporală 2040-2069 şi anii 2080': perioada temporală 2070-2099), conform unui ansamblu din 10 modele climatice globale impuse de trei scenarii de emisii ale gazelor cu efect de seră SRES A2, A1B şi B1. Rezultatele obținute permit să concluzionăm, că ca urmare a schimbărilor climatice, este anticipată o majorare semnificativă a duratei sezonului de vegetație şi a resurselor termice disponibile. Temperaturile extreme pe durata sezonului de iarnă vor afecta mai puțin culturile agricole, iar perioada cu zile fără îngheț va fi mai lungă. Rezultatele obținute pot fi utile pentru procesul de elaborare a strategiilor şi planurilor de acțiuni naționale şi regionale privind adaptarea la schimbările climatice a sectorului agricol al Republicii Moldova, la moment în proces de dezvoltare.*

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

INTRODUCTION

Climate change is expected to affect both regional and global food production through changes in overall agroclimatic conditions [1-2]. The observed warming trend throughout Europe (+0.90°C from 1901 to 2005) is well established [3]; According to Alcamo et al. (2007), the effects of climate change and increased atmospheric CO_2 levels by 2050 are expected to lead to small increases in European crop productivity, but temperature increases greater than approximately 2°C would likely lead to declines in the yields of many crops [4]. Several climate projections for 2050 exceed this 2°C threshold [5; 6]. Although different studies have resulted in different projections, all agree on a consistent spatial distribution of the effects, leading to the need for the regionalization of adaptation policy [7-9]. The projected increase in extreme weather events (e.g. periods of high temperature and droughts] over at least some parts of Europe is predicted to increase yield variability [10-14]. Technological development (e.g. new crop varieties and improved cropping practices) could ameliorate the effects of climate change [15-16]. However, there is evidence of a slowing rate of yield growth, either due to the closing of the yield gap between realized and potential yields [15;17-18], or due to policies such as stricter environmental regulation [19]. To date, there have been a limited number of reports [20-21] dealing with the changes expected in agroclimatic parameters at the pan-European scale, and many of these are review articles [12; 22-23]. Most studies of climate change impacts on crop yields apply either statistical models [24] or process-based crop simulation models [25-27]. Most process-based models are also capable of simulating, in addition, effects of enhanced CO_2 concentration and management practices on biomass, seed yields and water use of crops [28-30]. 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 analyzing the interactions between the many options of combining different crop cultivars with diverse management practices under a wide range of possible new environmental conditions [25, 31-33]. 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 agroclimate conditions for larger areas and its shifts under climate change [1; 21; 34-36]. The main objective of this work was: (i) to develop a set of temperature – based 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 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.

DATA AND METHODS

In this study, thermal agro-climatic 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 [see more in Taranu et al., 2012]. In the Table 1 are presented the definitions of the agro-climatic indices analyzed in this study. In the case of frost-based indices, the first frost day (FFD) and last frost day (LFD), the frost period (FP) and the number of frost days (NFD), we used the 0ºC thresholds. 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 general, the 5ºC mean temperature (T_{avg}) threshold is widely accepted for determining the thermal growing season, in particular for mid and high latitudes [37 - 39]. In our study, LGS $_{5,\ 10,\ 15ºC}$ is defined as the period from the growing season start (GSS $_{5,\ 10,\ 15ºC}$) to the growing season end (GSE). The GSS $_{5,\ 10,\ 15\ ºC}$ is the earliest date of series of days with the mean daily air temperature ≥ 5, 10 and 15ºC that is the beginning of such cumulated series of daily mean temperature deviations from the threshold value of 5, 10 and 15ºC that do not have negative values up to the end of the first 6 month of the year. The GSE $_{5,\ 10,\ 15ºC}$ in a given year is a day directly preceding the earliest date after the beginning of GSE $_{5,\ 10,\ 15ºC}$ of a series of days with the mean daily air

Table 1

THE DEFINITIONS OF AGRO-CLIMATIC INDICES HAVE BEEN USED IN THE ASSESSMENT

Indices	Abbreviation	Definition	Unit
Last frost day	LFD	Date of last spring frost	Date
First frost day	FFD	Date of first autumn frost	Date
Frost period	FP	Number of days between FFD and LDF	Date
Frost - free period	FFP	Number of days between LDF and FFD	Days
Start of Growing Season	GSS $_{5,\ 10,\ 15ºC}$	The earliest date of series of days with the mean daily air temperature of ≥ 5, 10 and 15ºC that is the beginning of such cumulated series of daily mean temperature deviations from the threshold value of 5, 10 and 15ºC that do not have negative values up to the end of the first 6 month of the year.	Date
End of Growing Season	GSE $_{5,\ 10,\ 15ºC}$	A day directly preceding the earliest date after the beginning of GSE $_{5,\ 10,\ 15ºC}$ of a series of days with the mean daily air temperature of ≤ 5, 10 and 15ºC that is the beginning of such cumulated series of daily mean temperature deviations from the threshold value of 5, 10 and 15ºC that do not have positive values up to the end of a year.	Date
Length of Growing Season	LGS $_{5,\ 10,\ 15ºC}$	Number of days between GSS $_{5,\ 10,\ 15ºC}$ and GSE $_{5,\ 10,\ 15ºC}$	Days
Active Growing Degree Days	AGDD $_{5,\ 10ºC}$	Accumulated sum of temperature degrees above 5ºC and 10ºC	°C
Effective Growing Degree Days	EGDD $_{5,\ 10ºC}$	Accumulated sum of temperature degrees above 5ºC and 10ºC minus T_{base}	°C

temperature ≤ 5, 10 and 15ºC that is the beginning of such cumulated series of daily mean temperature deviations from the threshold value of 5, 10 and 15ºC that do not have positive values up to the end of a year. The definition of LGS $_{5,\ 10,\ 15ºC}$ 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. Different indices are used to quantify that process. The active growing degree day (AGDD $_{5,\ 10ºC}$) and effective growing degree day (EGDD $_{5,\ 10ºC}$) 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 $_{Tb}$ for two different temperature thresholds (5 and 10ºC) was computed according to:

$$AGDD_{T_b} = \sum_{k=1}^{n} T_{avg}$$

where n is the number of days in a given growing season, T_{avg} is the daily average temperature from the start (GSS $_{5,\ 10ºC}$) to the end (GSE $_{5,\ 10ºC}$) of the growing season and T_b is the cardinal temperature (5, 10ºC) 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 10ºC) was computed according to:

$$EGDD_{T_b} = \sum_{k=1}^{n} (T_{avg} - T_b)$$

Where n is the number of days in a given growing season, T_{avg} is the daily average temperature from the start (GSS $_{5,\ 10ºC}$) to the end (GSE $_{5,\ 10ºC}$) of the growing season and T_b is the cardinal temperature 5 and 10ºC for initiation and termination of growth for different crop types. There is no accumulation in EGDD if $T_{avg} < T_b$.

RESULTS AND DISCUSSIONS

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 (Table 2).

In the Central and Southern AEZs the duration of the FP will decrease in both scenarios for 9-11 days, respectively. To be noted, that actually observed decrease for FP over the last two decades (1991-2010) was for the Northern AEZ ↘ -18, for the Central AEZs ↘ -14, and for the Southern AEZs ↘-11 days, compared to baseline climate. 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 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 (Table 3). 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

Table 2

Projected Ensemble Changes of the FFD $_{0ºC}$, LFD $_{0ºC}$ 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 $_{0ºC}$, date - Briceni (30/11); Chisinau (10/12); Cahul (09/12); the LFD $_{0ºC}$, date Briceni (16/03); Chisinau (06/03); Cahul (03/03); FP length of the period with the average daily air temperature is below 0ºC, days - Briceni (105); Chisinau (85); Cahul (83).*

Table 3

Projected Ensemble Changes of the LSF $_{0°C}$, FFD $_{0°C}$, (Dates) and FFP (Days) for SRES A2, A1B and B1 Emi - sion 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 0ºC, days - Briceni (260); Chisinau (280); Cahul (282).*

and Southern AEZs the duration of the FFP will increase in both scenarios for 9-11 days, respectively.

To be noted, that actually observed growth for FFP over the last two decades (1991-2010) was for the Northern AEZ ↗+18, for the Central AEZs ↗+14, and for the Southern AEZs ↗+11 days, compared to baseline climate. 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 3).

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. In fact, the observed changes in the duration of the LGS $_{5°C}$ over the last 20 years were as follows: ↘ -2 days in the Northern, ↗ +3 days in Central, and ↗ +8 days in Southern AEZs. By the end of the 21th century the LGS $_{5°C}$ will increase substantially from 14-21(B1) to 30-32 (A2) days in the Northern and Southern AEZs. 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

Table 4

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).*

Table 5

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).*

$_{5°C}$ 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.

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. In fact, the observed changes in the LGS $_{10°C}$ over the last 20 years were as follows: for the Northern ↘ -1 day, in Central ↗ +6 days, and ↗ +5 days in Southern AEZs. By the end of 2080s the LGS $_{10°C}$ will increase substantially from 32-34 (B1) to 41-42 (A2) days in the Central and Southern AEZs. 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 5).

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

The LGS $_{15°C}$ for the baseline climate varies from 118 days in the North of the country up to 141 days in the South. In fact, the observed changes in the LGS $_{15°C}$ over the last 20 years were as follows: for the Northern ↗ +1 day, in Central ↘ -6 days, and Southern AEZs ↗ +4 days. In connection to climate change is expected that the LGS $_{15°C}$ will increase by 2020s from 6 to 9 days in the Central and Southern AEZs. The highest growth by 14-15 days is possible in the Northern AEZ. By the end of 2080s the LGS $_{15°C}$ will increase substantially from 21-25 (B1) to 33-34 (A2) days in the Central and Southern AEZs. The tendency to maximum increase of the LGS $_{15°C}$ in the Northern areas will persist, and by the 2080s would be expected that such periods will be 27 (B1) and/or 40 (A2) days longer (Table 6).

According to [40; 41] 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 [42]. 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 [42-43].

Growing Degree Days (AGDD $_{5,\ 10°C}$ and EGDD $_{5,10°C}$)

The AGDD $_{5°C}$ and/or EGDD $_{5°C}$ for the baseline climate vary from 3105 and/or 1995°C in the North up to 3652 and/or 2472°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 $_{5°C}$

Table 6

Projected Ensemble Changes of the GSS $_{15°C}$, GSE $_{15°C}$ (Dates) and LGS $_{15°C}$ (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 $_{15°C}$	GSE $_{15°C}$	(+/-)	GSS $_{15°C}$	GSE $_{15°C}$	(+/-)	GSS $_{15°C}$	GSE $_{15°C}$	(+/-)
2020s									
Northern	10.05	19.09	**+15**	11.05	18.09	**+15**	10.05	18.09	**+14**
Central	05.05	08.09	**+6**	05.05	27.09	**+6**	04.05	27.09	**+6**
Southern	05.05	01.10	**+9**	05.05	30.09	**+9**	04.05	30.09	**+9**
2050s									
Northern	07.05	25.09	**+24**	06.05	26.09	**+26**	07.05	22.09	**+21**
Central	02.05	03.10	**+14**	29.04	05.10	**+20**	02.05	02.10	**+13**
Southern	03.05	09.10	**+19**	29.04	08.10	**+22**	02.05	27.09	**+18**
2080s									
Northern	01.05	01.10	**+40**	02.05	29.09	**+33**	05.05	26.09	**+27**
Central	23.04	14.10	**+33**	18.04	09.10	**+31**	28.04	06.10	**+21**
Southern	25.04	16.10	**+34**	23.04	12.10	**+32**	27.04	09.10	**+25**

Note. *The observed mean for baseline period 1961-1990: the GSS $_{15°C}$, dates - Briceni (15/05); Chisinau (06/05); Cahul (09/05); the GSE $_{15°C}$ - Briceni (10/10); Chisinau (09/09); Cahul (26/09); LGS $_{15°C}$, days - Briceni (118); Chisinau (141); Cahul (141).*

Table 7

Projected Ensemble Changes in the AGDD $_{5°C}$ and EGDD $_{5°C}$ for SRES A2, A1B and B1 Emission Scenarios Relative to the 1961-1990 Climatological Baseline Period in XXI Century

AEZ	A2				A1B				B1			
	AGDD $_{5°C}$	%	EGDD $_{5°C}$	%	AGDD $_{5°C}$	%	EGDD $_{5°C}$	%	AGDD $_{5°C}$	%	EGDD $_{5°C}$	%
2020s												
Northern	3437	**11**	2291	**15**	3453	**11**	2312	**16**	3430	**10**	2295	**15**
Central	3930	**10**	2720	**12**	3991	**11**	2773	**14**	3973	**11**	2759	**14**
Southern	3986	**9**	2770	**12**	4065	**11**	2828	**14**	4035	**10**	2811	**14**
2050s												
Northern	3757	**21**	2570	**29**	3803	**22**	2617	**31**	3654	**18**	2486	**25**
Central	4282	**20**	3033	**25**	4389	**23**	3113	**28**	4206	**17**	2957	**22**
Southern	4358	**19**	3091	**25**	4467	**22**	3175	**28**	4275	**17**	3016	**22**
2080s												
Northern	4267	**37**	2996	**50**	4103	**32**	2872	**44**	3779	**22**	2599	**30**
Central	4843	**35**	3508	**45**	4657	**30**	3322	**37**	4403	**23**	3126	**29**
Southern	4911	**34**	3575	**45**	4754	**30**	3433	**39**	4434	**21**	3155	**28**

Note. *The observed mean annual AGDD $_{5°C}$ and EGDD $_{5°C}$ for reference period (1961-1990) were as following: AGDD $_{5°C}$ - Briceni (3105°C); Chisinau (3581°C); Cahul (3652°C); EGDD $_{5°C}$ - Briceni (1995°C); Chisinau (2426°C); Cahul (2472°C).*

about 9-11% and/or 12-16%[2], with maximum increase in Northern AEZ. In fact, the observed changes in the AGDD$_{5°C}$ and/or EGDD $_{5°C}$ over the last 20 years were as follows: for the Northern +6.2 and/or 10.1%, + 5.5 and/or 7.5% in Central, and +4.6 and/or 6.6% in Southern AEZs. 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°C for the Northern to 4911 and 3575°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°C for the Northern, to 4434 and 3155°C for the Southern AEZs, relative to the baseline climate (Table 7; Figure 1).

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 $_{10°C}$. The AGDD $_{10°C}$ and/or EGDD $_{10°C}$ for the baseline climate vary from 2745 and/or 1025 °C in the North up to 3222 and/or 1402 °C in the South of the country. Already by 2020s the AGDD $_{10°C}$ or/and EGDD $_{10°C}$ will grow by 12-14 and/or 18-22%[3] under high emission scenario A2; and by 11-16

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

3. Here and throughout the text the first pair of number corresponds to AGDD $_{10°C}$, the second one EGDD $_{10°C}$.

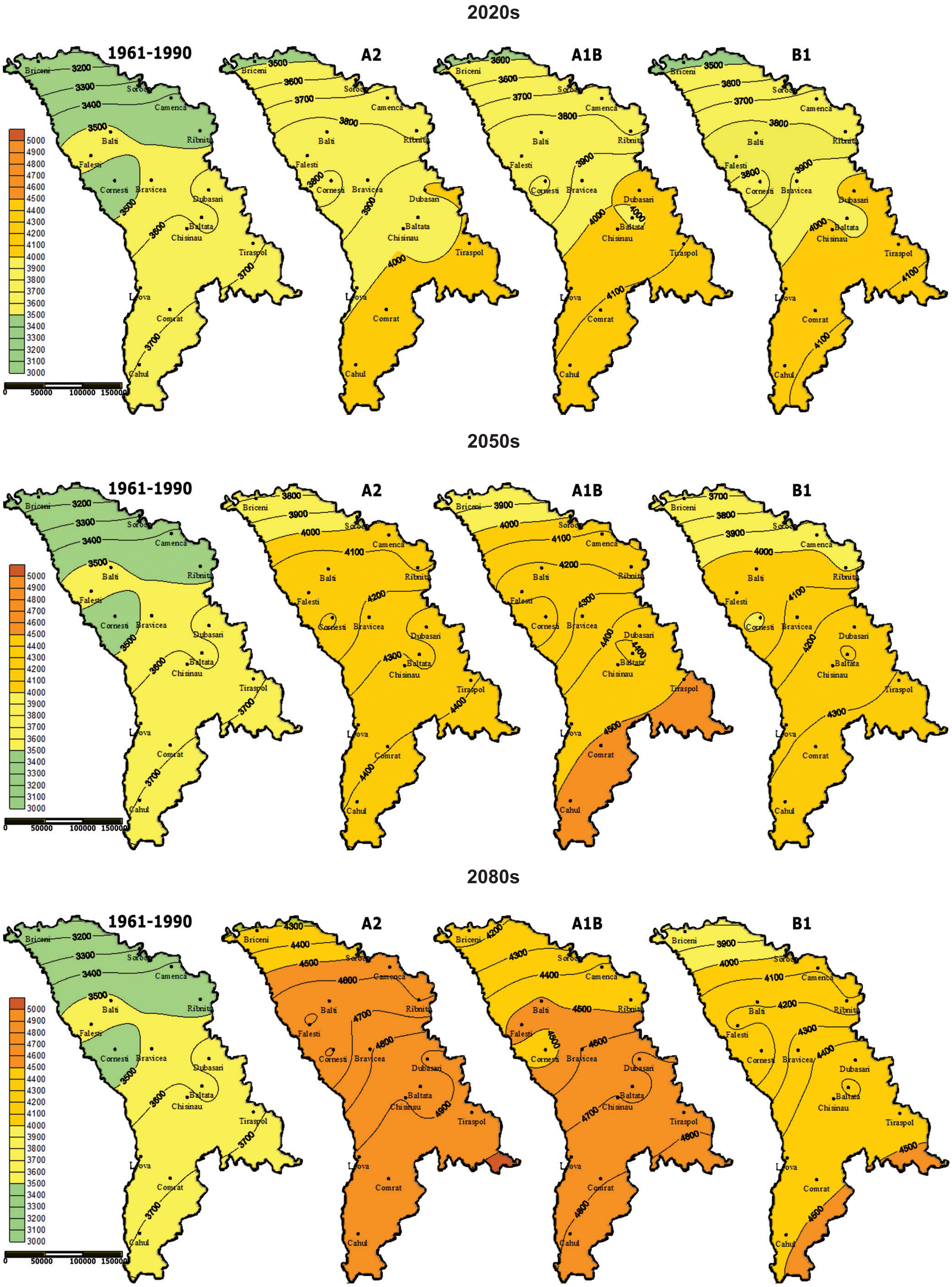

Figure 1: Projected Multi - Model Ensemble AGDD $_{5°}$, (°C) Spatial Development throughout the Republic of Moldova

Table 8

PROJECTED ENSEMBLE CHANGES IN THE AGDD $_{10°C}$ AND EGDD $_{10°C}$ FOR SRES A2, A1B AND B1 EMISSION SCENARIOS RELATIVE TO THE 1961-1990 CLIMATOLOGICAL BASELINE PERIOD IN XXI CENTURY

AEZ	*A2*				*A1B*				*B1*			
	AGDD $_{10°C}$	%	EGDD $_{10°C}$	%	AGDD $_{10°C}$	%	EGDD $_{10°C}$	%	AGDD $_{10°C}$	%	EGDD $_{10°C}$	%
						2020s						
Northern	3074	**12**	1253	**22**	3101	**13**	1278	**25**	3049	**11**	1262	**23**
Central	3627	**14**	1620	**18**	3692	**16**	1662	**21**	3679	**16**	1653	**20**
Southern	3682	**14**	1652	**18**	3724	**16**	1699	**21**	3732	**16**	1689	**20**
						2050s						
Northern	3833	**40**	1480	**44**	3481	**27**	1526	**49**	3292	**20**	1416	**38**
Central	3975	**25**	1891	**38**	4078	**28**	1951	**42**	3906	**23**	1817	**32**
Southern	4064	**26**	1932	**38**	4147	**29**	1999	**43**	3980	**24**	1859	**33**
						2080s						
Northern	3930	**43**	1834	**79**	3772	**37**	1742	**70**	3481	**27**	1514	**48**
Central	4516	**42**	2293	**67**	4308	**36**	2123	**54**	4096	**29**	1964	**43**
Southern	4600	**43**	2347	**67**	4439	**38**	2224	**59**	4128	**28**	1983	**41**

Note. *The observed mean annual sum of active and effective temperatures for reference period (1961-1990) were following: $\Sigma T_{ac\ >10°C}$ - Briceni (2745ºC); Chisinau (3175ºC); Cahul (3222°C); $\Sigma T_{ef\ >10°C}$ - Briceni (1025ºC); Chisinau (1375ºC); Cahul (1402ºC).*

and/or 20-23% according to the low emission scenario B1. In fact, the observed changes in the AGDD $_{10°C}$ and/or EGDD $_{10°C}$ over the last 20 years were as follows: +6.1 and/or 17.4% in the Northern, + 7.2 and/or 12.3% in Central and +6.5 and/or 11.3 % in Southern AEZs.

By the end of 2080s the AGDD $_{10°C}$ or/and EGDD $_{10°C}$ will increase essentially by 42-43 and/or 67-79% under the high emission scenario A2, and will make from 3930 and/or 1834°C for the Northern to 4600 and/or 2347°C in the Southern AEZs; slightly lower growth is projected according to the low emission scenario B1 by 27-28 and/or 41-48%, and will make from 3481 and/or 1514°C for the Northern to 4128 and/or 1983°C in the Southern AEZs relative to the baseline climate (Table 8).

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.

In this article a set of temperature – based agroclimatic indices: last (*LFD*), first (*FFD*) frost day; frost (*FP*), frost free (*FFP*) period; start (*GSS* $_{5,\ 10,\ 15\ °C}$), end (*GSE* $_{5,\ 10,\ 15\ °C}$), length (*LGS* $_{5,\ 10,\ 15\ °C}$) of growing season with T_{avg} above 5ºC, 10ºC and 15ºC; active growing degree days *(AGDD* $_{5,\ 10°C}$*)*; and effective growing degree days *(EGDD* $_{5,\ 10°C}$*)* representing the heat 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. Our results may be useful in further developing of national and regional adaptation strategies and plans specific to the Republic of Moldova agriculture sector, which is currently underway. Farmers and policy-makers 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 according to 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.

CONCLUSIONS

The main conclusions are the following:

1. 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. By the end of 2080s, duration of the FFP in the Central and

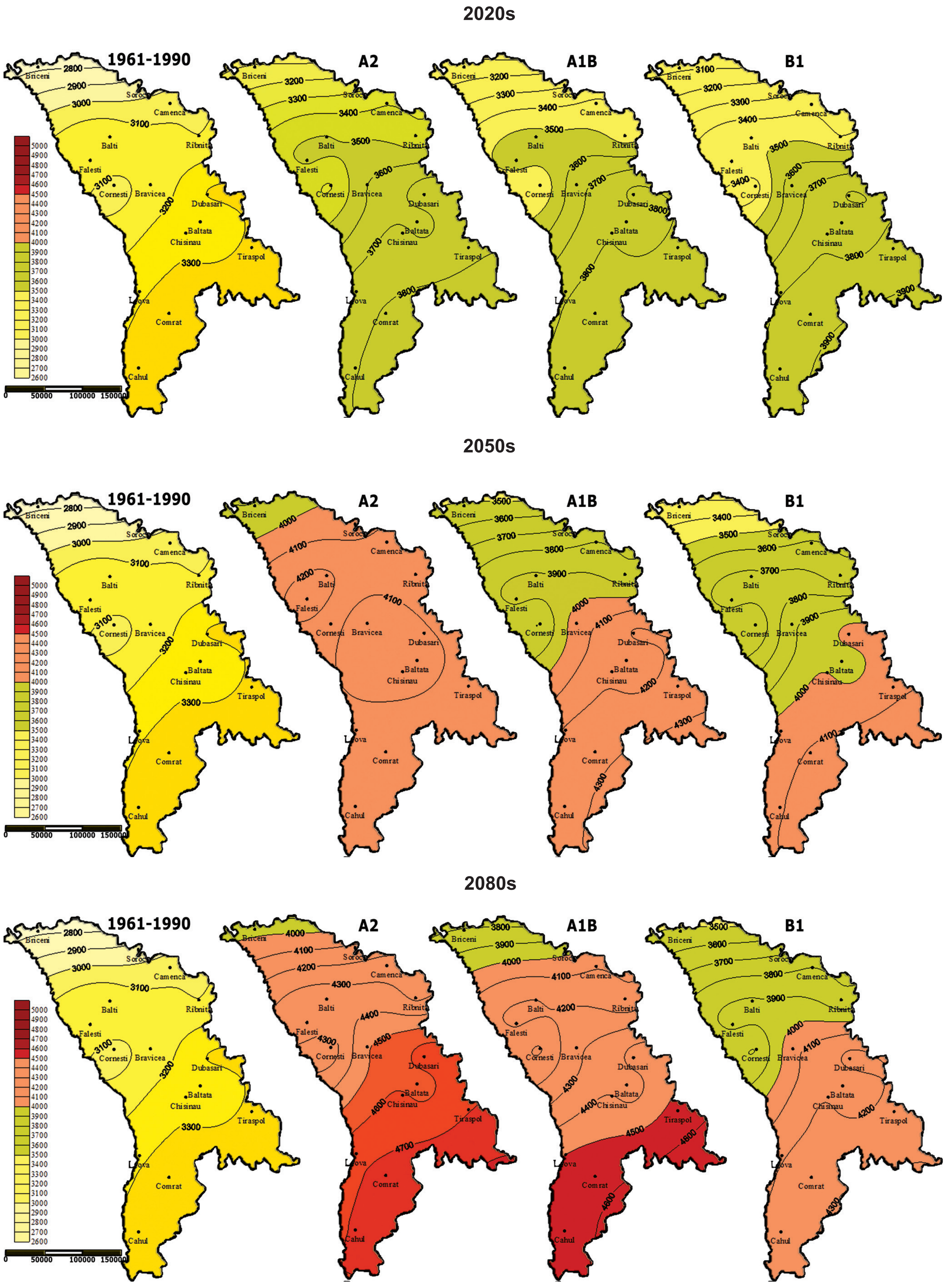

Figure 2: Projected Multi - Model Ensemble AGDD $_{10°}$, (°C) Development throughout the Republic of Moldova

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.

2. The LGS $_{5°C}$ will increase from 14-21 (B1) to 30-32 (A2) days in the Northern and Southern AEZs, the maximum increase by 24-36 days is projected in the Central AEZ.

3. For all AEZs the LGS $_{5°C}$ will increase, mainly due to a late finish in the autumn from 7 to 20 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.

4. The LGS $_{10°C}$ will increase from 32-34 (B1) to 41-42 (A2) days in the Central and Southern AEZs, the minimum increase about 25-37 days is expected in the Northern areas by the 2080s.

5. The LGS $_{15°C}$ will increase from 21-25 (B1) to 33-34 (A2) days in the Central and Southern AEZs. The tendency to maximum increase of the LGS $_{15°C}$ in the Northern areas will persist, and by the 2080s would be expected that such periods will be 27 - 40 days longer.

6. The AGDD $_{5°C}$ and/or EGDD $_{5°C}$ would increase significantly under high emission scenario A2 by 34-37% and/or 45-50%, and will make from 4267 and/or 2996°C in the Northern to 4911 and/or 3575°C in the Southern AEZs; slightly lower growth is expected according to low emission scenario B1 by 21-23% and/or 28-30%, varying from 3779 and/or 2599°C for the Northern, to 4434 and/or 3155°C for the Southern AEZs in the 2080s, relative to the baseline climate.

7. By the end of 2080s the AGDD $_{10°C}$ or/and EGDD $_{10°C}$ will increase to a large degree by 42-43% and/or 79-67% under the high emission scenario A2, and will make from 3930 and/or 1834°C for the Northern to 4600 and/or 2347°C in the Southern AEZs; slightly lower growth is projected according to the low emission scenario B1 by 27-28% and/or 48-41%, and will make from 3481 and/or 1514°C for the Northern to 4128 and/or1983°C in the Southern AEZs relative to the baseline climate.

BIBLIOGRAPHY

1. Fischer G, Shah M, Tubiello FN et al. (2005): Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. Philosophical Transactions of the Royal Society B, 360, 2067–2083.

2. Solomon S, Qin D, Manning M et al. (eds) (2007): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

3. Alcamo J, Moreno JM, Nova´ky B et al. (2007): Europe. Climate change 2007: impacts, adaptation and vulnerability. In: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE), pp. 541–580. Cambridge University Press, Cambridge, UK.

4. Easterling WE, Aggarwal PK, Batima P et al. (2007): Food, fibre and forest products. Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II. In: The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson

5. Giorgi F, Lionello P. (2008): Climate change projections for the Mediterranean region. Global and Planetary Change, 63, 90–104.

6. Taranu L., Bercu I., Deveatii D. (2012): Regional Climate Change Scenarios for the Republic of Moldova: Future Temperature and Precipitation Projections from Ensembles of 10 Global Climate Models. *Mediul Ambiant*. Nr.3 (63), P. 33-42.

7. Ciscar JC, Iglesias A, Feyen L et al. (2009): Climate change impacts in Europe. Final Report of the PESETA Research Project, EUR 24093 EN, JRC Scientific and Technical Reports. Available at: http://ftp.jrc.es/EURdoc/JRC55391.pdf

8. COM (2009): Adapting to climate change: Towards a European framework for action. Commission of the European Communities, Brussels, 1.4.2009, COM (2009) 147 final, White Paper.

9. NCCAS, http://clima.md/lib.php?l=ro&idc=237&

10. Jones PD, Lister DH, Jaggard KW, Pidgeon JD. (2003): Future climate impact on the productivity of sugar beet (Beta vulgaris L.) in Europe. Climatic Change, 58, 93–108.

11. Porter JR, Semenov MA. (2005): Crop responses to climatic variation. Philosophical Transactions of the Royal Society B, 360, 2021–2035.

12. Lavalle C, Micale F, Houston TD et al. (2009): Climate change in Europe. 3. Impact on agriculture and forestry. A review. Agronomy for Sustainable Development, 29, 433–446.

13. Quiroga S, Iglesias A. (2009): A comparison of the climate risks of cereal, citrus, grapevine and olive production in Spain. Agricultural Systems, 101, 91–100.

14. Iglesias A, Quiroga S, Schlickenrieder J. (2010): Assessing uncertainty to support climate change adaptation needs for Mediterranean crops. Climate Research, 44, 83–94.

15. Ewert F, Rounsevell MDA, Reginster I, Metzger MJ, Leemans R. (2005): Future scenarios of European agricultural land use I. Estimating changes in crop productivity. Agriculture, Ecosystems and Environment, 107, 101–116.

16. Peltonen-Sainio P, Jauhiainen L, Laurila IP. (2009a): Cereal yield trends in northern European conditions: changes in yield potential and its realisation. Field Crops Research, 110, 85–90.

17. Cassman KG, Dobermann A, Walters DT, Yang HS. (2003): Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review of Environment and Resources, 28, 315–358.

18. Lobell DB, Cassman KG, Field CB. (2009): Crop yield gaps: their importance, magnitudes, and causes. Annual Review of Environment and Resources, 34, 179–204.

19. Finger R. (2010): Evidence of slowing yield growth – the example of Swiss cereal yields. Food Policy, 35, 175–182.

20. Kenny GJ, Harrison PA. (1993): Chapter 11. Analysis of effects of climate change on broad scale patterns of agroclimate in Europe. In: The Effect of Climate Change on Agricultural and Horticultural Potential in Europe (eds Kenny GJ, Harrison PA, Parry ML), pp. 201–224. University of Oxford, UK.

21. Trnka, M., J. E. Olesen, K. C. Kersebaum, A. O. Skjelv_ag, J. Eitzinger, B. Seguin, et al. (2011): Agroclimatic conditions in Europe under climate change. Glob. Change Biol. 17: 2298–2318.

22. Olesen JE, Bindi M. (2002): Consequences of climate change for European agricultural productivity, land use and policy. European Journal of Agronomy, 16, 239–262.

23. Olesen JE, Trnka M, Kersebaum KC et al. (2011): Risk assessment and foreseen impacts on agriculture. European Journal of Agronomy, 34, 96–112.

24. Lobell, D. B. and M. B. Burke. 2010. On the use of statistical models to predict crop yield responses to climate change. Agric. For. Meteorol. 150:1443–1452.

25. Rötter, R. P., T. R. Carter, J. E. Olesen, and J. R. Porter. (2011b): Crop-climate models need an overhaul. Nat. Clim. Change 1:175–177.

26. White, J. W., G. Hoogenboom, B. A. Kimball, and G. W. Wall. (2011): Methodologies for simulating impacts of climate change on crop production. Field Crops Res. 124:357–368.

27. Osborne, T., G. Rose, and T. Wheeler. (2013): Variation in the global-scale impacts of climate change on crop productivity due to climate model uncertainty and adaptation. Agric. For. Meteorol. 170:183–194.

28. Nelson, G. C., M. W. Rosegrant, J. Koo, R. Robertson, T. Sulser, T. Zhu, et al. (2009): Climate change: impact on agriculture and costs of adaptation. Food Policy Report. International Food Policy Research Institute, Washington DC.

29. Ewert, F., M. K. van Ittersum, T. Heckelei, O. Therond, I. Bezlepkina, E. Andersen, et al. (2011): Scale changes and model linking methods for integrated assessment of agri-environmental systems. Agric. Ecosyst. Environ. 142:6 -17.

30. Angulo, C., R. P. Rötter, R. Lock, A. Enders, S. Fronzek, and F. Ewert. (2013): Implication of crop model calibration strategies for assessing regional impacts of climate change in Europe. Agric. For. Meteorol. 170:32–46.

31. Semenov, M. A. and N. G. Halford. (2009): Identifying target traits and molecular mechanisms for wheat breeding under a changing climate. J. Exp. Bot. 60:2791–2804.

32. Rötter, R. P., T. Palosuo, N. K. Pirttioja, M. Dubrovsky, T. Salo, S. Fronzek, et al. (2011a): What would happen to barley production in Finland if global warming exceeded 4°C? A model-based assessment. Eur. J. Agron. 35:205–214.

33. Rosenzweig, C., J. W. Jones, J. L. Hatfield, A. C. Ruane, K. J. Boote, P. Thorburn, et al. (2013): The Agricultural Model Intercomparison and Improvement Project (AgMIP): protocols and pilot studies. Agric. For. Meteorol. 170:166–182.

34. Harrison, P. A. and R. Butterfield. (1996): Effects of climate change on Europe-wide winter wheat and sunflower productivity. Clim. Res. 7:225–241.

35. Ramankutty N, Foley JA, Norman J, Mcsweeney K. (2002): The global distribution of cultivable lands: current patterns and sensitivity to possible climate change. Global Ecology and biogeography, 11, 377–392.

36. Rötter R. P., Höhn J., Trnka M., et al. (2013): Modelling shifts in agroclimate and crop cultivar response

under climate change. Ecology and Evolution. published by John Wiley & Sons Ltd. doi: 10.1002/ece3.782

37. Carter TR. (1998): Changes in the thermal growing season in Nordic counties during the past century and prospects for the future. *Agricultural and Food Science in Finland* **7**: 161-179.

38. Frich P, Alexander LV, Della–Marta P, Gleason B, Haylock M, Tank K., Teterson T. (2002): Observed coherent changes in climatic extremes during the second half of the twentieth century. *Climate Research* **19**: 193-212.

39. Menzel A, Jakobi G, Ahas R, Scheifinger H, Estrella N. (2003): Variations of the climatological growing season (1951-2000) in Germany compared with other countries. *Int. J. Climatol.* **23**: 793-812. DOI:10.1002/joc.915.

40. Rinaldi M. 2004. Water availability at sowing and nitrogen management of durum wheat: a seasonal analysis with the CERES-Wheat model. *Field Crops Research* **89:** 27–37. DOI:10.1016/j.fcr.2004.01.024.

41. Grassini P, Thorburn J, Burr C, Cassman KG. (2011): High-yield irrigated maize in the Western U.S. Corn Belt: I. On-farm yield, yield potential, and impact of agronomic practices. *Field Crops Research* **120:**142-150. doi:10.1016/j.fcr.2010.09.012.

42. L. Taranu, V. Scorpan, V. Toderas, T. Mironova. Agroclimatic assessment of the impact of possible changes in the thermal regime on the area of cultivation of late maize hybrids in the Republic of Moldova. Innovations transfer in agriculture activities in the context of climate change and sustainable development. Proceedings of the International Conference Chisinau, November 11-13 2009, P. 400-409. (In Russian) http://clima.md/lib.php?l=ro&idc=250&year=2009

43. Babinszky L., Halas V. and Verstegen M. (2011): Impacts of Climate Change on Animal Production and Quality of Animal Food Products, Climate Change - Socioeconomic Effects, Dr Houshan Kheradmand (Ed.), InTech, DOI: 10.5772/23840. Available from: http://www.intechopen.com/books/climate-change-socioeconomic-effects/impacts-of-climate-change-on-animal-production-and-quality-of-animal-food-products