AN ASSESSMENT OF CLIMATE CHANGE IMPACT ON THE REPUBLIC OF MOLDOVA'S AGRICULTURE SECTOR

A Research Study Complementing the Vulnerability and Adaptation Chapter of the Third National Communication of the Republic of Moldova under the United Nations Framework Convention on Climate Change

Lilia ŢĂRANU

An Assessment of Climate Change Impact on the Republic of Moldova's Agriculture Sector

A Research Study Complementing the Vulnerability and Adaptation Chapter of the Third National Communication of the Republic of Moldova under the United Nations Framework Convention on Climate Change

Chișinău, 2014

CZU 551.583:63(478)
Ţ 22

The Monograph has been developed within the Project „Republic of Moldova: Enabling Activities for the Preparation of the Third National Communication under the United Nations Framework Convention on Climate Change” implemented by the Ministry of Environment (MoEN) of the Republic of Moldova and United Nations Environment Programme (UNEP), with financial support of the Global Environment Facility (GEF).

Table of References

Title:	An Assessment of Climate Change Impact on the Republic of Moldova’s Agriculture Sector. *A Research Study Complementing the Vulnerability and Adaptation Chapter of the Third National Communication of the Republic of Moldova under the United Nations Framework Convention on Climate Change.*
Author:	Lilia ŢĂRANU (PhD)
Editors:	Vasile SCORPAN (PhD), Marius ŢĂRANU (MSc)
Peer reviewers:	Valerian CERBARI (Prof., PhD Hab.), Tamara LEAH (PhD), Nicolae BUCATARU (Prof., PhD Hab.)
Proofreading:	Elena BIVOL, Svetlana CHIRIŢĂ, Liliana URSU
Cover design:	Veaceslav POPOVSCHI
Print layout:	Natalia TACU-DOROGAN
Print:	S.E. Editorial-Printing Company “Tipografia Centrala”, Str. Florilor 1, MD-2068, Chisinau, Republic of Moldova
Internet Version:	This document is available at: <http://www.clima.md>

CIP description of the National Book Chamber

Ţăranu, Lilia.

An Assessment of Climate Change Impact on the Republic of Moldova’s Agriculture Sector: A Research Study Complementing the Vulnerability and Adaptation Chapter of the Third National Communication of the Republic of Moldova under the United Nations Framework Convention on Climate Change / Lilia Ţăranu; ed.: Vasile Scorpan, Marius Ţăranu; Climate Change Office, Min. of Environment of the Rep. of Moldova, United Nations Environment Progr. – Chişinău : S. n., 2014 (Î.S. F.E.-P. «Tipografia Centrală»). – 260 p.: tab.

Bibliogr. la sfârşitul cap. – 200 ex.

ISBN 978-9975-53-362-1.

Climate Change Office
Address:
156A, Mitropolit Dosoftei St., Of.37
MD 2004, Chisinau, Republic of Moldova
Tel.: +373 22 232247
Fax: +373 22 232247
e-mail: <clima@mediu.gov.md>
Web: http://www.clima.md

United Nations Environment Programme
Address:
UNEP, United Nations Avenue, Gigiri,
P.O. Box 30552, Nairobi, Kenya
Tel.: +254 20 624166
Fax: +254 20 624041
e-mail: <unepweb@unep.org>
Web: http://www.unep.org

ISBN 978-9975-53-362-1

Foreword

Dear Reader,

I have great pleasure in presenting you the research study "*An Assessment of Climate Change Impact on the Republic of Moldova's Agriculture Sector*", which is complementing the Vulnerability and Adaptation Chapter of the Third National Communication of the Republic of Moldova under the United Nations Framework Convention on Climate Change.

Agriculture is expected to suffer severely from the impacts of climate change. Precipitation, temperature, weather extremes, and evaporation rates all have significant impacts on production and agricultural production impacts economic development, food security, and the Republic of Moldova's development.

Impacts in this sector particular affect vulnerable groups who use agriculture as a means of subsistence and for income generation. Agricultural production also affects food prices, which impacts the entire economy.

The study discusses the current and potential future impacts from climate variability and climate change. It makes also recommendations for the further analysis within the agricultural sector.

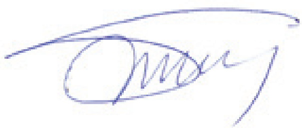
Because climate change is a broad-based and multi-sectoral issue, the Government, business and civil society will need to be engaged in the discussion on what the Republic of Moldova does to address it. Our aim is to inform those involved in this discussion, to break the silence and to illustrate the linkages between climate change and potential impacts, including economic damage.

The potential exists to influence new thinking about adaptation to climate change in the Republic of Moldova. Agriculture sector is very important to the economy. Sector is very vulnerable to climate change and low-income Moldavians in this sector would be more vulnerable to the negative effects and to the rising costs of adapting to them.

Both the Government and citizens are concerned and interested in the climate change issue. The Government is already pursuing several important strategies: the Low Emissions Development Strategy of the Republic of Moldova until 2020 and the Climate Change Adaptation Strategy of the Republic of Moldova.

While this study is not meant to be a comprehensive overview of all aspects of climate change impact on the Republic of Moldova's agriculture, it does reflect the breadth and depth of research that has been done in this sector to date, and it provides a link between a global phenomenon and the sector development issues facing the country. The research and analysis in this study indicates that, while climate change is likely to pose serious threats to agriculture sector development in the Republic of Moldova, it also has the potential to bring opportunities. The "climate for change" that currently exists in the Republic of Moldova will provide the country with the motivation it needs to rise to the challenge.

Vasile SCORPAN (PhD)



Manager
Climate Change Office, Ministry of Environment
of the Republic of Moldova

Acknowledgements

The author expresses gratitude to the Climate Change Office of the Ministry of Environment that contributed to and directly supported the development of the research study.

The author would like to thank also the Global Environment Fund (GEF) for the financial support, in particular Dr. Naoko Ishii (GEF Executive Secretary), the United Nations Environment Programme (UNEP), in particular Dr. George Manful (Programme Manager, UNEP), for the technical support provided along TNC Project implementation, and the Met Office Hadley Centre in the United Kingdom for the opportunity to be trained in using PRECIS (Providing REgional Climates for Impacts Studies) tool for generating high-resolution scenarios of future climate over the territory of the Republic of Moldova, in particular Mr. David Hein, Ms. Chloe Eagle and Mr. Tucker Simon. Without their crucial contribution, the development of this research study could not be achieved.

I would like to thank the staff of the National Bureau of Statistics, in particular Ms. Elena Orlova, Head of Direction „Environmental and Agricultural Statistics", Ms. Tatiana Isac and Ms. Maria Chiperi, senior consultants, Division „Agricultural Statistics", Ms. Ludmila Lungu, Head of Service "Environment Statistics", for their contribution on providing access to agriculture related statistic data, as well as to Ms. Lidia Trescilo, Head of Meteorology Direction, Ms. Tatiana Bugaiova, Head of Meteorology and Climatic Center and Ms. Tatiana Mironova, Head of Agrometeorology Monitoring Center, State Hydrometeorologic Service of the Republic of Moldova, for their contribution on providing access to meteorologic and climatic related data.

I also want to thank Mr. Igor Bercu, shared services manager at Electronic Governance Center and Mr. Dumitru Deveatii, IT programmer at Endava IT Services Company, for their technical contribution to developing climate scenarios for the Republic of Moldova, as well as to Mr. Gherman Bejenaru, Head of the Center for Scientific Researches and GIS, State Hidrometeorological Service and Ms. Galina Mleavaia, Scientific Researcher, Laboratory of

Climatology, Institute of Ecology and Geography of the Academy of Sciences of Moldova, for their contribution in generating high-resolution climatic maps.

I would like to thank also Ms. Elena Bivol, Ms. Svetlana Chirita and Ms. Liliana Ursu, freelance translators, for their availability to proofreading different chapters of this research study, as well as Prof. PhD Hab. Valerian Cerbari, Head of Pedology Laboratory, Dr. Tamara Leah, Vice-Director of the Institute of Pedology, Agrochemistry and Soil Pretection “Nicolae Dimo” of the Academy of Sciences of Moldova, and Prof. PhD Hab. Nicolae Bucataru, Technical University of Moldova, for their kind agreement to peer review the research study.

I also want to thank Dr. Vasile Scorpan, the project manager of UNEP-GEF Project “Republic of Moldova: Enabling Activities for the Preparation of the Third National Communication under the United Nations Framework Convention on Climate Change”, for his continuous involvement during project implementation, as well as for his great contribution in editing the research study.

This chapter would be incomplete, without thanks to my family, for their continuous support during writing this monograph.

Contents

CHAPTER 3
Climate Change and Agroclimatic Condition in the Republic of Moldova

CHAPTER 4
Potential Impact of Climate Change on Agriculture Sector

List of Acronyms and Abbreviations

AEZ	Agro-Ecological Zone
$AGDD_{5, 10°C}$	Active Growing Degree Days
AI	Aridity Index
AOGCMs	Coupled Atmosphere–Ocean General Circulation Models
Apr	April
AR4	IPCC Forth Assessment Report
Art.	Article
ASM	Academy of Science of Moldova
Aug	August
B	Billion
BCCR_BCM2.0	Global circulation model developed by Bjerknes Centre for Climate Research, Norway
^{0}C	Celsius degrees
CCCma_CGCM3_T63	Global circulation model developed by the Canadian Centre for Climate Modelling and Analysis, Canada
CCI	Climate Change Index
CCO	Climate Change Office
CDD	Consecutive Dry Days
CMIP3	Coupled Model Intercomparison Program phase 3
CSIROMk3	Climate model developed by Australia's Commonwealth Scientific and Industrial Research Organization
CWD	Consecutive Wet Days
Dec	December
DJF	Winter season: December, January and February
DSSAT	Decision Support System for Agrotechnology Transfer
DTR	Diurnal Temperature Range
E	Potential evaporation (mm)
ECHAM5-OM	Atmospheric general circulation model developed at the Max-Planck Institute for Meteorology, Germany
EC	European Community
EEA	European Environment Agency
$EGDD_{5, 10°C}$	Effective Growing Degree Days
EPIC	Erosion Product Impact Calculator

EU	European Union
FAO	Food and Agriculture Organization
FD	Frost days
Feb	February
FFD	First Frost Day
FFL	Frost-free period length
FFP	Frost - free period
FNC	First National Communication
FP	Frost Period
GCM	Global Climate Model
GCOS	Global Climate Observing System
GDP	Gross Domestic Product
GEF	Global Environmental Facilities
GFDL_CM2.1	Global circulation model developed by the Geophysical Fluid Dynamics Laboratory, USA
GHG	Greenhouse gases
GIS	Geographic Information System
GPS	Global Positioning System
GST	Growing Season Temperature
ha	Hectares
HadCM3	Hadley Centre Coupled Model, version 3, a circulation model developed by the Met Office in United Kingdom
HI	Huglin Index
HTC	Hydro-Thermal Coefficient
$GSE_{5, 10, 15°C}$	End of Growing Season
$GSS_{5, 10, 15°C}$	Start of Growing Season
Jan	January
JJA	Summer season: June, July, August
Jun	June
Jul	July
IBEC	Index of the Biological Effectiveness of the Climate
IPCC	Intergovernmental Panel for Climate Change
LFAs	Less Favored Areas
LFD	Last Frost Day

$LGS_{5, 10, 15°C}$	Length of Growing Season
km	kilometer
km^2	Square kilometer
mm	Millimeter
m	Meter
m^2	Square meter
m^3	Cubic meter
M-K	Mann-Kendall Test
MAFI	Ministry of Agriculture and Food Industry
MAM	Spring season: March, April and May
Mar	March
May	May
MDL	Moldovan Lei
MEC	Ministry of Economy
MoEN	Ministry of Environment
MRI_CGCM2.3.2	Global circulation model developed by the Meteorological Research Institute, Japan
NAP	National Action Plan
NCCAS	National Climate Change Adaptation Strategy
NCs	National Communications
NCAR_CCSM3	Global circulation model developed by the National Centre for Atmospheric Research, USA
NDT	Number of days with maximum and/or minimum temperature
NEU	Northern Europe
NFD	Number of Frost Days
NH	Northern Hemisphere
NHDR	National Human Development Reports
NHMN	National Hydrological Monitoring Network
NIES_MIROC3.2_hires	Global circulation model developed by the National Institute for Environmental Studies, Japan
Nov	November
Oct	October
OECD	Organization for Economic Co-operation and Development
P	Precipitations
p-value	Indicates statistical significance

Pag.	Page
PE	Potential Evaporation
PRECIS	Providing Regional Climates for Impacts Studies
PRCPTOT	Annual total wet day precipitation
q	Quintals
R10mm	Number of heavy precipitation days - number of days where daily precipitation amount ≥ 10 mm
R20mm	Number of very heavy precipitation days - number of days where daily precipitation amount ≥ 20 mm
R95pTOT%	Contribution from very wet days - daily precipitation amount on a wet day is 95th percentile of precipitation on wet days in base period
R99pTOT%	Contribution from extremely wet days - daily precipitation amount on a wet day is the 99th percentile of precipitation on wet days in base period
R	Sum precipitation level
R2	Coefficient of Determination
r	Pearson Correlation Coefficient
RCCI	Regional Climatic Change Index
RCM	Regional Climate Models
RM	Republic of Moldova
RX1day	Maximum one-day precipitation
SAR	IPCC Second Assessment Report
SEM	Southern Europe and Mediterranean
Sep	September
SDII	Simple daily intensity index - the ratio of annual total precipitation to the number of wet days
SH	Southern Hemisphere
SHS	State Hydrometeorological Service
SNC	Second National Communication
SON	Autumn season: September, October and November
SRES	Special Report on Emissions Scenarios
SU	Summer days - count of days where daily maximum temperature > 25°C
T	Temperature
TAR	IPCC Third Assessment Report
TEM	Terrestrial Ecosystem Model

THI	Temperature-Humidity Index
TNC	Third National Communication
TN10p	Cold nights - number of days where TN < 10th percentile
TN90p	Warm nights - number of days where TN > 90th percentile
TX10p	Cold day-times - number of days where TX < 10th percentile
TX90p	Warm day-times - number of days where TX > 90th percentile
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USD	$ US
WB	World Bank
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
x	Mean
Y	Yield
Σ	Sum
Δ	Difference
σ	Standard deviation
°	Degrees
%	Per cent

Introduction

Republic of Moldova is highly vulnerable to climate variability and change. According to a range of studies, including the National Human Development Report (2009) and the Third National Communication (TNC) under the United Nations Framework Convention on Climate Change (2013), the impacts of climate change are expected to intensify as changes in temperature and precipitation affect economic activity (more detail on these anticipated impacts is described in the chapters following). Furthermore, socio-economic vulnerability to these changes is high.

The Republic of Moldova is one of the least advanced countries in the Europe and Central Asia region – in 2012, Moldova had the fourth lowest Human Development Index out of 30 countries in the region[1].

The economy was in decline before 1991, a process that was intensified with separation from the USSR, and the Republic of Moldova's economy suffered during the recent economic crisis. The impacts of climate change on agriculture are of particular concern – agriculture is a major source of income in the country, where more than half the population lives in rural areas and about one third of the labor force is employed in agriculture.

The socio-economic costs of climate related natural disasters such as droughts, floods and hail are significant and both their intensity and frequency are expected to further increase as a result of climate change.

During the period 1984-2006, Moldova's average annual economic losses due to natural disasters were about US$61 million, or 2.13 percent of national GDP. More recent events have had a significant impact: the 2007 and 2012 year droughts caused estimated losses of about US$1.0 billion (MDL 12 billion) and US$0.4 billion (MDL 5 billion); the 2008 floods cost the country about US$120 million. The most recent floods in 2010 are estimated to have had an adverse economic impact on GDP of about 0.15 percent, with total damage and losses estimated at approximately US$42 million. The floods primarily affected rural and agricultural regions of the country.

Climate change is increasingly recognized as fact of national importance, but so far the national strategic framework lacks integrated climate change

[1] http://hdr.undp.org/sites/default/files/reports/14/hdr2013_en_complete.pdf.

mitigation or adaptation measures. Therefore, there is a need for a strategic framework at the national level to ensure that a qualitative, effective and coherent climate change adaptation process takes place.

The Research Study "An Assessment of Climate Change Impact on the Republic of Moldova's Agriculture Sector" which complements the Vulnerability and Adaptation Chapter of the Third National Communication of the Republic of Moldova under the United Nations Framework Convention on Climate Change (2013) will provide for this process a comprehensive and scientific background to deal with the climate change challenge in the Republic of Moldova.

1.1. Current Climate of the Republic of Moldova: Observed Trends and Variability

In the Republic of Moldova, climate data, specifically changes in temperature and precipitation, has been measured via the hydro-meteorological monitoring network since 1886. Recordings show a clear increase in both mean annual temperature and precipitation (**Figure 1-1 and 1-2**):

- During the period 1887 to 2010, average annual **temperatures** have increased by approximately 1^0C.
- During the same period, **precipitation** has increased by 66 mm.

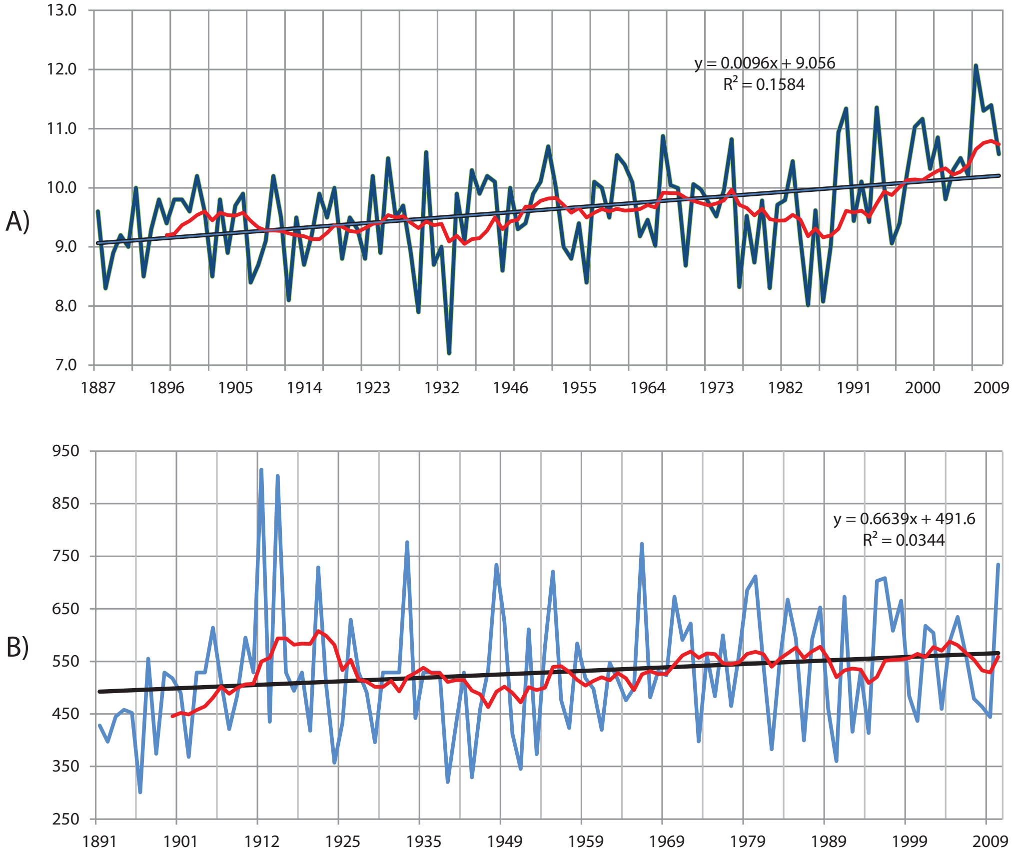


Figura 1-1: Trends of annual average air temperature change (^{0}C) for 1887-2010 (A) and precipitation (mm) for 1891-2010: blue (Actual Course Trend), black solid line (linear trend Secular Course) and red line (10 year moving average trend) at the meteorological station Chisinau

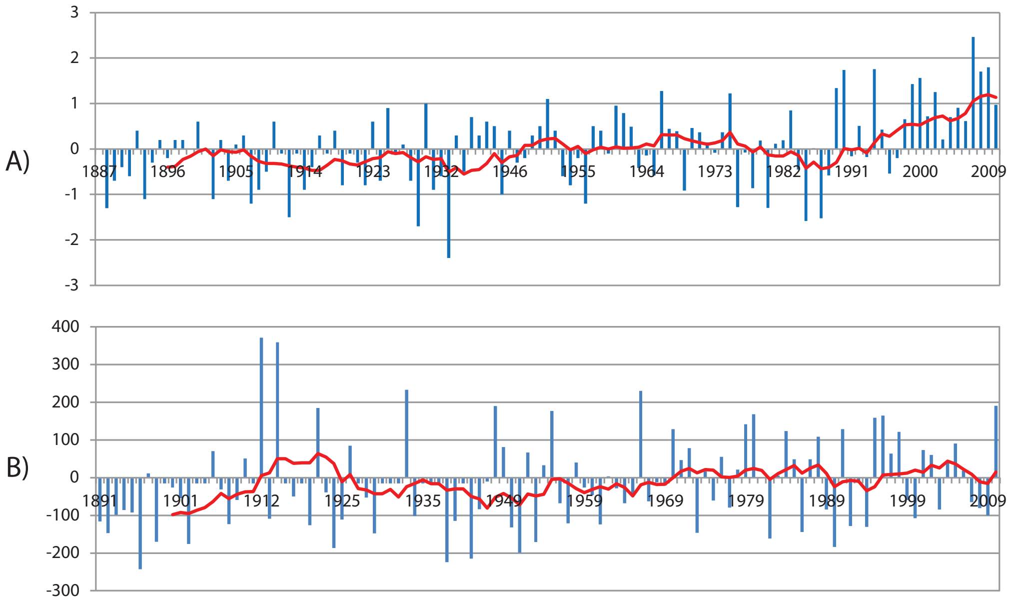


Figure 1-2: Anomaly and 10 year moving average trend in annual mean temperature (°C), for 1987-2010 (A) and annual precipitation (mm), for 1891-2010 (B) (all values shown are anomalies, relative to the 1961-1990 mean climate)

The character of observed changes to the Republic of Moldova's climate was identified through the trends and variability of individual climatic variables. The early 90's years of 20th century are usually taken as a "benchmark" for global warming, therefore the seasonal and annual temperature and precipitation data at Chisinau meteorological station (for which there are available the longest series of instrumental observation) have been studied and compared for two periods: 1887-1980 (for temperature) and 1891-1980 (for precipitation), respectively for 1981-2010 (**Tables 1-1 and 1-2 and Figure 1-3**). The climate change may be considered real if the parameters of the trends are statistically significant.

As can be seen from **Table 1-1** and **Figure 1-3**, a slight increase in annual air temperature (at a 90 per cent level) in the Republic of Moldova, observed before the 90's years of 20th century (***0.05 °C per decade and/or ~0.5 °C per century***) is followed by a sharp increase in the last three decades (1981-2010) (***about 0.63 °C per decade and/or ~6.3 °C per century***). Moreover, compared to the first period (1887-1980), the temperature trends in the last three decades are statistically significant for summer and annual (at a 99 per cent confidence level) and for spring and autumn seasons (at 95 per cent confidence level).

Table 1-1: Average air temperature (⁰C/year) and precipitation trends (mm/year) and their statistical significance of change (*p-value*) for two time periods at Chisinau meteorological station in the Republic of Moldova

Season	Average Air temperature				Precipitation			
	1887-1980		1981-2010		1891-1980		1981-2010	
	Trend	*p-value*	*Trend*	*p-value*	*Trend*	*p-value*	*Trend*	*p-value*
Winter	0.010	0.214	0.039	0.300	0.472	0.108	1.234	0.258
Spring	0.005	0.352	0.061	**0.028**	- 0.059	0.823	0.187	0.873
Summer	0.002	0.578	0.097	**0.000**	0.619	0.291	- 1.406	0.392
Autumn	0.003	0.545	0.048	**0.032**	0.412	0.256	1.291	0.412
Annual	0.005	0.097	0.063	**0.001**	1.448	0.073	1.301	0.578

Note: Bold is used to mark statistically significant values.

Absolutely during all season's precipitation trends for the two periods are positive, with the exception of spring season of the 1891-1980 period and summer season of the 1981-2010 period, where the trends were negative. However, the precipitation trends in these periods are not statistically significant with the exception of annual trend for 1891-1980 years ($p \leq 0.1$), so it can be noted just a tendency to a slight increase in the precipitations (**Table 1-1; Figure 1-3**).

The comparison of the mean air temperatures and standard deviations for two referred periods, both season and annual, have confirmed substantial changes in the temperature regime mentioned above (**Table 1-2**).

Table 1-2: Comparison of the mean (x) and standard deviation (σ) of the seasonal and annual air temperatures and precipitation for the period before 1981 year (x_1, σ_1) and beyond (x_2, σ_2)

Season	Average Air temperature						Precipitation					
	x_1	x_2	p	σ_1	σ_2	p	x_1	x_2	p	σ_1	σ_2	p
Winter	-2.2	-1.1	**0.009**	1.96	1.77	0.539	100.6	105.6	0.638	47.42	48.26	0.615
Spring	9.4	10.2	**0.006**	1.25	1.33	0.651	121.5	123.7	0.829	42.02	54.16	**0.090**
Summer	20.5	21.3	**0.001**	1.06	1.17	0.465	185.9	186.1	0.992	94.38	76.31	0.207
Autumn	10.1	10.3	0.444	1.34	1.08	0.189	113.1	132.2	0.170	58.55	55.29	0.130
Annual	9.5	10.2	**0.001**	0.71	0.97	**0.024**	521.1	547.6	0.333	130.79	108.22	0.261

Note: Bold is used to mark statistically significant values.

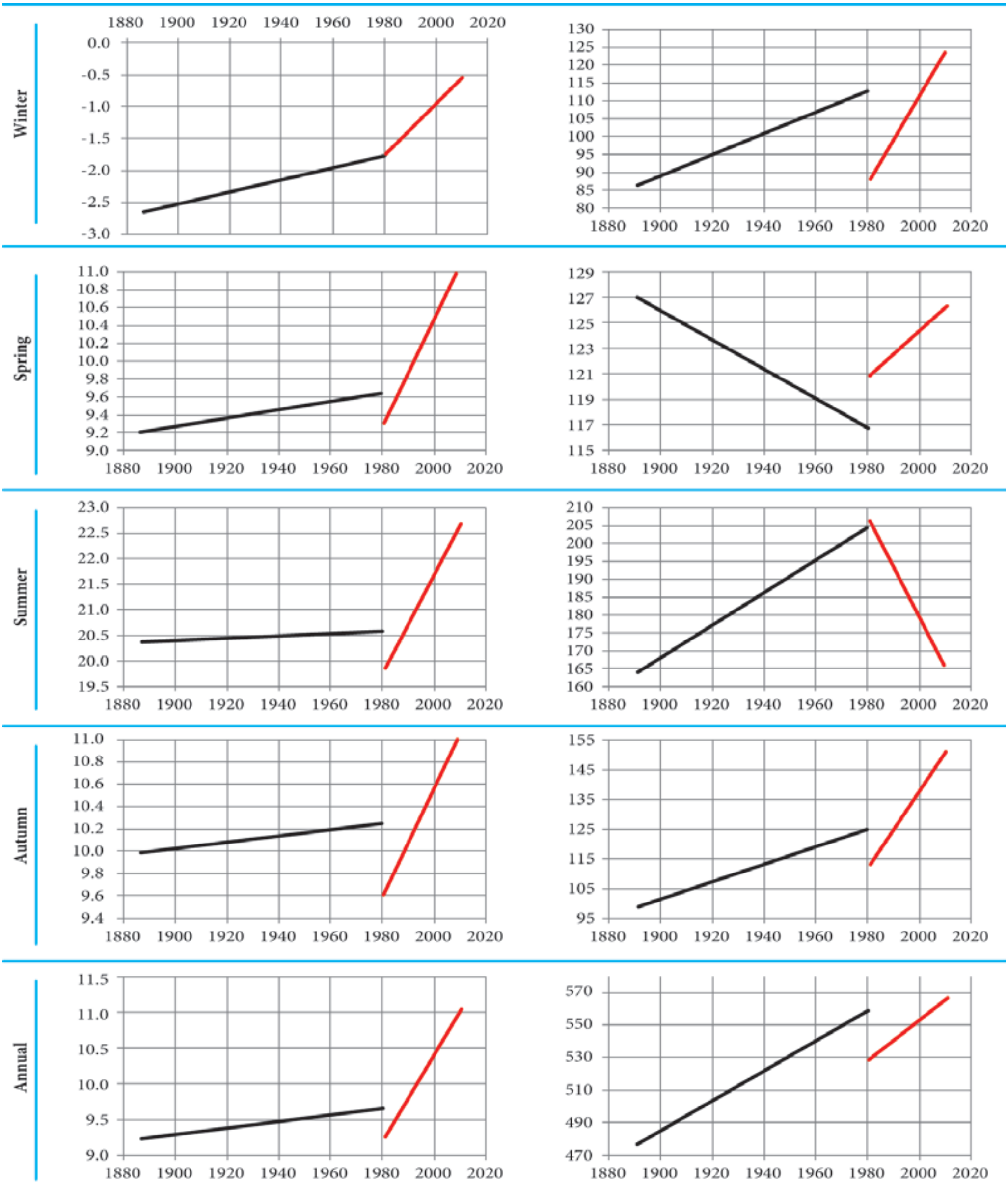


Figure 1-3: Trends in average air temperature (^{0}C/year) – left side, and precipitation (mm/year) – right side, for the period before 1981 year and beyond, at the Chisinau Meteorological Station

It may be stated with *high level confidence* that the mean values of the seasonal (except autumn) and annual temperatures in last three decades (1981-2010) are different from the previous time period, while the variability remains practically the same (except annual temperature for which there was identified a significant increase in the inter-annual variability of mean annual temperatures for the last three decades).

The comparison of the mean values of the total amount of precipitation (**Table 1-2**) shows the lack of statistically significant difference, however slight increase of average annual precipitation (mainly due to the fall) cannot be regarded as statistically significant, it may be explained by inter-annual fluctuations. Also, there aren't revealed any statistically significant differences in the variability of precipitation, with the exception of spring season.

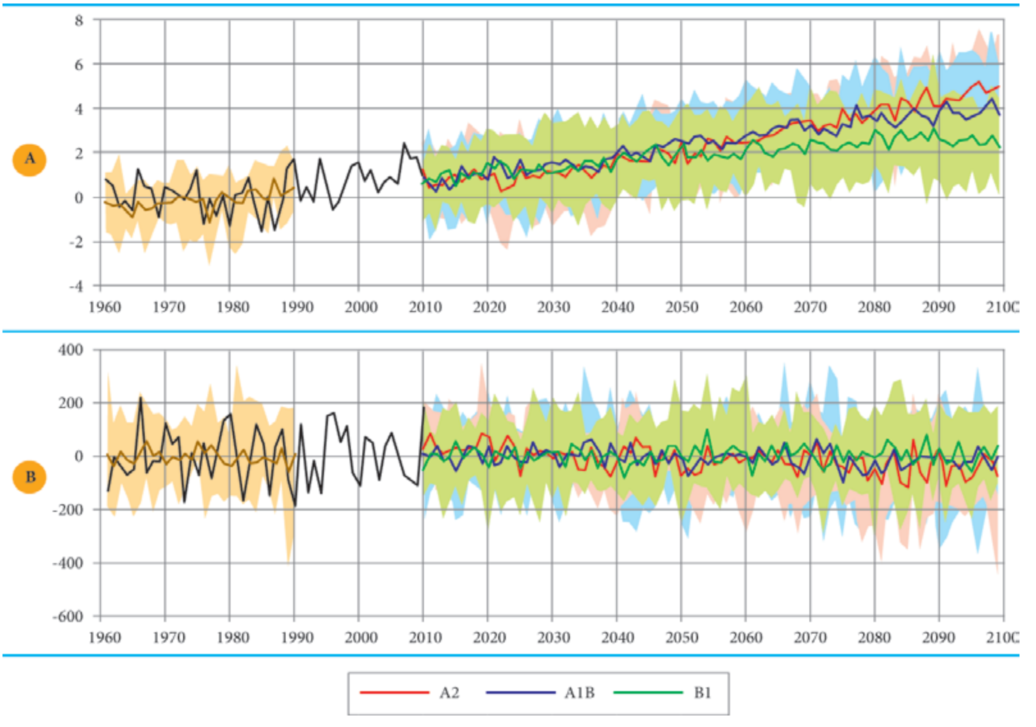


Figure 1-4: Trends in (A) Annual Mean Temperatures (°C) and (B) Precipitation (mm) Anomalies for the Recent Past and Projected Future

The **Figure 1-4** present trends in annual mean temperature (°C) and precipitation (mm) for the recent past and projected future. All values shown are anomalies, relative to the 1961-1990 mean climate. Black curves show the mean of observed data anomalies from 1961 to 2010, brown curves show the average ensemble (solid line) and range (shading) of model simulations of recent climate across an ensemble of 10 GCMs. Colored lines from 2010 onwards show the average (solid line) and range (shading) of the ensemble projections of climate under three emissions scenarios (SRES A2 - red, A1B – blue, and B1 – green). Colored bars on the right-hand side of the projections summarize the range of mean 2080s climates simulated by the 10 GCMs for each emissions scenario.

1.2. Temperature Extremes

A recent *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX; Field *et al.*, 2012), published by the Intergovernmental Panel on Climate Change (IPCC), provides a global overview of our current knowledge about extreme weather and climate events and their implications for society. Global climate change is affecting the frequency and intensity of extreme events. Extremes of both warm and cool temperature are important indicators, as they can have strong impacts on natural as well as human systems. Importantly, a temperature that is 'normal' for one region may be extreme for another region that has not regularly experienced this temperature in the past. For example, mortality has been estimated to increase by between 1 and 4% for every 1°C increase above a location specific temperature threshold, with the elderly, disabled and socio-economically deprived at most risk (Baccini et al., 2008; EEA, 2011a; EEA, 2012). Recent European summer heat waves and winter cold spells have had severe socio-economic and ecological impacts. The record-breaking 2003 and 2010 heat waves led to tens of thousands of heat-related deaths across Europe (Robine et al., 2008; Barriopedro et al., 2011), crop shortfalls, extensive forest fires and record high prices on the energy market amongst many other effects (Schär et al., 2004; García-Herrera et al., 2010). In the winters of 2005/2006 and 2009/2010, parts of Europe experienced unusually cold temperatures that caused travel disruption, cold-related mortality and high energy consumption (Cattiaux et al., 2010).

1.2.1. Data and Methods

The indices of extreme values were calculated based on the daily data for the period from 1961 to 2010. Climate scientists have identified a set of 27 core indices for analysing daily data of temperature and precipitation (Karl et al., 1999; Peterson et. al., 2001; 2005; Alexander et al., 2006). The definitions for a core set of 27 descriptive indices of extremes defined by the Joint CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI, see http://www.clivar.org/organization/etccdi/etccdi.php). From the list of climate change indices, for the purpose of the analysis the temperature extremes, six (three warm and three cold) temperature indices were determined (**Table 1-3**).

Table 1-3: The definitions of temperature-based extreme indices have been used in the assessment

Indices	Abbreviation	Definition	Unit
Cold temperature indices			
Frost days	FD	Number of days where TN (daily minimum temperature) < 0°C	Days
Cold nights	TN10p	Number of days where TN < 10th percentile	Days
Cold day-times	TX10p	Number of days where TX < 10th percentile	Days
Warm temperature indices			
Summer days	SU	Count of days where TX (daily maximum temperature) > 25°C	Days
Warm nights	TN90p	Count of days where TN > 90th percentile	Days
Warm day-times	TX90p	Count of days where TX > 90th percentile	Days

Four indices were defined by the means of percentile (10th and 90th) of maximum (TX) or minimum (TN) values of daily temperatures of the standard climate period from 1961 to 1990) and three indices are related to the number of frosty and summer days (indices defined by fixed rates – daily TN < 0°C and TX > 25°C or 30°C). Temperature – based extremes indices were calculated according to Klein Tank et al., 2009.

1.2.2. Recent Extreme Temperature Events

Extreme high temperatures, for example number of warm days and nights and heat waves, have become more frequent in the past while extreme low temperatures, for example cool days and nights, cold spells and frost days, have become less frequent (Klein Tank and Wijngaard, 2002; IPCC, 2007b; Donat et al., 2013). The average length of summer heat waves over Western Europe has doubled since 1880, and the frequency of hot days has almost tripled (Della-Marta et al., 2007). Furthermore, there has been a clustering of exceptionally warm European summers (Barriopedro et al., 2011) and Cattiaux (2012) concludes that recent spring and autumn temperatures were also exceptionally warm – the 2011 spring in Western Europe was the second warmest, after 2007, within the 1948–2011 time series, while the 2011 year's autumn was the second warmest after 2006. All these observations are consistent with the general warming trends observed across Europe. Since 1960, significant increases in the number of warm days and nights, and decreases in the number of cool days and nights have been noted throughout Europe (**Figure 1-5**).

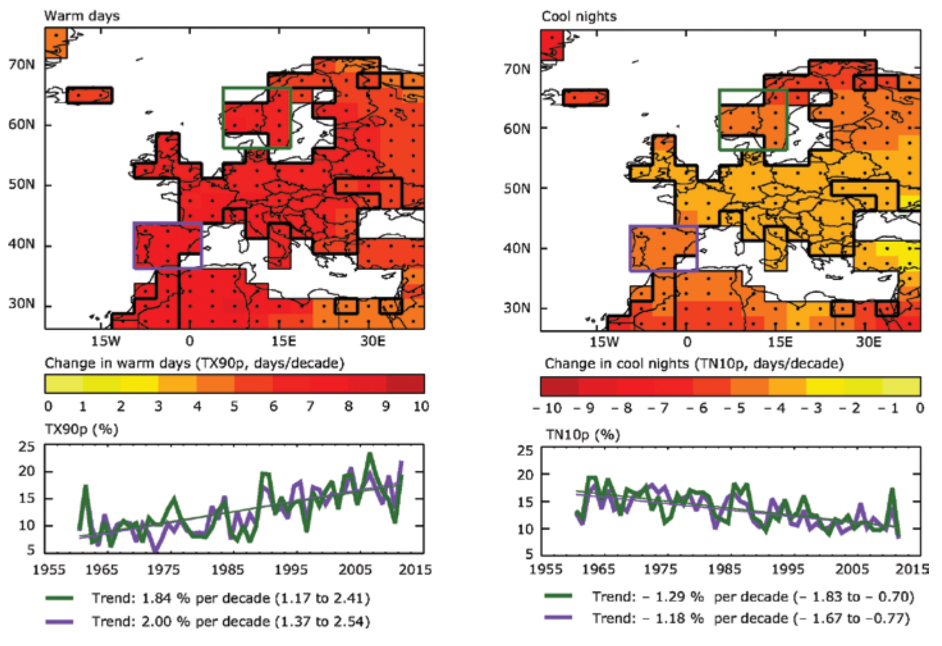


Figure 1-5: Trends in warm days and cool nights across Europe 1960-2012.

Note: Warm days are defined as being above the 90th percentile of the daily maximum temperature and cool nights as below the 10th percentile of the daily minimum temperature (Alexander et al., 2006). Grid boxes outlined in solid black contain at least three stations and so are likely to be more representative of the grid-box. High confidence in the long-term trend is shown by a black dot. (In the maps above, this is the case for all grid boxes.) Area averaged annual time series of percentage changes and trend lines are shown below each map for one area in Northern Europe (green line, 5.6° to 16.9°E and 56.2° to 66.2°N) and one in South-Western Europe (purple line, 35.6° to 1.9°E and 36.2° to 43.7°N).

Source: ECA&D dataset (Klein Tank and Wijngaard, 2002; EEA, 2012).

Between 1960 and 2011, the number of warm days increased by between 4 and 10 days per decade across Europe, and the number of warm nights increased by between 5 and 11 per decade. The number of cool nights has decreased by between 1 and 6 per decade in the same period. Western and Central Europe have shown the largest increases in warm days/nights, and the Iberian Peninsula, North-western Europe and Scandinavia have shown the largest warming in cool days/nights. Despite a clear long-term warming trend across Europe, it is normal to observe considerable variability between and within years (EEA, 2012).

Climate change affects the frequency and intensity of climate extremes through changes in the statistical properties of the temperature distribution. In the period of 1960-2010 statistical significant increases in the number of warm nights and days, and decreases in the frost days, cold nights and days have been observed throughout the Republic of Moldova's Agro-Ecological Zones (AEZs).

Between the 1961 and 2010 the number of warm nights has increased by 5 and 7 days per decade across the Republic of Moldova's AEZs, and the number of warm days increased by 3 days per decade in Northern AEZ and by 4 days per decade in Southern AEZ.

The number of days when the maximum temperature of day exceeds 30°C, which is considered potentially harmful to human wellbeing or to agricultural crops have increased by about 2 days per decade in Northern AEZ and by 3 days per decade in Southern AEZ (**Table 1-4; Figure 1-6**). This is consistent with a global trend to significantly more warm nights and slightly more hot days, as identified in numerous temperature series across the globe (Frich et al., 2002; Alexander et al., 2006).

At many stations in Europe the number of frost days and cold nights and days has decreased significantly in recent decades (Klein Tank and Können, 2003; Alexander et al., 2006). An overall decrease in cold nights has been observed in South-western Europe and in the Western Mediterranean; with greatest signals in Spain and Southern France (Kiktev et al., 2003; Klein Tank and Können, 2003; Alexander et al., 2006; Brunet et al., 2007; Rodríguez-Puebla et al., 2010). Over the Eastern Mediterranean, the reduction in cold winter nights is less pronounced. Some areas in the Aegean and Black Seas and Turkey have even experienced a slight increase in cold nights (Efthymiadis et al., 2011). In North and Central Europe many regions have experienced a trend to fewer cold days and nights since 1950.

Table 1-4: Descriptive statistics and trend parameters calculated for the temperature – based extreme indices for the 1961-2010 time period in the Republic of Moldova

AEZs	Indices	Descriptive Statistics				Trend Parameters		
		Mean	Std. Dev.	Max	Min	R^2	*P*-value	Trend
Northern	***Cold temperature indices***							
	FD (d)	117	15.78	151	82	0.17	**0.0024**	-0.44
	TN10p (-8.4^{0}C) (d)	32	15.07	67	6	0.09	**0.0367**	-0.30
	TX10p (-1.8^{0}C) (d)	34	14.86	70	8	0.03	0.2123	-0.18
	Warm temperature indices							
	SU(d)	53	15.4	91	19	0.06	0.0756	0.26
	TN90p (14.1^{0}C) (d)	44	14.71	77	13	0.38	**0.0000**	0.61
	TX90p (26.0^{0}C) (d)	41	13.42	73	12	0.09	**0.0310**	0.27
	ND_{30} (d)	9	6.98	26	0	0.15	**0.0043**	0.19
Central	***Cold temperature indices***							
	FD (d)	96	14.78	125	67	0.09	**0.0306**	-0.30
	TN10p (-8.4^{0}C) (d)	33	13.99	67	8	0.02	0.3403	-0.13
	TX10p (-1.8^{0}C) (d)	35	13.81	71	10	0.01	0.6133	-0.07
	Warm temperature indices							
	SU(d)	75	16.68	110	34	0.01	0.4448	0.12
	TN90p (14.1^{0}C) (d)	46	15.22	85	18	0.47	**0.0000**	0.70
	TX90p (26.0^{0}C) (d)	41	14.62	76	7	0.05	0.1263	0.21
	ND_{30} (d)	19	11.35	50	1	0.11	**0.0172**	0.25
Southern	***Cold temperature indices***							
	FD (d)	95	15.52	127	63	0.05	0.1038	-0.24
	TN10p (-8.4^{0}C) (d)	33	12.81	65	10	0.03	0.2579	-0.14
	TX10p (-1.8^{0}C) (d)	34	13.60	72	12	0.01	0.4692	-0.09
	Warm temperature indices							
	SU(d)	80	15.83	114	44	0.05	0.1264	0.23
	TN90p (14.1^{0}C) (d)	43	13.67	73	17	0.31	**0.0000**	0.51
	TX90p (26.0^{0}C) (d)	43	15.71	85	12	0.13	**0.0082**	0.39
	ND_{30} (d)	21	12.42	58	2	0.13	**0.0106**	0.29

Note: Climate indices and their abbreviations are described in Table 1. Bold numbers indicate significant trends at ≥99; 95% level.

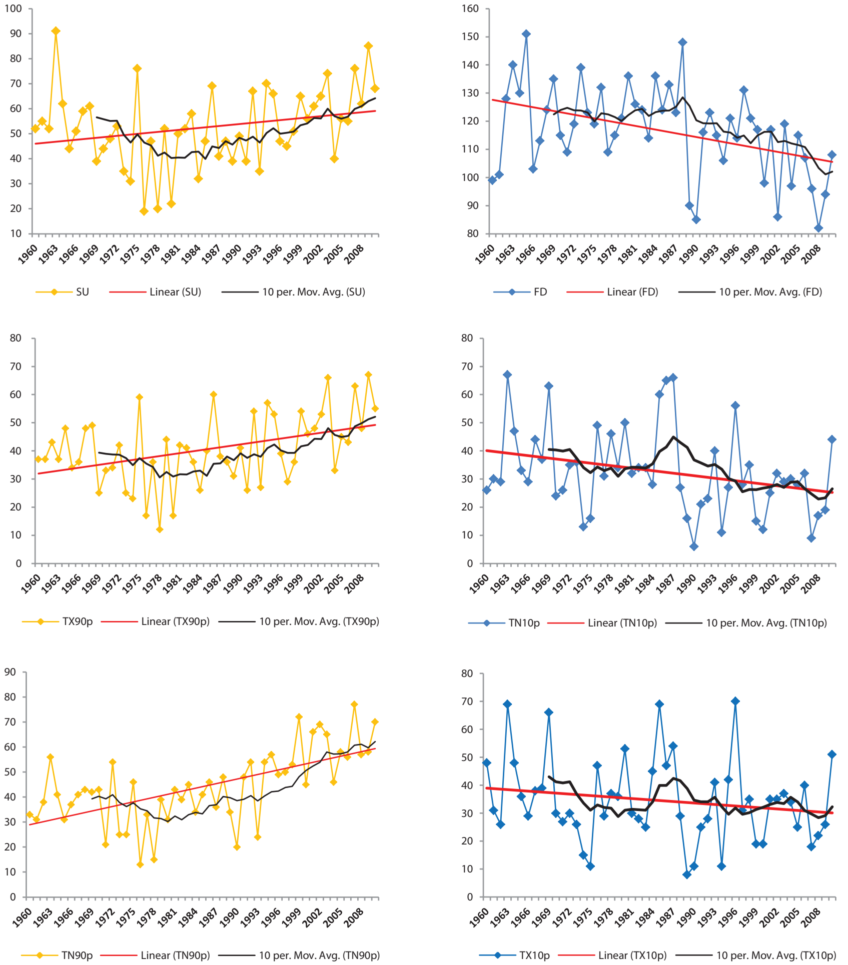


Figure 1-6: The Trend of Warm (Left) and Cold (Right) Temperature Indices in Northern AEZ for the 1961-2010 time periods

The number of frost days over the Republic of Moldova has decreased by about 4 days per decade in northern AEZ and by 3 days per decade in central AEZ, when the number of cold nights statistical decreased by 3 days per decade only over northern AEZ in the same period (**Table 1-4**). The changes in the trend of warm temperature extremes indices were greater than the changes of the cold temperature extremes indices throughout the Republic of Moldova's AEZs. In the northern and southern AEZs have been shown the largest statistical significant increases in warm nights/days and number of days which exceed 30°C; in northern AEZs also have been observed a statistical significant decrease in frost days and cold nights (**Table 1-4; Figure 1-6**).

1.3. Precipitation Extremes

Changes in the frequency and intensity of extreme precipitation (see Box 1 for definitions) can have considerable impacts on society, including the environment, agriculture, industry and ecosystem services. An assessment of past trends and future projections of extreme precipitation is therefore essential for advising policy decisions on mitigation and adaptation to climate change (Kendon et al., 2008). The risks posed by precipitation-related hazards, such as flooding events (including flash floods) and landslides, are also influenced by non-climatic factors, such as population density, floodplain development and land-use change. Estimates of trends in heavy or extreme precipitation are more uncertain than trends in mean precipitation because, by their nature, extreme precipitation events have a low frequency of occurrence. This leads to greater uncertainties when assessing the statistical significance of observed changes (EEA, 2012).

Box 1: Definition of precipitation extremes

The term ***'precipitation extreme'*** can refer to both high and low extremes of precipitation. High extremes of precipitation are defined either by the amount of precipitation in a given time period (e.g. daily or hourly) or by the period above a location-specific threshold. Indicators for extreme precipitation may be defined in terms of return periods (such as 1 in 20 years, termed absolute extremes). Alternatively, they may be defined relative to the normal precipitation distribution in an area (e.g. the heaviest 5% of daily precipitation averaged over a 30-year time period, relative extremes). The former captures infrequent but possibly high impact events, whereas the latter has a more frequent sampling rate, capturing on average 18 days per year (over 30 years). The approach that is chosen depends largely on the application of the end user. Low extremes of precipitation can be quantified in terms of consecutive dry days. Note, however, that an assessment of changes in drought conditions should also consider other factors, such as soil moisture and vegetation responses to changing atmospheric CO_2 concentration (EEA, 2012).

1.3.1. Data and Methods

The indices of extreme precipitation values were calculated based on the daily observations data of precipitation for the period from 1961 to 2010. Climate scientists have identified a set of 27 core indices for analysing daily data of temperature and precipitation (Karl et al., 1999; Peterson T.C and et. al., 2001, 2005; Alexander et al., 2006). The definitions for a core set of 27 descriptive indices of extremes defined by the Joint CCl / CLIVAR / JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI, see http://www.clivar.org/organization/etccdi/etccdi.php).

From the list of climate change indices, for the purpose of the analysis the precipitation extremes, nine precipitation indices were determined (**Table 1-5**).

Table 1-5: The definitions of precipitation extreme indices have been used in the assessment

Indices	Abbreviation	Definition and calculation	Unit
Annual total wet day precipitation	**PRCPTOT**	Annual total precipitation from days ≥ 1mm. Let RR*wj* be the daily precipitation amount on a wet day *w* (RR ≥ 1 mm) in period *j*. Then PRCPTOT*j* = sum (RR*wj*).	mm
Contribution from very wet days	**R95pTOT%**	100 * **R95pTOT**/PRCPTOT. Let RR*wj* be the daily precipitation amount on a wet day *w* (RR ≥ 1 mm) in period *j* and let RR*wn*95 be the 95th percentile of precipitation on wet days in the base period *n* (1961- 1990). Then R95pTOTj = sum (RR*wj*), where RR*wj* > RR*wn*95.	%
Contribution from extremely wet days	**R99pTOT%**	100 * **R99pTOT** / PRCPTOT. Let RR*wj* be the daily precipitation amount on a wet day *w* (RR ≥ 1 mm) in period *j* and let RR*wn*99 be the 99th percentile of precipitation on wet days in the base period *n* (1961-1990). Then R99pTOT*j* = sum (RR*wj*), where RR*wj* > RR*wn*99.	%
Maximum one-day precipitation	**RX1day**	Monthly maximum 1-day precipitation. Let RR*ij* be the daily precipitation amount on day *i* in period *j*. The maximum one-day value for period *j* is RX1day*j* = max (RR*ij*).	mm
Simple daily intensity index	**SDII**	The ratio of annual total precipitation to the number of wet days (≥ 1 mm). Let RR*ij* be the daily precipitation amount on wet day *w* (RR ≥ 1 mm) in period *j*. If *W* represents the number of wet	mm / day
Number of heavy precipitation days	**R10mm**	Annual count when precipitation ≥10mm. Let RR*ij* be the daily precipitation amount on day *i* in period *j*. Count the number of days where RR*ij* ≥ 10 mm.	Days

Indices	Abbreviation	Definition and calculation	Unit
Number of very heavy precipitation days	**R20mm**	Annual count when precipitation ≥ 20mm. Count of days where RR ≥ 20 mm Let RR*ij* be the daily precipitation amount on day *i* in period *j*. Count the number of days where RR*ij* ≥ 20 mm.	Days
Consecutive dry days	**CDD**	Maximum number of consecutive days when precipitation<1mm. Let RR*ij* be the daily precipitation amount on day *i* in period *j*. Count the largest number of consecutive days where RR*ij* < 1 mm.	Days
Consecutive wet days	**CWD**	Maximum number of consecutive days when precipitation ≥ 1mm. Let RR*ij* be the daily precipitation amount on day *i* in period *j*. Count the largest number of consecutive days where RR*ij* ≥ 1 mm.	Days

Precipitation extremes indices were calculated according to Klein Tank et al., 2009; including contribution from very wet days (R95pTOT), and contribution from extremely wet days (R99pTOT), due to their potential to have significant societal impacts (Donat M.G. et al., 2013).

In applications of statistics to climatology, such as the estimation of moments of statistical distributions, analysis of trends, correlation analysis, etc., parametric methods are commonly utilized. Their correct use requires several assumptions to be fulfilled, including the type of distribution (most frequently normal), serial independence (i.e. zero autocorrelation), and stationarity.

The estimate of trend by the least-squares regression for climatic element yi and time variable (years) *xi, i* = 1; . . . ; n, was used the well-known form:

$$b = \frac{n\sum_{1}^{n} x_i y_i - \sum_{1}^{n} x_i \sum_{1}^{n} y_i}{n\sum_{1}^{n} ([x_i])^2 - \sum_{1}^{n} ([x_i])^2}$$

and its (p ∗ 100)% confidence interval, assuming normality of the distribution, expressed as:

$$b = \mp \frac{\frac{t_1 + p}{2^{\sigma} E}}{n^{\frac{1}{2}} S_x}$$

where $\frac{t_1+p}{2}$ is the $\frac{1+p}{2}$ quantile of the t distribution, σ_E is the standard deviation of residuals, and S_x is the standard deviation of x (Wilks, 1995; von Storch and Zwiers, 1999).

Non-parametric (distribution-free) methods, which relax the assumptions, may serve as an alternative. They tend to be more resistant to a misbehavior of the data (e.g. to outliers) than the parametric methods, at the expense of being less efficient, that is, they have larger uncertainty in the statistical estimate. An introductory review of non-parametric statistical methods applicable in climatology has been provided by Lanzante (1996).

The non-parametric Mann-Kendall (M-K) test is widely used for detecting trends in hydrological and meteorological parameters (e.g., Huth and Pokorná; Modarres and da Silva, 2007; Wang et al., 2008; Mishra and Singh, 2010; Zhang et al., 2011; EEA, 2012; Donat et al., 2013). The test does not require the data to be distributed normally. Further, the test has a low sensitivity to abrupt breaks in the time series (Jaagus, 2006), and can test trends in a time series without requiring normality or linearity (Wang et al., 2008).

For non–parametric estimate was used an Excel template – MAKESENS – developed for detecting and estimating trends in the time series of annual values of atmospheric and precipitation concentrations. The procedure is based on the nonparametric Mann-Kendall test for the trend and the nonparametric Sen’s method for the magnitude of the trend. The Mann-Kendall test is applicable to the detection of a monotonic trend of a time series with no seasonal or other cycle. The Sen’s method uses a linear model for the trend (Salmi et al., 2002).

1.3.2. Recent Extreme Precipitation Events

Annual precipitation records averaged across Europe show no significant changes since 1950 according to the E-OBS dataset (Haylock et al., 2008), based on the European Climate Assessment dataset (Klok and Klein Tank, 2009). At the sub-continental scale, the trend in precipitation is most significant in north-eastern and south-western Europe. The majority of Scandinavia and the Baltic States have observed an increase in annual precipitation of greater than 14 mm per decade, with an increase of up to 70 mm per decade in western Norway. In contrast, annual precipitation has decreased in the Iberian Peninsula, in particular in north-western Spain and in northern Portugal (**Figure 1-7**).

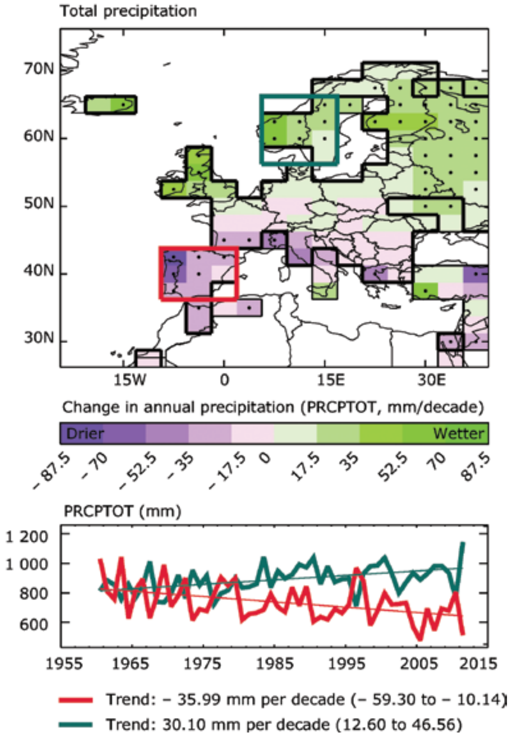


Figure 1-7: Trends in annual precipitation across Europe (1960–2012)

Note: The trends are calculated using a median of pairwise slopes algorithm. Black dots represent high confidence in the sign of the long-term trend in the box (if the 5^{th} to 95^{th} percentile slopes are of the same sign). Boxes which have a thick outline contain at least three stations. Area averaged annual time series of percentage changes and trend lines are shown below each map for one area in Northern Europe (blue line, 5.6 to 16.9°E and 56.2 to 66.2°N) and one in South-Western Europe (red line, 35.6 to 1.9°E and 36.2 to 43.7 °N).

Source: HadEX dataset, updated with data from the ECA&D dataset, EEA 2012.

While there is some evidence linking land use, in particular forest cover, to local and regional precipitation patterns (Millán, 2008), it is not clear if the relatively minor land-use changes since 1950 have influenced the observed precipitation trends.

The patterns of recent changes in precipitation indices appear spatially more heterogeneous across the Republic of Moldova than the consistent warming pattern seen in the temperature indices. Observational records of most of the precipitation extreme indices do not indicate significant trends in case of parametric as well as non-parametric (distribution-free) estimations across the Republic of Moldova. Some changes in these variables have been observed across the Republic of Moldova's AEZs but most of them are not statistically significant due to large natural variability. Most of the precipitation indices show changes toward more intense precipitation over northern and central AEZs. Such changes in extreme precipitation are found, for example, for the average intensity of daily precipitation (SDII), number of heavy (R10mm) and very heavy precipitation days (R20mm) (see **Figure 1-8: blue and red trend lines**; and **Table 1-6**).

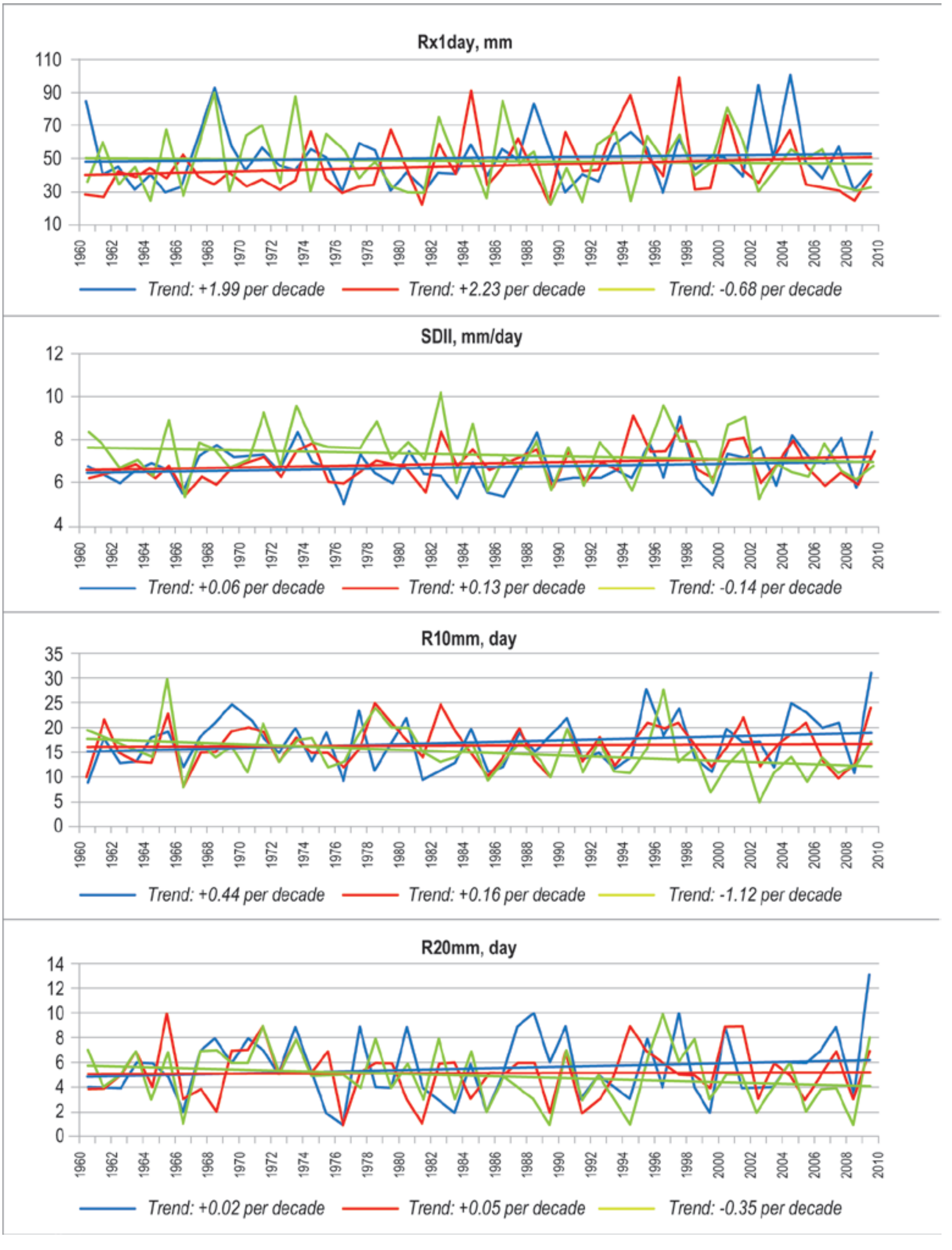


Figure 1-8: Trends in maximum one-day precipitation (RX1day), simple daily intensity index (SDII), heavy precipitation days (R10mm), and very heavy precipitation days (R20mm): blue line – northern AEZ, red line – central AEZ and green line – southern AEZ (1961–2010)

All indices display upward trends during the past 50 years. Similar patterns of change are also found for the annual total precipitation in wet days (PRCP-TOT) and contribution from very wet days (R95pTOT) and extremely wet days (R99pTOT), (see **Figure 1-8: blue and red trend lines;** and **Table 1-6**).

Table 1-6: Mann – Kendall Test (Z) of Precipitation Extreme Indices

AEZ	RX1day	SDII	R10mm	R20mm	PRCPTOT	R95pTOT	R99pTOT	CDD	CWD
Northern	0.33	0.64	1.18	0.69	0.59	0.92	0.60	-1.01	0.40
Central	0.90	1.32	0.34	0.25	0.55	0.85	0.42	-1.20	-0.36
Southern	-0.36	-1.04	-2.61**	-1.87^{+}	-1.50	0.15	0.46	0.53	-1.81^{+}

Note: The presence of a statistically significant trend is evaluated using the Z value. A positive (negative) value of Z indicates an upward (downward) trend. In this research, significance levels of α = 0.001***, 0.01** and 0.05*, $\alpha = 0.1^{+}$ were applied.

All precipitation-based indices show larger areas with not significant trends toward wetter conditions than areas with drying trends. In southern AEZ have been observed not significant trends toward less frequent and intense precipitation, except for contribution from extremely wet days (R99pTOT) (see **Figures 1-8** and **1-9: green trend line;** and **Table1-6**).

Observational records do not indicate widespread significant trends in either the number of consecutive wet days (indicating flood risks) or dry days (indicating drought risks) across Europe (**Figure 1-10**).

Some changes in these variables have been observed across Europe, but most of them are not statistically significant due to large natural variability. Interestingly, parts of North-western and North-eastern Europe show significant increasing trend in both the number of wet days and dry days. The proportion of Europe that has experienced extreme or moderate meteorological drought conditions did not change significantly during the 20th century (Lloyd-Hughes and Saunders, 2002). Summer droughts have also shown no statistically significant trend during the period 1901–2002 (Robock et al., 2005).

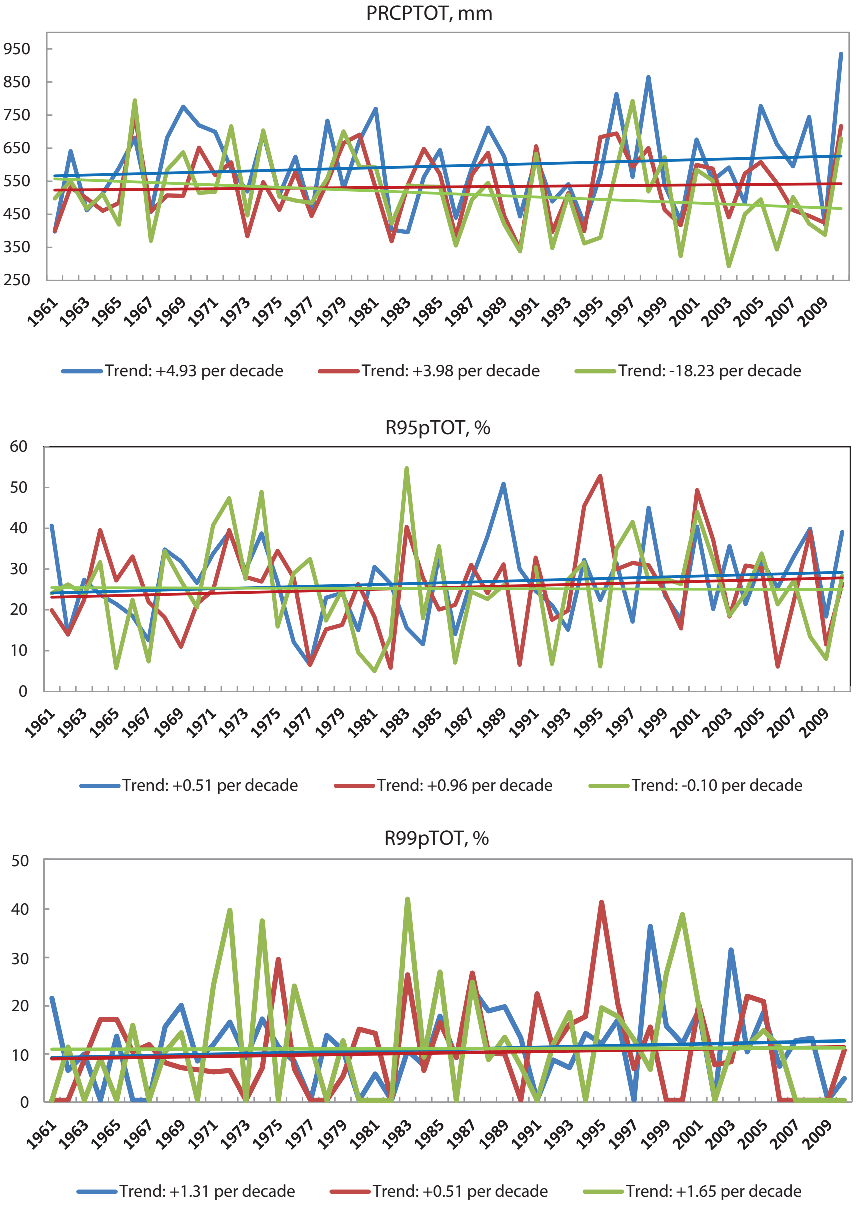


Figure 1-9: Trends in total precipitation in wet days (PRCPTOT), precipitation due to very wet days (R95pTOT, %) and precipitation due to extremely wet days (R99pTOT, %): blue line – northern AEZ, red line – central AEZ and green line – southern AEZ (1961–2010)

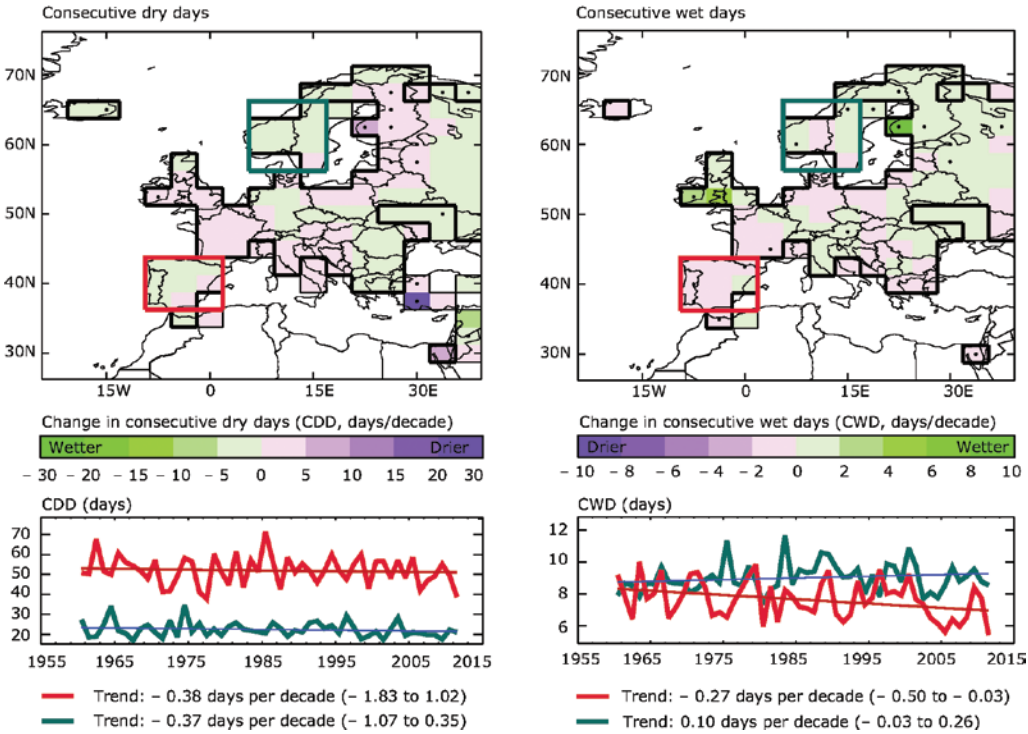


Figure 1-10: Trends in consecutive dry and consecutive wet days (1960-2012)

Note: High confidence in a long-term trend is shown by a black dot (if the 5th to 95th percentile slopes are of the same sign). Boxes which have a thick outline contain at least three stations. Area averaged annual time series of percentage changes and trend lines are shown below each map for one area in Northern Europe (blue line, 5.6 to 16.9 °E and 56.2 to 66.2 °N) and one in South-western Europe (red line, 35.6 - to 1.9°E and 36.2 to 43.7°N).

Source: HadEX dataset, updated with data from the ECA&D dataset, EEA, 2012.

Observational records do not indicate significant trends in either the number of dry days (indicating drought risks) or consecutive wet days (indicating flood risks) in case of parametric as well as non-parametric (distribution-free) estimations across Republic of Moldova. Some changes in these variables have been observed across Republic of Moldova’s AEZs but all of them are not statistically significant due to large natural variability. According to parametric as well as non-parametric (distribution-free) estimations, central AEZ reveals decreasing trends, not statistically significant, in both the number of wet days and dry days, also, in southern AEZ have been observed not statistically significant trends toward increasing trends in the number of dry days (indicating drought risks) and decreasing in the number of wet days (indicating flood risks). According to non-parametric (distribution-free) estimations in northern AEZ have been observed not statistically significant trends toward increasing in the number of wet days (indicating flood risks), and decreasing in the number of dry days (see **Table 1-6** and **Figure 1-11**).

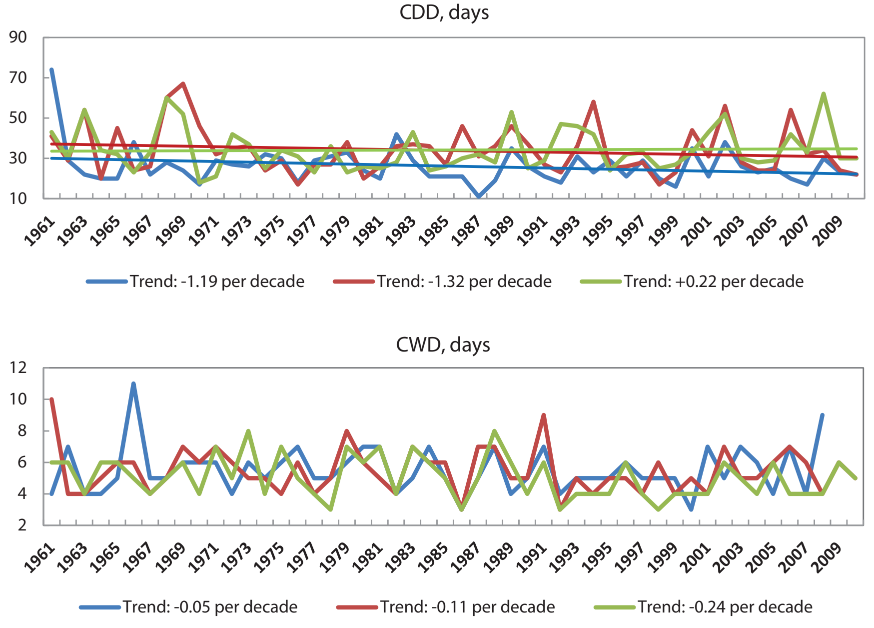


Figure 1-11: Trends in consecutive dry days (CDD) and consecutive wet days (CWD): blue line – northern AEZ, red line – central AEZ and green line – southern AEZ (1961–2010)

CONCLUSIONS

The main conclusions are the following:

1. The character of observed changes to the Republic of Moldova's climate was identified through the trends and variability of individual climatic variables. The slight growth in annual air temperature (at a 90 per cent level) in the Republic of Moldova, observed before the 90's years of 20^{th} century *(0.05 ^{0}C per decade and/or ~0.5^{0}C per century)* is followed by a sharp increase *(about 0.63^{0}C per decade and/or ~6.3^{0}C per century)* in the last three decades (1981-2010).
2. Moreover, compared to the first period (1887-1980), the temperature trends in the last three decades are statistically significant for summer

season and annual (at a 99 per cent confidence level) and for spring and autumn seasons (at 95 per cent confidence level).

3. During all seasons' precipitation trends for the two evaluated periods are positive, with the exception of spring season of the 1891-1980 periods and summer season of the 1981-2010 periods, where the trends were negative. However, the precipitation trends in these periods are not statistically significant with the exception of annual trend for 1891-1980 periods ($p \leq 0.1$), so it can be noted just a tendency to a slight increase in the precipitations.
4. Climate change could affect the frequency and intensity of climate extremes through changes in the statistical properties of the temperature and precipitation distribution.
5. In the period of 1961-2010 statistical significant increases in the number of warm nights and days, and decreases in the frost days, cold nights and days have been observed throughout the Republic of Moldova's AEZs.
   a. The number of warm nights has been increased by 5 and 7 days per decade across the Republic of Moldova's AEZs, and the number of warm days increased by about 3 days in northern AEZ and by 4 days per decade in southern AEZ.
   b. The number of days when the maximum temperature of day exceeds 30°C, which is considered potentially harmful to human wellbeing or agricultural crops have been increased by about 2 days in northern AEZ and by 3 days per decade in southern AEZ.
   c. The number of frost days over the Republic of Moldova has decreased by about 4 days per decade in northern AEZ and by 3 days per decade in central AEZ, when the number of cold nights statistical decreased by 3 days per decade only over northern AEZ in the same period.
   d. The changes in the trend of warm temperature extremes indices were greater than the changes of the cold temperature extremes indices throughout the Republic of Moldova's AEZs. Northern and southern AEZs have been shown the largest statistical significant increases in warm nights/days and number of days which exceed 30°C, and in northern AEZs also have been observed a statistical significant decrease in frost days and cold nights.
6. The patterns of recent changes in precipitation indices appear spatially more heterogeneous across the Republic of Moldova than the consistent

warming pattern revealed in the temperature indices. Observational records of most of the precipitation extreme indices do not indicate significant trends in case of parametric as well as non-parametric (distribution-free) estimations across the Republic of Moldova.

7. Most of the precipitation indices show changes toward more intense precipitation over northern and central AEZs. Such changes in extreme precipitation are found for the average intensity of daily precipitation (SDII), number of heavy (R10mm), very heavy precipitation days (R20mm), annual total precipitation in wet days (PRCPTOT), and contribution from very wet days (R95pTOT) and extremely wet days (R99pTOT). All of these indices display upward trends during the past 50 years.
    a. In southern AEZ has been observed not significant trends toward less frequent and intense precipitation, except for contribution from extremely wet days (R99pTOT).
    b. Observational records do not indicate significant trends in either the number of dry days (indicating drought risks) or consecutive wet days (indicating flood risks) in case of parametric as well as non-parametric (distribution-free) estimations across Republic of Moldova. Some changes in these variables have been observed across Republic of Moldova's AEZs but all of them are not statistically significant due to large natural variability.
    c. According to parametric as well as non-parametric (distribution-free) estimations central AEZ shows decreasing not statistically significant trends in both the number of wet days and dry days, and in southern AEZ have been observed not significant trends toward increasing trends in the number of dry days (indicating drought risks) and decreasing in the number of wet days (indicating flood risks).
    d. In northern AEZ according to non-parametric (distribution-free) estimations has been observed not significant trends toward increasing in the number of wet days (indicating flood risks), and decreasing in the number of dry days.

Bibliography

1. **Alexander, L.V et al. (2006)**, *Global observed changes in daily climate extremes of temperature and precipitation*. Journal of Geophysical Research. 111: D09109.
2. **Alexander, L.V., Zhang, X., Peterson, T.C., Caesar, J., Gleason, B., Klein Tank, A.M.G., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F., Tagipour, A., Rupa Kumar, K., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D.B., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M., Vazquez-Aguirre, J.L. (2006),** *Global observed changes in daily climate extremes of temperature and precipitation*. Journal of Geophysical Research: Atmospheres 111, DOI: 10.1029/2005JD006290.
3. **Baccini, M., Biggeri, A., Accetta, G., Kosatsky, T., Katsouyanni, K., Analitis, A., Anderson, H. R., Bisanti, L., D'Ippoliti, D., Danova, J., Forsberg, B., Medina, S., Paldy, A., Rabczenko, D., Schindler, C. et al. (2008)**, *Heat effects on mortality in 15 European cities.* Epidemiology, 19(5), 711–719. DOI:10.1097/EDE.0b013e318176bfcd.
4. **Barriopedro, D., Fischer, E.M., Luterbacher, J., Trigo, R.M., García-Herrera, R. (2011),** *The Hot Summer of 2010: Redrawing the Temperature Record Map of Europe.* Science, 332, 220–224.
5. **Brunet, M., Jones, P.D., Sigró, J., Saladié, O., Aguilar, E., Moberg, A., Della-Marta, P.M., Lister, D., Walther, A., López, D. (2007),** *Temporal and spatial temperature variability and change over Spain during 1850–2005.* Journal of Geophysical Research: Atmospheres, 112, DOI: 10.1029/2006JD008249.
6. **Cattiaux, J. (2012),** *Contribution of Atmospheric Circulation to remarkable European Temperatures of 2011*. Bulletin of the American Meteorological Society, 93, 1041–1067.
7. **Cattiaux, J., Vautard, R., Cassou, C., Yiou, P., Masson-Delmotte, V., Codron, F. (2010), Winter 2010 in Europe: A cold extreme in a warming climate.** Geophysical Research Letters, 37, DOI:10.1029/2010GL044613.
8. **Della-Marta, P.M., Haylock, M.R., Luterbacher, J., Wanner, H. (2007),** *Doubled length of western European summer heat waves since 1880*. J. Geophys. Res: Atmospheres, 112, D15103, DOI: 10.1029/2007JD008510.
9. **Donat, M. G., et al. (2013),** *Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset.* J. Geophys. Res. Atmos., 118, DOI:10.1002/jgrd.50150
10. **EEA, (2011a),** *Mapping the impacts of natural hazards and technological accidents in Europe* (EEA Technical report No 13/2010). European Environment Agency, Copenhagen. <http://www.eea.europa.eu/publications/mapping-the-impacts-of-natural>.
11. **EEA, (2012),** *Climate change, impacts and vulnerability in Europe 2012*. Report No. 12/2012. European Environment Agency, Copenhagen.
12. **Efthymiadis, D., Goodess, C.M., Jones, P.D. (2011),** *Trends in Mediterranean gridded temperature extremes and large-scale circulation influences.* Natural Hazards and Earth System Science, 11, 2199–2214.
13. **Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.K., Allen, S.K., Tignor, M., Midgley, P.M. (Eds.) (2012),** *Manag-*

ing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, New York, USA.

14. **Frich, P., Alexander, L.V., Della-Marta, P., Gleason, B., Haylock, M., Tank, A.M.G.K., Peterson, T. (2002),** *Observed coherent changes in climatic extremes during the second half of the twentieth century.* Climate Research, 19, 193–212.
15. **García-Herrera, R., Díaz, J., Trigo, R.M., Luterbacher, J., Fischer, E.M. (2010),** *A Review of the European Summer Heat Wave of 2003.* Critical Reviews in Environmental Science and Technology, 40, 267–306.
16. **Haylock, M. R., Hofstra, N., Klein Tank, A. M. G., Klok, E. J., Jones, P. D. and New, M. (2008),** *A European daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006.* Journal of Geophysical Research 113 (D20), DOI: 10.1029/2008JD010201.
17. **Huth, R. and Pokorná, L. (2004),** *Parametric versus non-parametric estimates of climatic trends.* Theor. Appl. Climatol., 77, 107-112.
18. **Jaagus, J. (2006),** *Climatic changes in Estonia during the second half of the 20th century in relationship with changes in large-scale atmospheric circulation*. Theor. Appl. Climatol., 83, 77-88.
19. **Karl, T.R., Nicholls N. and Ghazi A. (1999),** *CLIVAR/GCOS/WMO workshop on indices and indicators for climate extremes: workshop summary.* Climatic Change, 42, 3–7;
20. **Kendon, E. J., Rowell, D. P. and Jones, R. G. (2008),** *Robustness of Future Changes in Local Precipitation Extremes.* Journal of Climate, 21, 4280–4297. DOI:10.1175/2008JCLI2082.1.
21. **Kiktev, D., Sexton, D.M.H., Alexander, L., Folland, C.K. (2003),** *Comparison of Modeled and Observed Trends in Indices of Daily Climate Extremes.* Journal of Climate, 16, 3560–3571.
22. **Klein Tank, A. and Wijngaard, J. (2002),** *Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment.* International Journal of Climatology, 22(12), 1441–1 453. DOI:10.1002/joc.773.
23. **Klein Tank, A.M.G, F.W. Zwiers and X. Zhang. (2009),** *Guidelines on Analysis of extremes in a changing climate in support of informed decisions for adaptation.* Climate Data and Monitoring WCDMP-No. 72, TD 1500. World Meteorological Organization, Geneva, Switzerland. Available at <http://www.wmo.int/datastat/documents/ WCDMP_72_TD_1500_en_1_1.pdf>.
24. **Klein Tank, A.M.G., Können, G.P. (2003),** *Trends in Indices of Daily Temperature and Precipitation Extremes in Europe, 1946–99.* Journal of Climate, 16, 3665–3680.
25. **Klok, E. J. and Klein Tank, A.M.G. (2009),** *Updated and extended European dataset of daily climate observations.* International Journal of Climatology, 29, 1182–1191. doi:10.1002/joc.1779.
26. **Lanzante, J.R. (1996),** *Resistant, robust and non-parametric techniques for the analysis of climate data: Theory and examples, including applications to historical radiosonde station data.* International Journal of Climatology, 16, 1197–1226.

27. **Lloyd-Hughes, B. and Saunders, M.A. (2002),** *A drought climatology for Europe.* International Journal of Climatology, 22, 1571–1592. DOI:10.1002/joc.846.
28. **Millán, M.M. (2008),** *Drought in the Mediterranean and summer floods in the UK and central and eastern Europe: What global climate models cannot see regarding the hydrological cycles in Europe and why* (Unpublished internal Gammeltoft-RACCM CIRCE report produced for the European Commission). EC, Brussels.
29. **Mishra, A.K. and Singh, V.P. (2010),** *Changes in extreme precipitation in Texas.* J. Geophys. Res., 115, D14106. DOI: 10.1029/2009JD013398.
30. **Modarres, R. and da Silva, V.P.R. (2007),** *Rainfall trends in arid and semi-arid regions of Iran.* J. Arid. Environ, 70, 344-355.
31. **Peterson, T.C. et al. (2001),** *Report on the Activities of the Working Group on Climate Change Detection and Related Rapporteurs, 1998–2001.*Rep. WCDMP-47, WMO-TD 1071. Geneva: WMO;
32. **Peterson, T.C. (2005),** *Climate change indices.* WMO. Bulletin. 54(2), 83–86.
33. **Robine, J.-M., Cheung, S.L.K., Le Roy, S., Van Oyen, H., Griffiths, C., Michel, J.-P., Herrmann, F.R. (2008),** *Death toll exceeded 70,000 in Europe during the summer of 2003.* Comptes Rendus Biologies, 331, 171–178.
34. **Robock, A., Mingquan, M., Vinnikov, K., Trofimova, I. V. and Adamenko, T. I. (2005),** *Forty-five years of observed soil moisture in the Ukraine: No summer desiccation (yet).* Geophysical Research Letters, 32, L03401. DOI: 10.1029/2004GL021914.
35. **Rodríguez-Puebla, C., Encinas, A.H., García-Casado, L.A., Nieto, S. (2010),** *Trends in warm days and cold nights over the Iberian Peninsula: relationships to large-scale variables.* Climatic Change, 100, 667–684.
36. **Schär, C., Vidale, P.L., Lüthi, D., Frei, C., Häberli, C., Linger, M.A., Appenzeller, C. (2004).** *The role of increasing temperature variability in European summer heat waves.* Nature, 427, 332–336.
37. **Timo Salmi, Anu Määttä, Pia Anttila, Tuija Ruoho-Airola and Toni Amnell. (2002),** *Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates – the Excel template application MAKESENS.* Publications on Air Quality No. 31 Report code FMI-AQ-31, August 2002. 35p.
38. **Von Storch, H., Zwiers F.W. (1999),** *Statistical analysis in climate research.* Cambridge: Cambridge University Press, 484 pp.
39. **Wang, W., Chen, X., Shi, P. and Van Gelder, P.H. A.J. M. (2008),** *Detecting changes in extreme precipitation and extreme streamflow in the Dongjiang River Basin in southern China.* Hydrol. Earth. Syst. Sci., 12, 207-221.
40. **Wilks, D.S. (1995),** *Statistical methods in the atmospheric sciences.* San Diego: Academic Press, 464 pp.
41. **Zhang, Q., Xu, C.-Y., Chen, Y.D. and Ren, L. (2011),** *Comparison of evapotranspiration variations between the Yellow River and Pearl River basin, China.* Stoch. Environ. Res. Risk Assess., 25, 139-150.

Chapter 2. Climate Change Scenarios for Agriculture Vulnerability and Adaptation Assessment

This chapter is a review of the national climate scenarios for Republic of Moldova within the broader context of the likely regional (EU) impacts of climate change. Projected seasonal changes in two key meteorological variables – temperature and precipitation – are outlined for three 30-year future time periods: the 2020s, 2050s and 2080s. Changes in extremes of temperature and precipitation are also discussed.

2.1. An Uncertainty Cascade in Future Climate Change Drivers

2.1.1. Socioeconomic Scenarios

Socioeconomic scenarios (SRES) projecting greenhouse gas emissions in CO_2 equivalents are the backbones of impact studies, providing the basis for assessing the impact of climate change on human activities, including agriculture (Parry et al., 2005). Scenarios are neither predictions nor forecasts in a traditional sense; rather they are images of the future, or alternative futures that are meant to assist in climate change analysis (Nakicenovic, 2000). As an alternative, mitigation scenarios can be used with atmospheric CO_2 concentrations stabilized by 2100 (Arnell et al., 2002; Tubiello and Fischer, 2007).

2.1.2. Global and Regional Climate Models

The best available tool for predicting climatic change from greenhouse gas (GHG) emission scenarios is the atmosphere–ocean general circulation model (AOGCM) (Giorgi and Mearns, 2002). The atmospheric component of an AOGCM (the atmospheric GCM) is coupled to a land-surface scheme and used to predict changes in land based state variables (e.g. soil moisture). GCMs compute future climates under anthropogenic forcing, i.e. present and projected future emissions of GHGs (IPCC, 2001a). Their use in impact assessment studies of climate change is widespread (IPCC, 2001b; Reilly et al., 2001). These models provide internally coherent climate dynamics by solving globally all climate-relevant physical equations. It is recognized that GCM projections present significant uncertainties, in part through issues of scale resolution, and in part through imperfect understanding of key climate dynamics (IPCC, 2001a). Even among GCMs with similar temperature-change simulations, predictions of regional precipitation responses may vary significantly, in part because of the intrinsic chaotic nature of climate and in part because of differences in model approach to resolving local to regional atmospheric dynamics. For example, GCM predictions of the magnitude and location of soil moisture changes often disagree and are often difficult to compare with one another, since the land surface schemes employed by the various AOGCMs differ considerably, and their accuracy is questionable (Cornwell and Harvey, 2007). This presents a problem when assessing the impacts of climatic change on crops. For example, many studies project impacts using a single GCM (IPCC, 2007a), thus neglecting a major source of uncertainty. Moreover, the spatial resolution of most GCMs is low, which much reduces the realism of local projections of climate change, especially in areas with complex terrain. Among the methods used to provide insight on climate description at regional scales, regional climate models forced by GCMs have become a widely used tool for regional climate studies (Giorgi and Mearns, 1999; IPCC, 2007a). Since new information is added to the regional climate models by modelling GCM-subgrid processes, the RCMs' fields may have different statistical properties that those of the original GCM (Mearns et al., 1999). This is especially apparent with highly anisotropic fields such as precipitation (Machenhauer et al., 1998).

2.1.3. Downscaling Methods

While working with scenarios, difficulties have often been encountered in relation to the disparity of scales between global and regional climate models (RCM) on the one hand and the local application of models on the other hand. For this reason, GCM or RCM results are usually downscaled with the help of high resolution atmospheric models (dynamical downscaling) and/or statistical models and stochastic weather generators (statistical downscaling).

Dynamical downscaling is most demanding in terms of computational resources. Statistical downscaling has the advantage of being computationally fast, but tends to introduce additional uncertainties into the scenarios (Calanca et al., 2008). The uncertainty originating from the choice of global and regional model formulation in climate-change downscaling experiments has been analyzed (Beniston et al., 2007), by conducting a co-ordinated set of climate modelling experiments.

While there are a number of contrasted approaches for statistical downscaling (e.g. anomalies, variable corrections, De´que´ et al., 2005; statistical disaggregation, Boe´ et al., 2006), they all require accurate climatic data and long time series and are therefore most applicable in regions with a high density of weather stations. Moreover, it should be noted that the validation of a statistical downscaling algorithm for present day climate conditions does not necessarily imply the validity of its climate change projections, the plausibility of which needs to be compared with direct GCM model outputs (Boe´ et al., 2006). The task of deriving better estimates of changing variability and extreme events is thus still intrinsically difficult (IPCC, 2007a) and this limits the confidence in climate model projections. Finally, it should be noted that a number of past impact studies with a focus on agriculture have taken arbitrary adhoc incremental annual, seasonal or monthly anomalies for the long-term mean temperature and precipitation. Therefore, part of the literature does not reflect the likely range of climate change impacts but only the effects of a certain degree of temperature and/or precipitation change.

In order to assess uncertainties arising from future climatic and atmospheric drivers on crop and pasture productivity better, an ensemble of regional climate models carefully downscaled to reflect better the local distribution of key climatic variables like rainfall is needed (Challinor et al., 2007, 2009). This approach could be generalized by comparing several crop and pasture models for a range of greenhouse gas emission scenarios and/or of mitigation scenarios in order to quantify the probability of avoided impacts brought by greenhouse gas mitigation.

2.1.4. Ensemble Climate Impacts Assessment

Climate change prediction contains many inherent uncertainties (Schellnhuber et al. 2006): uncertainties in projected emissions, and resultant concentrations, of greenhouse gases mean that the climate forcing cannot be known precisely. The response of climate to a projected forcing, as calculated by climate models, is also uncertain. Any forecast of weather (beyond a few days), climate variability, or climate change cannot be made deterministically. This is because sensitivity to uncertainty in the model initial conditions, as well as uncertainties caused by parameterized model physics, limits the predictability of the atmosphere. The response of physical and biological systems, such as crop growth or disease dynamics, to any projected climate also contains uncertainties (see e.g., Mearns et al. 2003).

Multiple climate simulations, known as ensembles, are used to sample the inherent uncertainties outlined above. Scenarios of future greenhouse gas emissions are used to sample the possible ranges of climate forcing. Uncertainty in the model initial conditions can be assessed by running a model many times with different initial conditions. Uncertainty in model structure (e.g., representation of atmospheric physics) can be assessed by using more than one model (e.g., Randall et al. 2007) or by varying model parameters (e.g., Murphy et al., 2004; Stainforth et al., 2005). On seasonal time scales, ensembles that use more than one model can give more skilful results on average than any single model ensemble (Hagedorn et al., 2005). Such multi model ensembles are an efficient way of providing information for climate impacts because a range of existing models are used, thus making good use of globally available computer resources (see e.g., Palmer et al., 2004, 2005).

There are currently efforts to consider holistically the broad range of time scales in climate prediction and to move toward seamless weekly-to-decadal ensemble prediction of the complete climate system (see e.g., WCRP, 2007). In particular, decadal time scales may prove to have both quality (i.e., skill) and value (Troccoli and Palmer, 2007). Such systems may be able to capture the emergent climate change signal. It has been suggested, by using a simple model (Cox and Stephenson, 2007), that total uncertainty in climate prediction may be at a minimum at 30–50 yrs. lead time, when the uncertainty in initial conditions will have fallen significantly, but the uncertainty in greenhouse gas emissions is not yet prohibitively large.

In agricultural impacts, the methods used to bridge the gap in spatial scale on which crop and climate models operate compound the inaccuracy and imprecision in the climate model (Hansen and Jones, 2000). Furthermore, current and future adaptive crop management practices are not known with precision. Despite these uncertainties, a consensus on some impacts is emerging. However, such conclusions need to be continually updated as knowledge advances. For example, even though a consensus is emerging on the response of crop yield to mean temperature changes (Easterling et al. 2007), the response functions are not universally applicable (Challinor et al., 2009).

Furthermore, the response of crops to pests, weeds, diseases and climate extremes is still not well understood. Recent years have seen a move toward the use of ensemble methods with impact modeling (e.g., Collins and Knight, 2007; Lejenäs, 2005; Challinor et al., 2005a) so that at least some of the uncertainties in prediction are quantified. Although the quantification of uncertainty is being increasingly recognized as important in the broader scientific literature, it is only relatively recently that its importance is being recognized in regional impacts assessments (e.g., Cruz et al. 2007). Because the impacts model itself can be a significant source of uncertainty (Challinor et al., 2005c, 2008), we now look in some detail at the methods available for crop yield modeling (Challinor et al., 2009).

2.2. Developing Climate Scenarios for the Republic of Moldova's Climate Vulnerability and Adaptation Assessment

2.2.1. Data and Methods

There are various ways of constructing climate scenarios (review of methods in Carter et al, 1999, 2007; Mearn and Hulme, 2001). These include climate model-based approach, temporal and spatial analogue, expert judgment and incremental scenarios for climate impact and adaptation assessments. In order to drive detailed regional projections, it is recommended to use complex atmosphere–ocean global climate models (AOGCMs; hereafter abbreviated as GCM). The General Circulation Models is a numerical representation of the climate system based on physical, chemical, and biological properties of its components, their interactions and feedback processes, accounting for all or some of its known properties.

One of the major problems in applying GCM projections to regional impact assessments is the coarse spatial scale of the gridded estimates in relation to many of the exposure units being studied. Several methods have been adopted for developing regional GCM-based scenarios at the sub-grid scale, a procedure variously known as "regionalisation" or "downscaling".

A very popular method to obtain higher spatial resolution for predictions of climate variables is known as the 'change-factor' or 'delta' method (Wilby et al., 2004). In the context of downscaling, however, it is assumed that the baseline climate is at higher resolutions than resolutions of a global climate model. Consequently, high-resolution climate scenarios are obtained through a combination of high-resolution baseline data with coarse-scale information on climate change from global climate models.

Firstly, the reference climatology is established for the site or region of interest. Depending on the application this might be a representative long-term average such as 1961-1990, or an actual meteorological record such as daily maximum temperatures. Secondly, changes in the equivalent temperature variable for the GCM grid–box closest to the target site are calculated. For example, a difference of 2.5˚C might occur by subtracting the mean GCM temperatures for 1961-1990 from the mean of the 2050s. Thirdly, the temperature change suggested by the GCM (in this case, +2.5˚C) is then simply added to each day in the reference climatology (Wilby, R., et al. 2004).

Limitations to 'change-factor' or 'delta' method downscaling techniques are: future climate scenarios only differ from the baseline climate in terms of the mean, maxima, and minima; all other properties of the data, such as the range and variability remain unchanged. It is assumed that spatial climatic patterns remain unchanged in the future. The method needs to be adjusted for precipitation (e.g., Arnell and Reynard, 1996), because addition (or multiplication) of observed precipitation by GCM precipitation can alter the number of rain days and extreme-event size (Wilby et al., 2004). Also, if a study involves a time series of daily climate data, the temporal sequencing of wet and dry days remains unchanged. The method can be used to explore time slices but not transient changes (Wilby et al., 2004).

Firstly, the method assumes that GCMs more accurately simulate relative change than absolute values, i.e. assuming a constant bias through time. Secondly, CFs only scale the mean, maxima and minima of climatic variables, ignoring change in variability and assuming the spatial pattern of climate will remain constant (Diaz Nieto and Wilby, 2005). Furthermore, for precipitation the temporal sequence of wet days is unchanged, when change in wet and dry spells may be an important component of climate change. Several modifications have been proposed. Prudhomme et al. (2002) suggest any increase in precipitation is distributed evenly among existing rain days, added to make each third dry day wet, or distributed on only the three wettest days to simulate an increase in extremes. The effectiveness of these arbitrary parameters is however, not assessed. Harrold and Jones (2003) rank GCM daily rainfall for current and future climates and use these to scale ranked historical precipitation series, a variation which is sensitive to change in extreme rainfall and wet day frequencies.

But this straightforward approach has relatively low computational costs and has been used in many studies (Prudhomme et al., 2002; Arnell, 2003 a,b; Eckhardt and Ulbrich, 2003; Diaz-Nieto and Wilby, 2005; Horton et al., 2010).

Studies undertaken to date for developing regional GCM-based scenarios in the Republic of Moldova have used the 30-year period 1961 to 1990 as a climatologic baseline, and have studied the influence of climate on relevant sectors within three time horizons: 2010-2039, 2040-2069 and 2070-2099.

Three individual coupled atmosphere-ocean General Circulation Models (GCMs) based on IS92a scenario were used for the vulnerability and adaptation assessments in the First and Second National Communications (FNC, 1998-2000 and SNC, 2005-2009) of the Republic of Moldova under the UNFCCC as described in the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report (SAR). The 2009/2010 NHDR for the Republic of Moldova used the experiments of an ensemble of six GCM experiments based on the SRES A2 and B2 scenarios for downscaling climate projections for the Republic of Moldova as recommended by IPCC Third Assessment Report (TAR).

The objective of this study was to construct new contemporary regional climate projections and examine the changes over the Republic Moldova's northern, central and southern AEZs in terms of the distribution of temperature and precipitation based on an ensemble of the 10 GCMs simulations used for the IPCC Fourth Assessment Report (AR4) covering the end of 20th (reference) and 21st (scenario) centuries introduced by three SRES emission scenarios A2, A1B and B1.

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) (Meehl et al., 2007a) (**Figure 2-1**): 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).

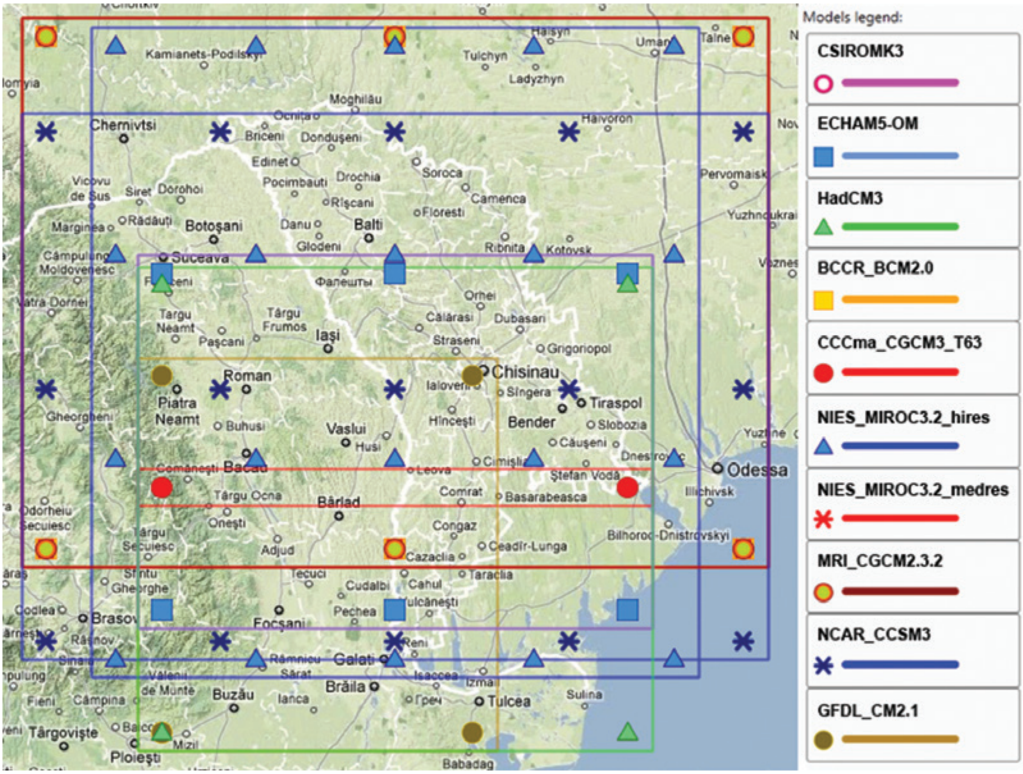
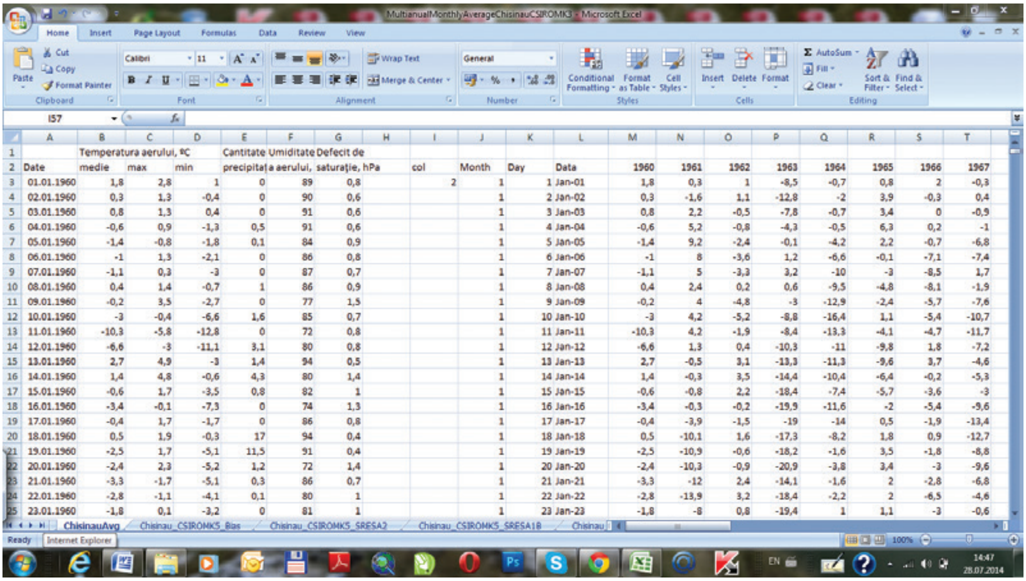


Figure 2-1: Number of Grid Points and Corresponding AOGCM Climate Prediction Area (Frame) for the Territory of the Republic of Moldova

The SRES A2, A1B and B1 emissions scenarios provide GHG concentrations determined by particular developmental storylines (Nakicenovic et al., 2000). While it is unlikely than any single emissions scenario or GCM projection will occur exactly as described, a suite of GCM simulations and GHG emissions profiles provides a range of possible climate outcomes that reflects the current level of expert knowledge. This approach to climate change scenarios was developed by the IPCC and provided the basis for its AR4 (2007).

In order to predict regional climate change for validation and downscaling procedure there were used the historic (1961-2010) observed climate data, recorded from 5 meteorological stations (Briceni, Balti, Chisinau, Tiraspol and Cahul) offered by the State Hidrometeorological Service, which include: daily total precipitation and monthly mean, minimum, maximum temperatures and humidity (see as an example Figure 2-2).



	A	B	C	D	E	F	G	H	I	J	K
1		Temperatura aerului, ºC			Cantitate	Umiditate	Defecit de				
2	Date	medie	max	min	precipitaț	a aerului,	saturaţie, hPa		col	Month	Day
3	01.01.1960	1,8	2,8	1	0	89	0,8		2	1	1
4	02.01.1960	0,3	1,3	-0,4	0	90	0,6			1	2
5	03.01.1960	0,8	1,3	0,4	0	91	0,6			1	3
6	04.01.1960	-0,6	0,9	-1,3	0,5	91	0,6			1	4
7	05.01.1960	-1,4	-0,8	-1,8	0,1	84	0,9			1	5
8	06.01.1960	-1	1,3	-2,1	0	86	0,8			1	6
9	07.01.1960	-1,1	0,3	-3	0	87	0,7			1	7
10	08.01.1960	0,4	1,4	-0,7	1	86	0,9			1	8
11	09.01.1960	-0,2	3,5	-2,7	0	77	1,5			1	9
12	10.01.1960	-3	-0,4	-6,6	1,6	85	0,7			1	10
13	11.01.1960	-10,3	-5,8	-12,8	0	72	0,8			1	11
14	12.01.1960	-6,6	-3	-11,1	3,1	80	0,8			1	12
15	13.01.1960	2,7	4,9	-3	1,4	94	0,5			1	13
16	14.01.1960	1,4	4,8	-0,6	4,3	80	1,4			1	14
17	15.01.1960	-0,6	1,7	-3,5	0,8	82	1			1	15
18	16.01.1960	-3,4	-0,1	-7,3	0	74	1,3			1	16
19	17.01.1960	-0,4	1,7	-1,7	0	86	0,8			1	17
20	18.01.1960	0,5	1,9	-0,3	17	94	0,4			1	18
21	19.01.1960	-2,5	1,7	-5,1	11,5	91	0,4			1	19
22	20.01.1960	-2,4	2,3	-5,2	1,2	72	1,4			1	20
23	21.01.1960	-3,3	-1,7	-5,1	0,3	86	0,7			1	21
24	22.01.1960	-2,8	-1,1	-4,1	0,1	80	1			1	22
25	23.01.1960	-1,8	0,1	-3,2	0	81	1			1	23

	L	M	N	O	P	Q	R	S	T
1									
2	Data	1960	1961	1962	1963	1964	1965	1966	1967
3	Jan-01	1,8	0,3	1	-8,5	-0,7	0,8	2	-0,3
4	Jan-02	0,3	-1,6	1,1	-12,8	-2	3,9	-0,3	0,4
5	Jan-03	0,8	2,2	-0,5	-7,8	-0,7	3,4	0	-0,9
6	Jan-04	-0,6	5,2	-0,8	-4,3	-0,5	6,3	0,2	-1
7	Jan-05	-1,4	9,2	-2,4	-0,1	-4,2	2,2	-0,7	-6,8
8	Jan-06	-1	8	-3,6	1,2	-6,6	-0,1	-7,1	-7,4
9	Jan-07	-1,1	5	-3,3	3,2	-10	-3	-8,5	1,7
10	Jan-08	0,4	2,4	0,2	0,6	-9,5	-4,8	-8,1	-1,9
11	Jan-09	-0,2	4	-4,8	-3	-12,9	-2,4	-5,7	-7,6
12	Jan-10	-3	4,2	-5,2	-8,8	-16,4	1,1	-5,4	-10,7
13	Jan-11	-10,3	4,2	-1,9	-8,4	-13,3	-4,1	-4,7	-11,7
14	Jan-12	-6,6	1,3	0,4	-10,3	-11	-9,8	1,8	-7,2
15	Jan-13	2,7	-0,5	3,1	-13,3	-11,3	-9,6	3,7	-4,6
16	Jan-14	1,4	-0,3	3,5	-14,4	-10,4	-6,4	-0,2	-5,3
17	Jan-15	-0,6	-0,8	2,2	-18,4	-7,4	-5,7	-3,6	-3
18	Jan-16	-3,4	-0,3	-0,2	-19,9	-11,6	-2	-5,4	-9,6
19	Jan-17	-0,4	-3,9	-1,5	-19	-14	0,5	-1,9	-13,4
20	Jan-18	0,5	-10,1	1,6	-17,3	-8,2	1,8	0,9	-12,7
21	Jan-19	-2,5	-10,9	-0,6	-18,2	-1,6	3,5	-1,8	-8,8
22	Jan-20	-2,4	-10,3	-0,9	-20,9	-3,8	3,4	-3	-9,6
23	Jan-21	-3,3	-12	2,4	-14,1	-1,6	2	-2,8	-6,8
24	Jan-22	-2,8	-13,9	3,2	-18,4	-2,2	2	-6,5	-4,6
25	Jan-23	-1,8	-8	0,8	-19,4	1	1,1	-3	-0,6

Figure 2-2: Historical Observed Climatic Data for Chisinau Station, offered by the State Hidrometeorological Service

Although it is not possible to predict the temperature or precipitation for a particular day, month, or even specific year because of fundamental uncertainties and natural variability in the changing climate system, GCMs are a valuable tool for projecting the likely range of changes over decadal to multidecadal time periods of GCMs. These projections, known as time slices, should be expressed relative to the baseline period (1961–1990). The time slices were centered around a given decade, for example, the 2020s time slice refers to the period from 2010–2039. Thirty-year time slices were used to provide an indication of the climate "normals" for those decades; by averaging over this period, much of the random year-to-year variability, or "noise," is cancelled out, while the long-term influence of increasing greenhouse gases, or "signal," remains. Thirty-year averaging is a standard used by meteorological and climate scientists (WMO, 1989).

The projections of future climate were obtained conform methodology described by (Wilby et al., 2004; and Carter, 2007). Firstly, the baseline climatology was established for the site or region of interest. Secondly, changes in mean temperature for the GCM grid–boxes closest to the target site were calculated as the difference between each model's future simulation and the same model's baseline simulation, whereas mean precipitation were based on the ratio of a given model's future precipitation to the same model's baseline precipitation (expressed as a percentage change). For example, a difference of 2.5˚C might occur by subtracting the mean GCM temperatures for 1961-1990 from the mean of the 2050s. Thirdly, the temperature change suggested by the GCM (in this case, +2.5˚ C) is then simply added to each day in the baseline climatology.

For a given time slice and a given emissions scenario, projections from 10 different GCMs (in case of SRES A1B and B1) and seven GCMs (in case of SRES A2) are considered in the analysis as equally likely representations of future climate. One ensemble member of each model of the temperature and precipitation field from the simulation of the 20th century and the SRES A2, A1B and B1 scenarios was used, and they are equally weighted for the multi-model (ensemble) average. Consequently, ensemble monthly, seasons and annual statistics (average, max, min and standard deviation) were computed directly from 7 x 30 (SRES A2) or 10 x 30 (SRES A1B and B1) time series. In terms of temporal aggregation, the following seasons have been considered: December–February (DJF), March–May (MAM), June–August (JJA) and September–November (SON). The next sections highlight the results obtained.

2.2.2. Validation

A more persuasive criterion for model selection is to adopt the GCMs that simulate the present-day climate most faithfully, on the premise that these GCMs would also yield the most reliable representation of future climate.

The approach involves comparing GCM simulations that represent present-day conditions with the observed climate. The GCM run is typically the control simulation of an equilibrium GCM experiment, but for transient experiments, the modeled period corresponding to the observed data (e.g., 1961-1990) is adopted. The modeled and observed data are projected to the same grid, and statistical methods employed to compare, for example, mean values, variability and climatic patterns.

2.2.2.1. Mean Temperature

The impact of overall method on GCM control run outputs for the baseline period can be assessed by ploting Taylor diagrams (Taylor, 2001) with reference to the observed climatology. This type of diagram has been widely used for GCMs or RCMs evaluation and comparison (Covey et al., 2003; Hellström & Chen, 2003; Vidal & Wade, 2008) and here are applied in an innovative way to assess different stages of refinement of GCM outputs.

In a Taylor diagram, the radial coordinate gives the magnitude of total standard deviation of the data considered, and the angular coordinate gives the correlation with the corresponding observed field. The reference point corresponding to the observed field thus has a radial coordinate equal to the standard deviation of this field and an angular coordinate equal to 1. From the relationship between the correlations of two fields, their standard deviations, and the centered pattern root mean square difference, it follows that the distance between the reference point and any model's point is proportional to the root mean square model error (Taylor, 2001).

Comparisons of annual mean temperature have been simulated by an ensemble and ten GCMs with observed values over **northern AEZ** are presented in **Figure 2-3**. For mean value comparisons, average observed and GCMs values are also provided. Although regional differences are apparent, the majority of models accurately simulate the mean value and spatial variability of observed annual temperatures over the different Republic of Moldova AEZs. For northern AEZ, the ensemble and five GCMs (ECHAM 5, BCCR_BCM2.0, NCAR_CCSM3.0, CCCma_CGCM3.1 (T63) and GFDL-CM2.1) models have simulated temperatures not significantly different from the observed 7.78°C. The MIROC3.2 medres and MIROC3.2 hires temperatures were significantly warmer than observed, and the CSIRO Mk3, HadCM3, and MRI_CGCM2.3 temperature, significantly colder. Annual variability is consistent among the GCMs as evidenced by the model cluster in the Taylor diagram. The CSIRO Mk3, ECHAM 5, NCAR_CCSM3.0, and GFDLCM2.1 models have standard deviations that are slightly lower than the observed, while the HadCM3, MRI_CGCM2.3, MIROC3.2 hires and CCCma_CGCM3.1 (T63) have standard deviations are slightly higher. Every model also has a very high correlation coefficient about 0.97-1.0 indicating that the models accurately represent the spatial pattern of variation over the region.

Temperature simulations over **central AEZ** display some differences from those over northern AEZ. The only two GCMs MIROC3.2 medres and NCAR_CCSM3.0 were not significantly different, while the ensemble and majority of GCMs (CSIRO Mk3, ECHAM 5, HadCM3, MRI_CGCM2.3, BCCR_BCM2.0, CCCma_CGCM3.1 (T63), and GFDLCM2.1) have given colder temperatures and MIROC3.2 hires temperatures are significantly warmer than the observed annual temperatures of 9.6°C. Here, in contrast to other areas, the ECHAM 5 model has given an annual temperature that is significantly colder than observed. Annual variability is consistent among the GCMs, as evidenced by the model cluster in the Taylor diagram. CSIRO Mk3, ECHAM 5, HadCM3, MIROC3.2 medres, NCAR_CCSM3.0, and GFDLCM2.1 models have standard deviations that are slightly lower than the observed, while the BCCR_BCM2.0, and MIROC3.2 hires have standard deviations are slightly higher and the ensemble, MRI_CGCM2.3, CCCma_CGCM3.1 (T63) have the same standard deviations as the observed data. Correlation coefficients were also very high about 0.98-1.0 indicating that the models accurately represent the annual pattern of variation over the region.

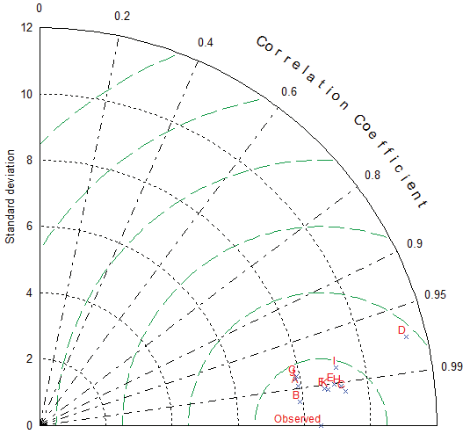
For **southern AEZ**, ensemble and three GCMs (CSIRO Mk3, ECHAM 5, and HadCM3) have simulated annual temperatures not significantly different from the observed 9.8°C. As is the case with other models, the BCCR_BCM2.0, MRI_CGCM2.3, CCCma_CGCM3.1 (T63), GFDLCM2.1, models have given colder temperatures, and the MIROC3.2 medres, NCAR_CCSM3.0, and MIROC3.2 hires warmer temperatures, than observed. Annual variability is consistent among the GCMs as evidenced by the model cluster in the Taylor diagram. The CSIRO Mk3, ECHAM 5, HadCM3, MIROC3.2 medres, NCAR_CCSM3.0, and GFDLCM2.1 models have standard deviations that are slightly lower than the observed, while the BCCR_BCM2.0, MIROC3.2 hires and CCCma_CGCM3.1 (T63) have standard deviations are slightly higher and the ensemble, and MRI_CGCM2.3 have the same standard deviations as the observed data.

Bar graphs showing the models' ability to simulate mean values of seasonal temperature over the Republic of Moldova's AEZs are provided in **Figure 2-4.** The GCMs display a great range in simulations, with no clear evidence of superiority for any region. Overall, the CSIRO Mk3, ECHAM 5, GFDLCM2.1, and NCAR_CCSM3.0 models tend to be better, in that the majority of their seasonal temperatures are not significantly different from those observed. The ensemble MRI_CGCM2.3, CCCma_CGCM3.1 (T63), MIROC3.2 medres were of intermediate ability, while the MIROC3.2 hires, HadCM3, and BCCR_BCM2.0 were least representative over all AEZs.

Figure 2-3: Taylor diagrams showing comparisons of GCMs and observed mean annual temperature value over (A) northern, (B) central, (C) southern AEZs

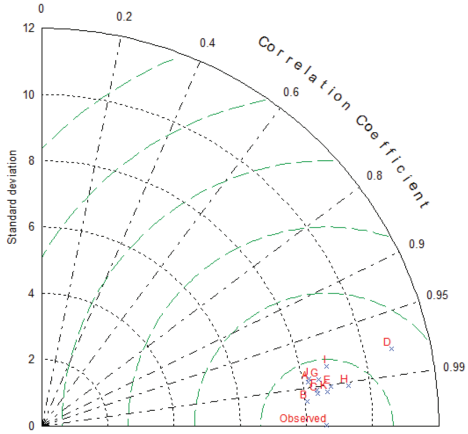
Note: Standard deviation and PRMSEs are in °C, with a contour interval of 1°C. The corresponding tables show mean temperatures (in °C) for the observed data and values for the ensemble and each of the ten models. A model point is close to the observed value if it has a similar standard deviation, a low PRMSE, and a high correlation, indicating that the two spatial patterns are similar.

A) Northern AEZ



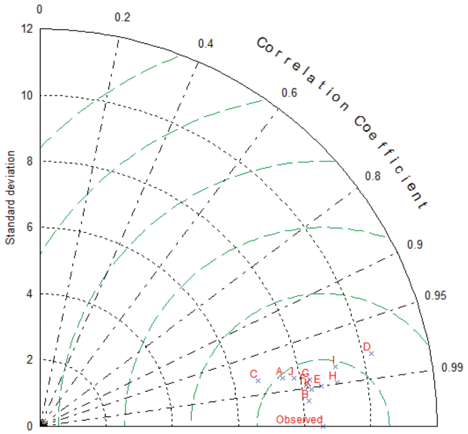
Data	Symbol	Temp (℃)
CSIRO MK3	A	6.8
ECHAM 5	B	7.5
Had CM3	C	5.3
BCCR_BCM2.0	D	5.8
MRI_CGCM2	E	5.6
MIROC3.2 medres	F	9.2
NCAR_CCSM3.0	G	8.8
MIROC3.2 hires	H	9.8
CCCma_CGCM3.1 (T63)	I	6.6
GFDLCM2.1	J	6.9
Ensemble	K	7.2
Observed		7.8

B) Central AEZ



Data	Symbol	Temp (℃)
CSIRO MK3	A	8.6
ECHAM 5	B	8.7
Had CM3	C	7.4
BCCR_BCM2.0	D	6.9
MRI_CGCM2	E	7.0
MIROC3.2 medres	F	10.3
NCAR_CCSM3.0	G	10.5
MIROC3.2 hires	H	11.4
CCCma_CGCM3.1 (T63)	I	8.3
GFDLCM2.1	J	8.0
Ensemble	K	8.7
Observed		9.6

C) Southern AEZ



Data	Symbol	Temp (℃)
CSIRO MK3	A	9.6
ECHAM 5	B	9.8
Had CM3	C	8.8
BCCR_BCM2.0	D	7.9
MRI_CGCM2	E	8.4
MIROC3.2 medres	F	11.5
NCAR_CCSM3.0	G	11.3
MIROC3.2 hires	H	12.1
CCCma_CGCM3.1 (T63)	I	8.6
GFDLCM2.1	J	8.6
Ensemble	K	9.7
Observed		9.8

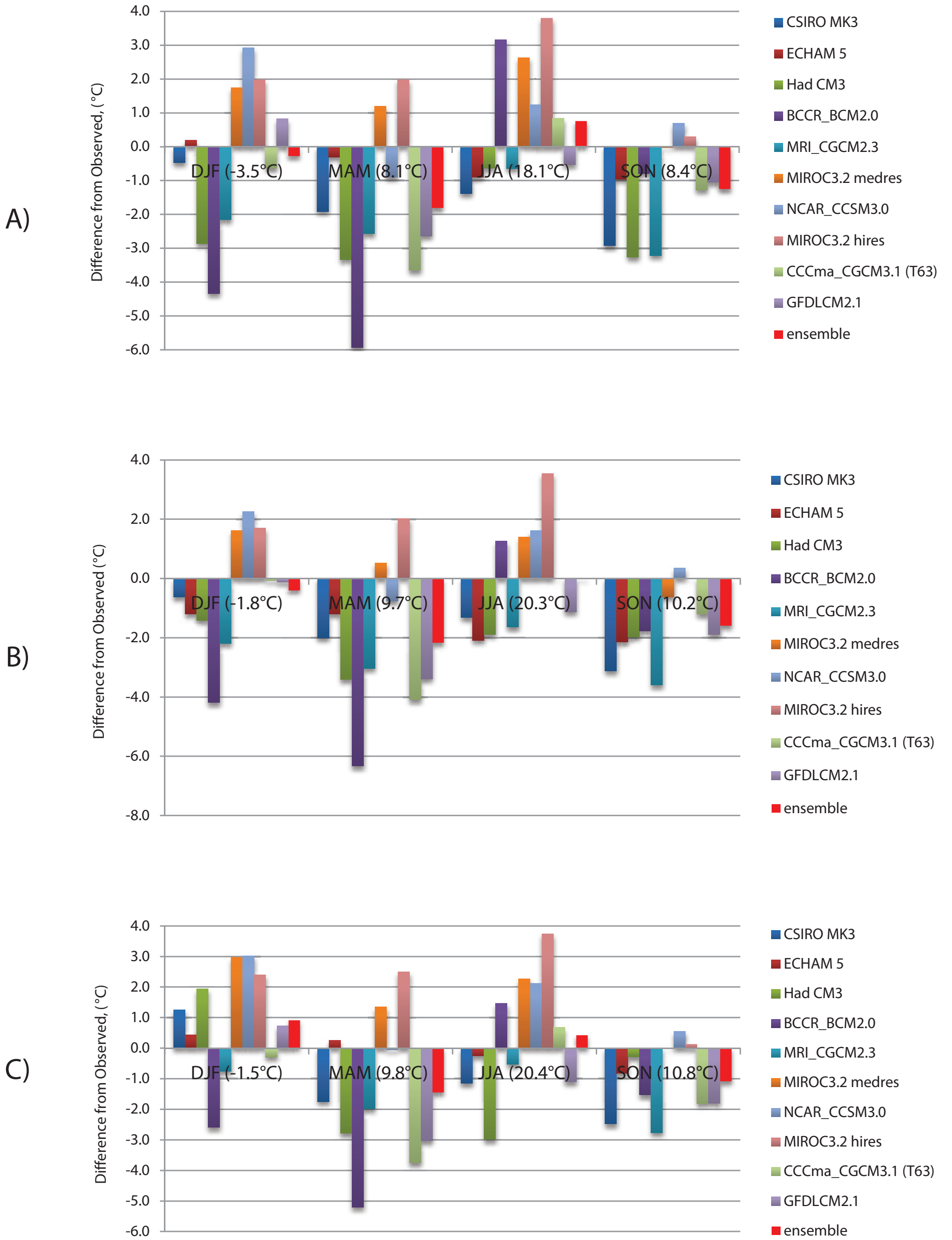


Figure 2-4: Seasonal comparisons of GCMs and observed mean temperature value (°C) over (A) northern, (B) central and (C) southern AEZs

Note: Units are given as differences (GCMs minus observed) from the observed values provided in parentheses.

On a seasonal basis, transition season's autumn and spring tends to be associated with the largest differences, likely attributable to greater temperature variability at those times of year. Summer and winter is best characterized by the models, particularly over northern and central AEZs, while autumn and spring temperatures are best simulated by most models over southern AEZ. Reasons for these seasonal preferences are unclear and warrant further investigation.

In summary, the models vary in their ability to replicate the mean temperature values, in all AEZs the ensemble and ECHAM5 model represent the best annual variability since they are associated with standard deviations near the observed value and have low PRMSEs and higher correlation coefficients. The ensemble mean of ten members over northern and southern AEZs shows a high agreement with observed annual mean temperature in terms of mean (not significantly different from the observed) and annual distributions (correlation of 0.99), while over central AEZ was displayed some differences, the ensemble as well as majority of GCMs (CSIRO Mk3, ECHAM 5, HadCM3, MRI_CGCM2.3, BCCR_BCM2.0, CCCma_CGCM3.1 (T63), and GFDLCM2.1) have given colder temperatures.

The temperature simulations also have a similar degree of accuracy over all AEZs, with no clear evidence of superiority in any given area. Although substantial regional and seasonal variability exists among the models, **Figures 2-3** and **2-4** above suggest that the ensemble, ECHAM 5, GFDLCM2.1, CSIRO Mk3 and NCAR _CCSM3.0 best replicate annual and seasonal temperatures over the territory of the Republic of Moldova. The MIROC3.2 medres and MIROC3.2 hires were of intermediate accuracy, with the simulating temperatures that are generally warmer than observed, and the CCCma_CGCM3.1 (T63), MRI_CGCM2.3 with the simulating temperatures colder than observed. For the most part, the HadCM3 and BCCR_BCM2.0 were least representative of temperature in Republic of Moldova AEZs; both simulate temperatures that are significantly colder than those observed.

2.2.2.2. Total Precipitation

Annual precipitation comparisons (**Figure 2-5**) show substantially higher variations than the temperature comparisons.

The most prominent feature is that BCCR_BCM2.0 and GFDLCM2.1 considerably over-predict annual precipitation, while the CCCma_CGCM3.1 (T63) model significantly underestimates annual precipitation in all AEZs. For example in central AEZ, the BCCR_BCM2.0 and GFDLCM2.1 values are respectively more on 190.9 and 113 mm, and the CCCma_CGCM3.1 (T63) value is less on 109.6 mm than the observed value of 544.2 mm. The MRI_CGCM2.3 simulates precipitations better, but also over-estimates it by 103.6 and 116.2 mm over central and northern AEZs. Correlation coefficients were high for the ensemble and five models CSIRO Mk3, MRI_CGCM2.3, MIROC3.2 medres, CCCma_CGCM3.1 (T63) and GFDLCM2.1, from 0.83 to 0.96 indicating that the models accurately represent the annual pattern of variation, but not amount of precipitation over northern AEZ.

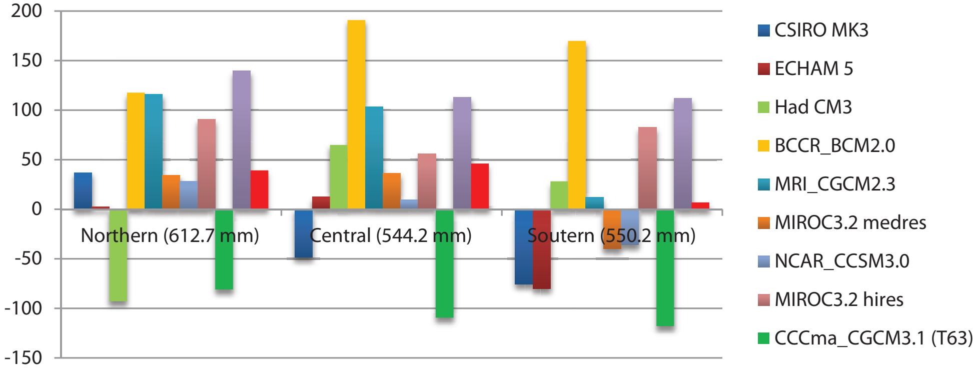


Figure 2-5: Annual comparisons of GCMs and observed precipitation value (mm) over northern, central and southern AEZs

Note: Units are given as differences (GCMs minus observed) from the observed values provided in parentheses.

In central AEZ only three models MRI_CGCM2.3, MIROC3.2 medres, CCCma_CGCM3.1 (T63) and ensemble were associated with statistically significant correlation coefficients from 0.58 to 0.82, while low correlation coefficients (statistically not significant) and standard deviation smaller than observed were received for the ensemble and all models over southern AEZ (**Table 2-1**).

The seasonal precipitation regimes are illustrated in **Figure 2-6**. The red line shows the observed monthly climatology for each AEZ. In all AEZs, the seasonal cycles present their maximum values during summer in June and two low precipitation periods, the main one during autumn in October and a secondary one during spring in March.

Table 2-1: The Pearson correlations between observed mean annual precipitation and different GCMs

AEZ	GCM										
	CSIRO MK3	ECHAM 5	Had CM3	BCCR_BCM2_0	MRI_CGCM2_3	MIROC3_2 medres	NCAR_ CCSM3_0	MIROC3_2 hires	CCCma_ CGCM3_1 _T63_	GFDLCM2_1	Ensemble
Northern	0.88***	0.57	0.11	0.07	0.96***	0.93***	0.05	-0.40	0.83***	0.74**	0.88***
Central	0.12	0.26	-0.21	0.20	0.82***	0.72**	0.25	-0.43	0.71**	0.56	0.58*
Southern	-0.28	-0.37	-0.30	-0.45	-0.04	0.31	0.10	-0.34	0.39	0.43	0.02

Note: Asterisk is used to mark statistically significant values: p-value ≤ 0.001*** indicate statistically significant non-zero correlations at the 99.9% confidence level, p-value ≤0.01** indicate statistically significant non-zero correlations at the 99.0%, and p-value ≤0.05* indicate statistically significant non-zero correlations at the 95.0% confidence level.

The Figure 2-7 and Table 2-2 provides model comparisons of seasonal precipitation over the over the three Republic of Moldova's AEZs. Seasonal values are best simulated by the majority of models over northern and southern AEZs. In these regions, the CSIRO Mk3, ECHAM 5, HadCM3, MIROC3.2 medres, CCCma_CGCM3.1 (T63), MRI_CGCM2.3, NCAR_CCSM3.0, MIROC3.2 hires, and an ensemble displays no significant differences in spring and autumn. The BCCR_BCM2.0, NCAR_CCSM3.0, and MIROC3.2 hires significantly overestimate precipitation in winter while the NCAR_CCSM3.0 and CCCma_CGCM3.1 (T63) significantly underestimate the summer precipitation over all the Republic of Moldova AEZs. The best models most accurately have represented the Republic of Moldova AEZs season precipitations were MIROC3.2 medres which significantly overestimate DJF precipitation only in northern and significantly underestimate JJA precipitation in southern AEZs and CSIRO Mk3 which significantly overestimate MAM precipitation only in central and significantly underestimate JJA precipitation in central and southern AEZs.

A)

B)

C)

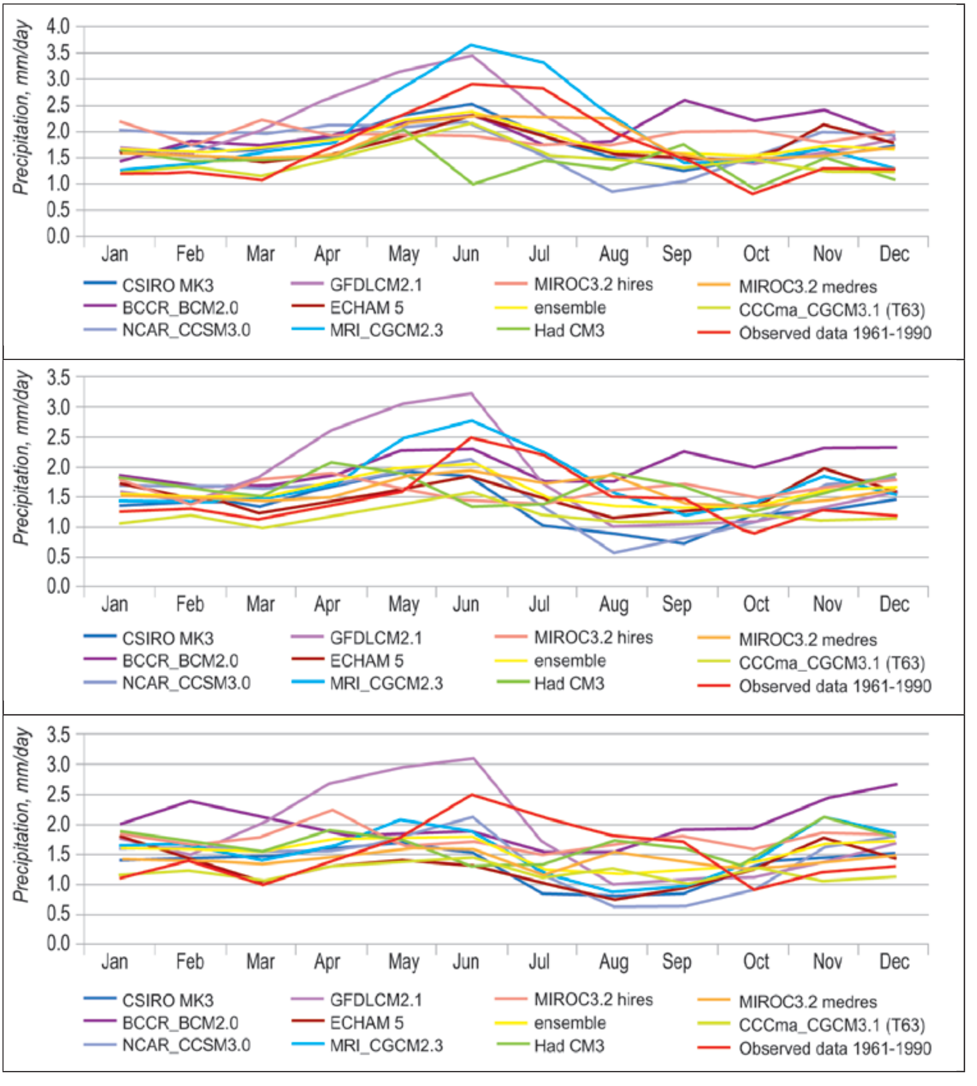


Figure 2-6: Long-term mean monthly precipitation pattern over (A) northern, (B) central and (C) southern AEZs. Comparison of observed and GCMs data (nearest grid points).

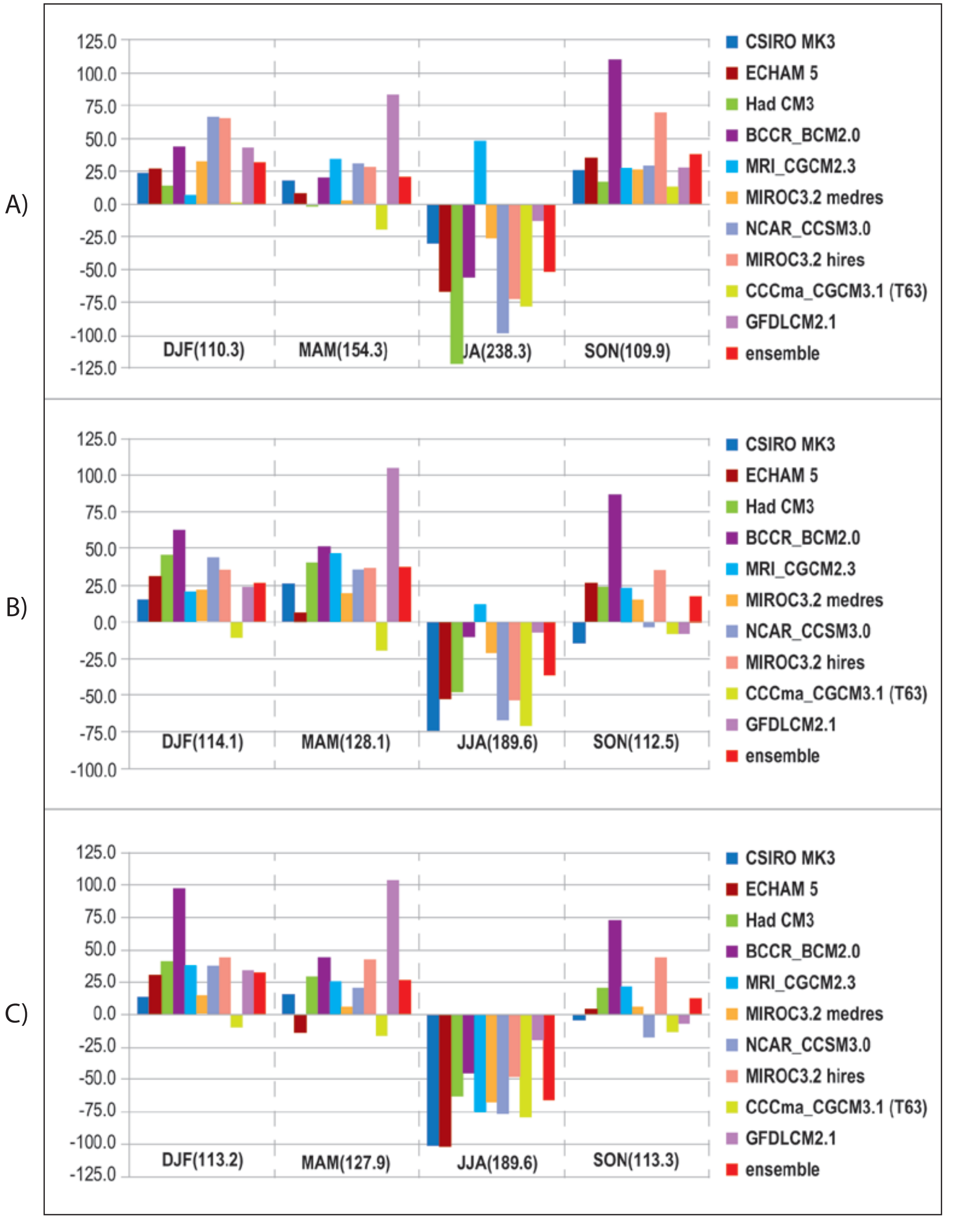


Figure 2-7: Seasonal comparisons of GCMs and observed mean precipitation value (mm) over (A) northern, (B) central and (C) southern AEZs

Note: Units are given as differences (GCMs minus observed) from the observed values provided in parentheses.

Table 2-2: Seasonal GCMs-simulated mean precipitation value (%) over northern, central, and southern AEZs. Units are given as differences (GCMs minus observed) from the observed values (1961-1990).

Seasons	AEZs	GCMs											Observed data, (mm) 1961 -1990
		CSIRO MK3	ECHAM 5	Had CM3	BCCR_BCM2.0	MRI_CGCM2.3	MIROC3.2 medres	NCAR_CCSM3.0	MIROC3.2 hires	CCCma_CGCM3.1 (T63)	GFDLCM2.1	Ensemble	
DJF	Northern	21	24	12	40	6	29	60	59	1	39	29	110.3
	Central	13	28	41	55	19	20	38	32	-9	21	24	114.1
	Southern	13	27	37	86	34	14	34	39	-8	30	29	113.2
MAM	Northern	12	6	-1	13	22	2	20	18	-12	54	13	154.3
	Central	26	7	32	40	36	16	28	29	-15	82	29	128.1
	Southern	12	-11	23	34	21	5	16	33	-13	81	21	128.1
JJA	Northern	-13	-28	-51	-24	20	-11	-41	-30	-32	-6	-22	238.3
	Central	-59	-41	-37	-8	10	-16	-52	-41	-56	-6	-28	189.6
	Southern	-52	-52	-32	-23	-38	-35	-39	-25	-40	-10	-34	195.8
SON	Northern	24	31	16	100	25	24	26	63	12	25	35	109.9
	Central	-13	24	19	68	18	12	-3	28	-6	-6	14	112.5
	Southern	-4	4	18	66	20	5	-15	39	-12	-6	11	113.3

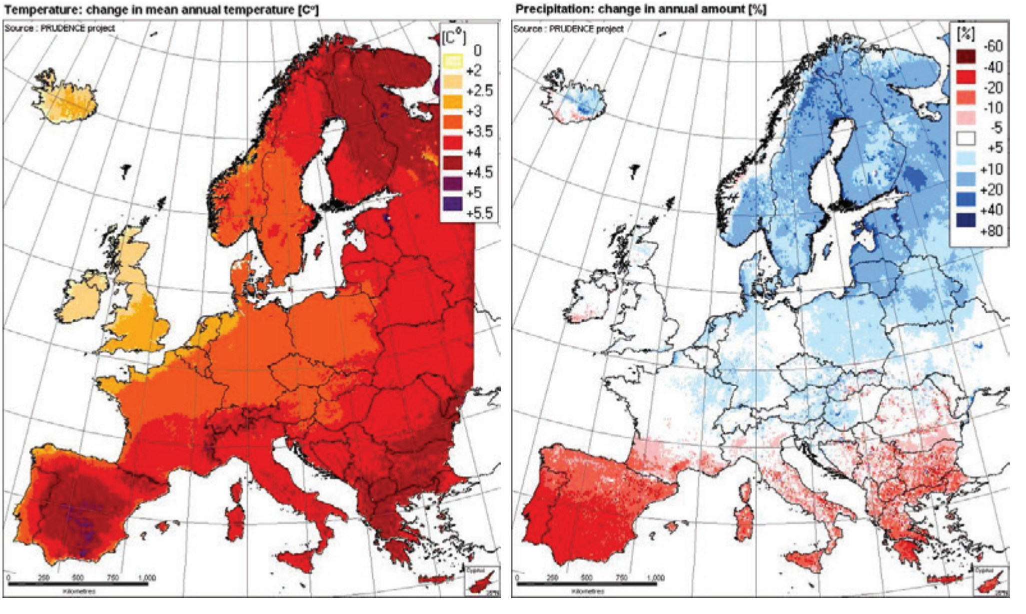
Note: Red color is used to mark statistically significant values.

This investigation was not designed to provide answers as to which GCMs should be used for future impact studies over the three AEZs, but rather to assess the relative ability of current generation of climate models to replicate the regional particularities of observed temperature and precipitation on annual and seasonal scales. It is possible that certain GCMs could realistically simulate future temperature and precipitation changes even if they not accurately replicate current climate over AEZ. However, it is suggested that more confidence can be placed in those models that give better simulations of observed climate.

2.2.3. Climate Changes Projections for the Republic of Moldova's AEZs

2.2.3.1. Temperature

In this century, the warming in Europe is projected to continue at a rate somewhat greater than its global mean, with the increase in 20-year mean temperatures (from its values in 1980 to 1999) becoming clearly discernible within a few decades. Under the SRES A1B scenario, the simulated area and annual mean warming from 1980-1999 to 2080-2099 varies from 2.3^{0}C to 5.3^{0}C in Northern Europe (NEU) and from 2.2^{0}C to 5.1^{0}C in Southern Europe and Mediterranean (SEM). The warming in northern Europe is likely to be largest in winter and that in the Mediterranean area largest in summer (IPCC, 2007a). For spatial distribution of EU absolute change in mean annual temperature between control period (1961-1990) and 2071-2100, under IPCC SRES A2 scenario (see **Figure 2-8**), based on data from EC-funded project PRUDENCE (http://prudence.dmi.dk/).



Figures 2-8 and 2-9: Absolute change in mean annual temperature and precipitation between control period 1961-1990 and 2071-2100, under IPCC SRES A2 scenario

Source: Data from EC-funded project PRUDENCE (HadCM3 global circulation model, and HIRHAM regional climate model in 12km resolution) (http://peseta.jrc.ec.europa.eu/docs/ClimateModel.html), maps elaborated by EC JRC/IES.

The AEZs are defined as geographic regions having similar climate and soils for agriculture (FAO, 1978). Such zonation schemes have been used to identify yield variability and limiting factors for crop growth (Caldiz et al., 2002; Williams et al., 2008), to regionalize optimal crop management recommendations (Seppelt, 2000), compare yield trends (Gallup and Sachs, 2000), to determine suitable locations for new crop production technologies (Geerts et al., 2006; Araya et al., 2010) and to analyze impacts of climate change on agriculture (Fischer et al., 2005).

The three SRES emissions scenarios project similar temperature in the near-term decades +1.2-1.4^{0}C over the Republic of Moldova. Only beginning around the 2050s the three emissions scenarios produce temperature patterns that are distinguishable from each other. This is due to both the large inertia of the climate system it takes centuries for the full climate effects of greenhouse gas emissions to be felt and, the fact that it takes time for the different emissions scenarios to produce large differences in greenhouse gas concentrations.

Annual changes for temperatures are very homogeneous over the Republic of Moldova's AEZs. Accordingly, the rate of warming is higher under SRES A2 ensembles average reach +4.3^{0}C; the medium under SRES A1B +3.8^{0}C, and smaller under the SRES B1 scenario ensembles average would be +2.7^{0}C by the 2080s (**Table 2-3** and **Figure 2-10**). But individual GCMs show an increase of up to 5.1-6.2°C (see **Figures 2-11, 2-12** and **2-13**).

All the GCM models used agree that for the three future periods (2020s, 2050s and 2080s) there will be an increase of the winter temperature, with respect to the control period (1961-1990). As it was expected, the magnitude of the positive found differences is increasing with increasing greenhouse gas forcing. It can be seen that the temperature rise will be larger over the northern and central parts of the country (**Figure 2-14**).

More specifically, the ensembles, driven by the A2 emission scenario, estimate that the North AEZ will experience the most significant warming during winter, with average temperatures rising up to 4.9^{0}C by the 2080s. For the rest of the study area the winter temperature increase will be 0.5 to 1.0 degrees lower. The pattern of change derived from the ensembles B1 models is quite similar, but the magnitude of change is lower (increase about 2.6 to 3.0^{0}C over the Republic of Moldova) with the maximum warming seen again in Northern and Central AEZs (**Tables 2-3**; **Figure 2-15; 2-16; 2-17**).

Table 2-3: Projected Ensemble Annual and Seasons Mean Air Temperature (ΔT, °C) Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s for SRES A2, A1B and B1 GCMs Experiments, Relative to the Climatological Baseline Period (1961-1990)

Season	*Average 1961-1990*	SRES	*Projected changes by the 2020s*			*Projected changes by the 2050s*			*Projected changes by the 2080s*		
			Min	*Average*	*Max*	*Min*	*Average*	*Max*	*Min*	*Average*	*Max*
						Northern AEZ					
Annual	**7.8**	**A2**	0.4	1.3	2.6	1.8	**2.7**	4.5	2.9	**4.3**	6.2
		A1B	0.5	1.3	2.0	1.2	**2.7**	3.7	2.3	**3.7**	5.0
		B1	0.7	1.3	1.9	1.5	**2.1**	3.3	1.7	**2.7**	3.6
DJF	**-3.5**	**A2**	0.5	1.4	3.4	2.0	**3.4**	6.4	3.3	**4.9**	8.0
		A1B	0.0	1.2	2.2	0.9	**2.8**	4.3	2.2	**4.0**	5.7
		B1	0.8	1.4	2.6	1.5	**2.3**	4.3	1.4	**3.0**	4.5
MAM	**8.1**	**A2**	0.3	1.2	3.1	1.3	**2.2**	4.7	2.5	**3.6**	5.9
		A1B	0.4	1.3	2.2	1.1	**2.5**	3.9	1.9	**3.4**	5.4
		B1	0.5	1.3	2.0	1.1	**2.0**	3.1	1.2	**2.4**	3.6
JJA	**18.1**	**A2**	0.5	1.2	2.4	1.4	**2.5**	3.5	2.2	**4.5**	6.1
		A1B	0.7	1.6	2.4	1.4	**3.0**	4.7	1.9	**4.1**	6.7
		B1	0.7	1.5	2.3	1.2	**2.3**	3.6	1.5	**2.9**	4.5
SON	**8.4**	**A2**	0.7	1.5	2.8	1.8	**2.6**	4.6	3.2	**4.6**	6.5
		A1B	0.7	1.3	2.0	1.1	**2.7**	3.8	1.9	**3.6**	5.3
		B1	0.6	1.2	1.9	0.9	**2.0**	3.4	1.3	**2.6**	3.8
						Central AEZ					
Annual	**9.6**	**A2**	0.4	1.2	1.9	1.8	**2.5**	3.4	3.0	**4.3**	5.2
		A1B	0.5	1.4	2.0	1.2	**2.8**	3.7	2.4	**3.8**	5.1
		B1	0.8	1.4	2.0	1.5	**2.2**	3.5	1.7	**2.7**	3.9
DJF	**-1.8**	**A2**	0.2	1.0	2.4	1.9	**2.8**	4.2	3.3	**4.3**	5.4
		A1B	-0.2	1.2	2.2	0.8	**2.7**	4.1	2.1	**4.2**	6.8
		B1	0.9	1.4	2.6	1.5	**2.3**	3.7	1.5	**2.9**	4.3
MAM	**9.7**	**A2**	0.0	0.9	1.3	1.4	**1.9**	2.7	2.7	**3.4**	4.2
		A1B	0.4	1.2	2.1	1.0	**2.5**	3.7	2.0	**3.6**	6.7
		B1	0.5	1.3	2.1	1.2	**2.0**	3.2	1.2	**2.4**	3.7
JJA	**20.3**	**A2**	0.5	1.4	2.4	1.4	**2.9**	4.5	2.3	**5.1**	7.0
		A1B	0.6	1.7	2.6	1.4	**3.1**	5.0	1.8	**4.1**	6.9
		B1	0.7	1.6	2.5	1.2	**2.4**	3.8	1.5	**3.0**	4.8
SON	**10.2**	**A2**	0.8	1.3	2.0	1.8	**2.5**	3.1	3.3	**4.4**	5.0
		A1B	0.7	1.4	2.2	1.2	**2.7**	3.9	1.1	**3.5**	5.3
		B1	0.7	1.3	2.2	1.0	**2.1**	3.7	1.4	**2.7**	3.9

Season	Average 1961-1990	SRES	Projected changes by the 2020s			Projected changes by the 2050s			Projected changes by the 2080s		
			Min	Average	Max	Min	Average	Max	Min	Average	Max
Southern AEZ											
Annual	**9.8**	**A2**	0.4	1.2	1.9	1.9	**2.5**	3.4	3.0	**4.2**	5.1
		A1B	0.4	1.4	2.0	1.2	**2.8**	3.8	2.3	**3.8**	5.1
		B1	0.8	1.4	2.0	1.5	**2.2**	3.4	1.7	**2.7**	3.9
DJF	**-1.5**	**A2**	0.1	0.9	2.3	1.4	**2.5**	3.9	3.2	**3.9**	5.0
		A1B	-0.3	1.1	2.1	0.4	**2.4**	3.8	1.7	**3.5**	5.0
		B1	0.8	1.2	2.4	1.2	**2.0**	3.4	1.4	**2.6**	4.0
MAM	**9.8**	**A2**	0.0	0.8	1.2	1.5	**2.8**	2.6	2.7	**3.3**	4.0
		A1B	0.2	1.2	2.0	0.8	**2.4**	3.5	1.9	**3.3**	4.7
		B1	0.4	1.2	2.0	1.1	**1.9**	3.0	1.2	**2.3**	3.6
JJA	**20.4**	**A2**	0.5	1.4	2.3	1.4	**3.0**	4.3	2.3	**5.2**	6.9
		A1B	0.6	1.7	2.6	1.4	**3.2**	4.8	2.0	**4.3**	6.9
		B1	0.7	1.5	2.4	1.2	**2.5**	4.0	1.5	**3.1**	4.8
SON	**10.8**	**A2**	0.7	1.3	2.0	1.6	**2.4**	3.0	3.2	**4.7**	4.9
		A1B	0.6	1.4	2.1	1.1	**2.7**	3.8	1.8	**3.6**	5.3
		B1	0.7	1.3	2.1	2.0	**2.1**	3.6	1.3	**2.6**	3.9

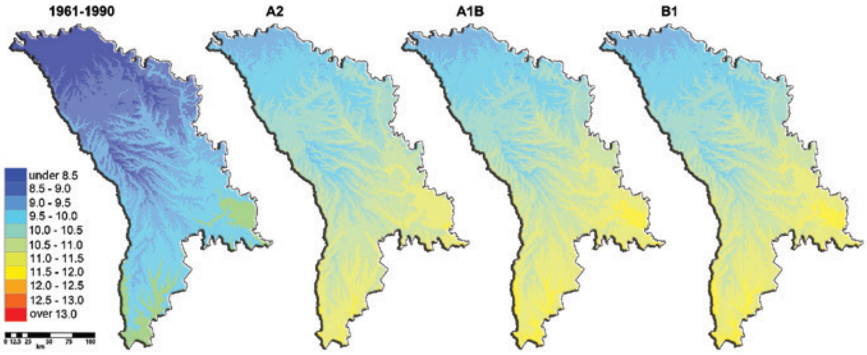
The summer warming is found to be even larger than winter, but the spatial distribution of the changes is quite different.

The strongest temperature rise occurs over the southern and central AEZs. The climate change experiments from the ensembles project an increase up to 5.1-5.2^{0}C over the central and southern AEZs, according to the SRES A2 scenario. The northern AEZ's summer temperature rise will be lower up to 4.5^{0}C.

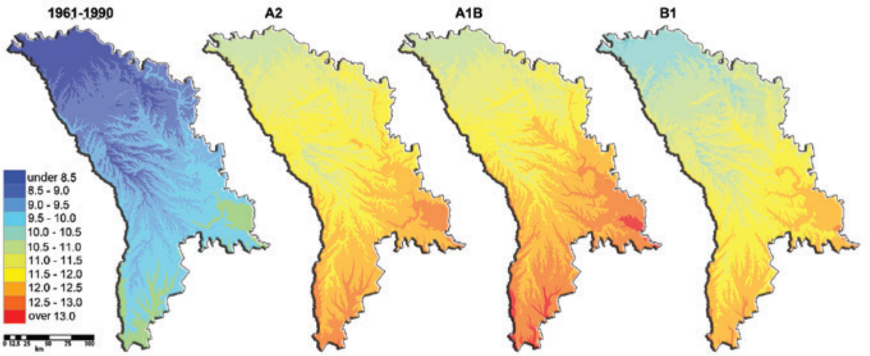
The corresponding results from the SRES B1 scenario show less intense differences in temperature increase. Estimations of simulations from the ensembles show that the warming will be quite uniform from 2.9^{0}C to 3.1^{0}C over whole Republic of Moldova's AEZs (**Figure 2-18**).

In comparison to the European SEM region (IPCC, 2007a) the Republic of Moldova is expected to have the same annual future temperature change as other parts of the region. Under the A1B scenario the simulated annual area and average warming from 1961-1990 to 2080s varies from 2.3^{0}C to 5.3^{0}C in northern and from 2.1^{0}C to 5.1^{0}C in southern AEZs.

2020s



2050s



2080s

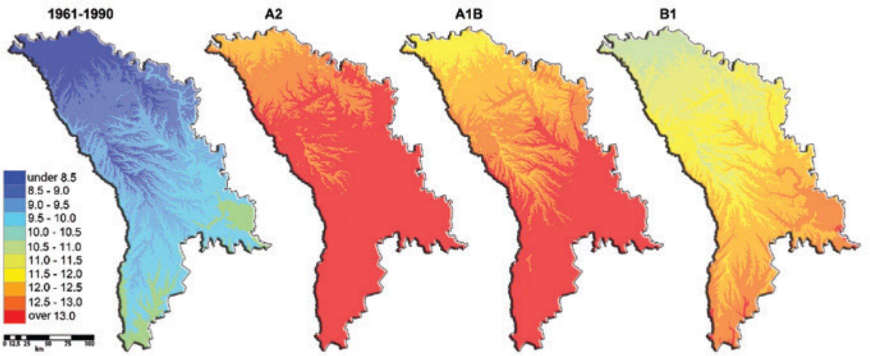


Figure 2-10: Projected Multi-Model Ensemble Annual Mean Air Temperature throughout the Republic of Moldova[1]

[1] Climate Change Office, 2012: http://www.clima.md/public/files/ProiectiiClima/en/ClimateMaps.html

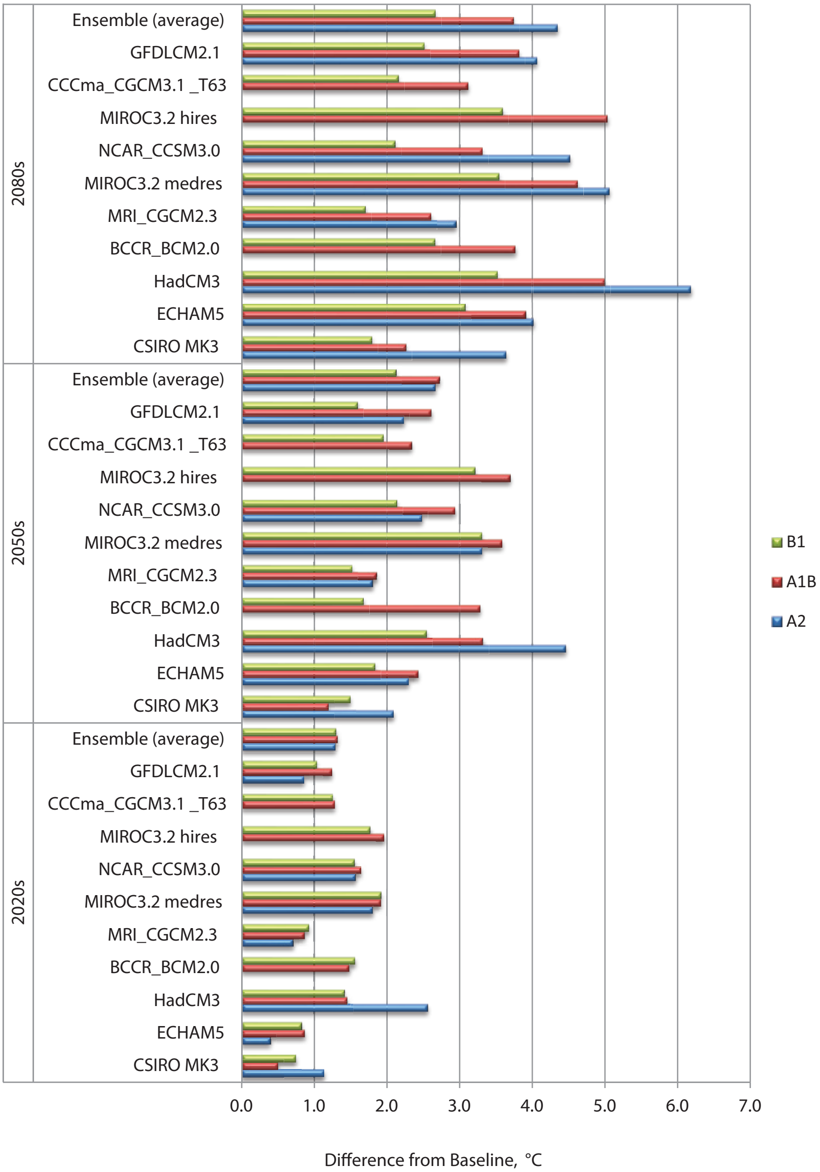


Figure 2-11: Projected Ensemble and Individual GCMs Annual Mean Air Temperature Changes (ΔT, °C) Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s for SRES A2, A1B and B1 Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990) in the Northern AEZ

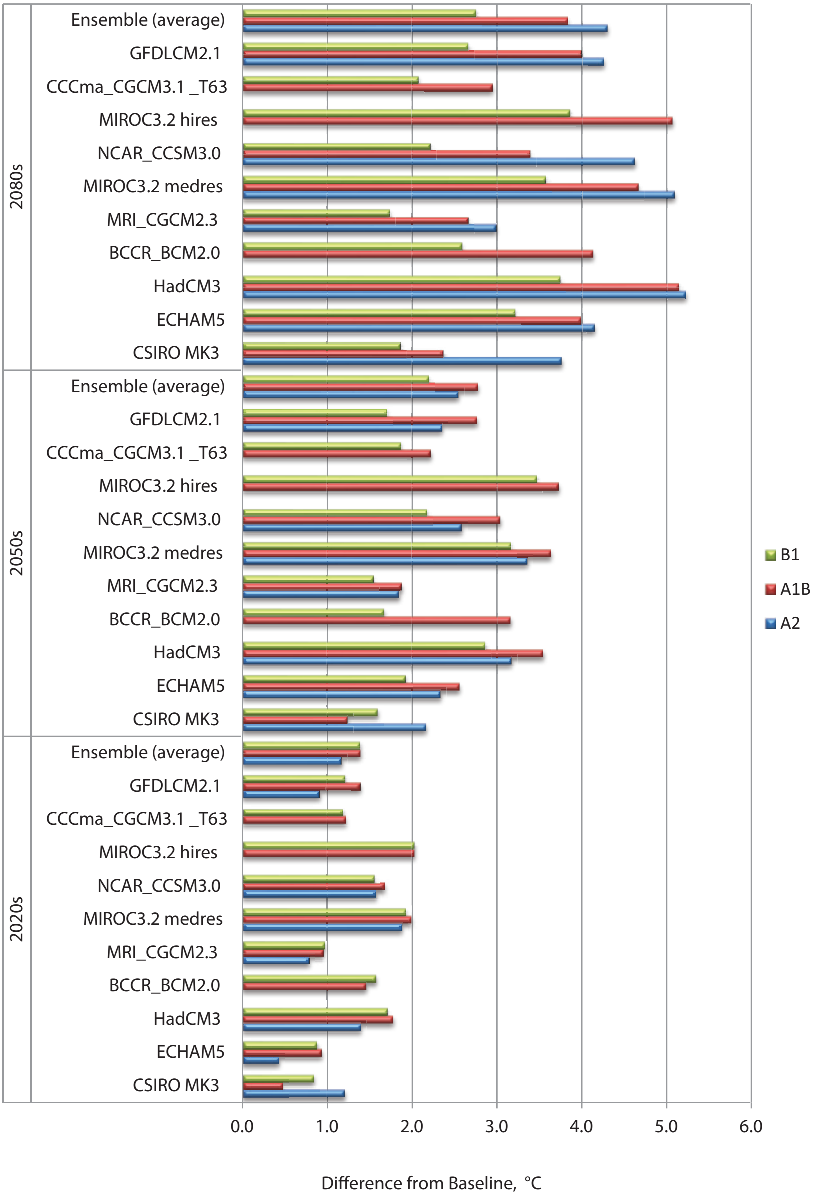


Figure 2-12: Projected Ensemble and Individual GCMs Annual Mean Air Temperature Changes (ΔT, °C) Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s for SRES A2, A1B and B1 Emission Scenarios Relative to the Climatological Baseline Period (1961-1990) in the Central AEZ

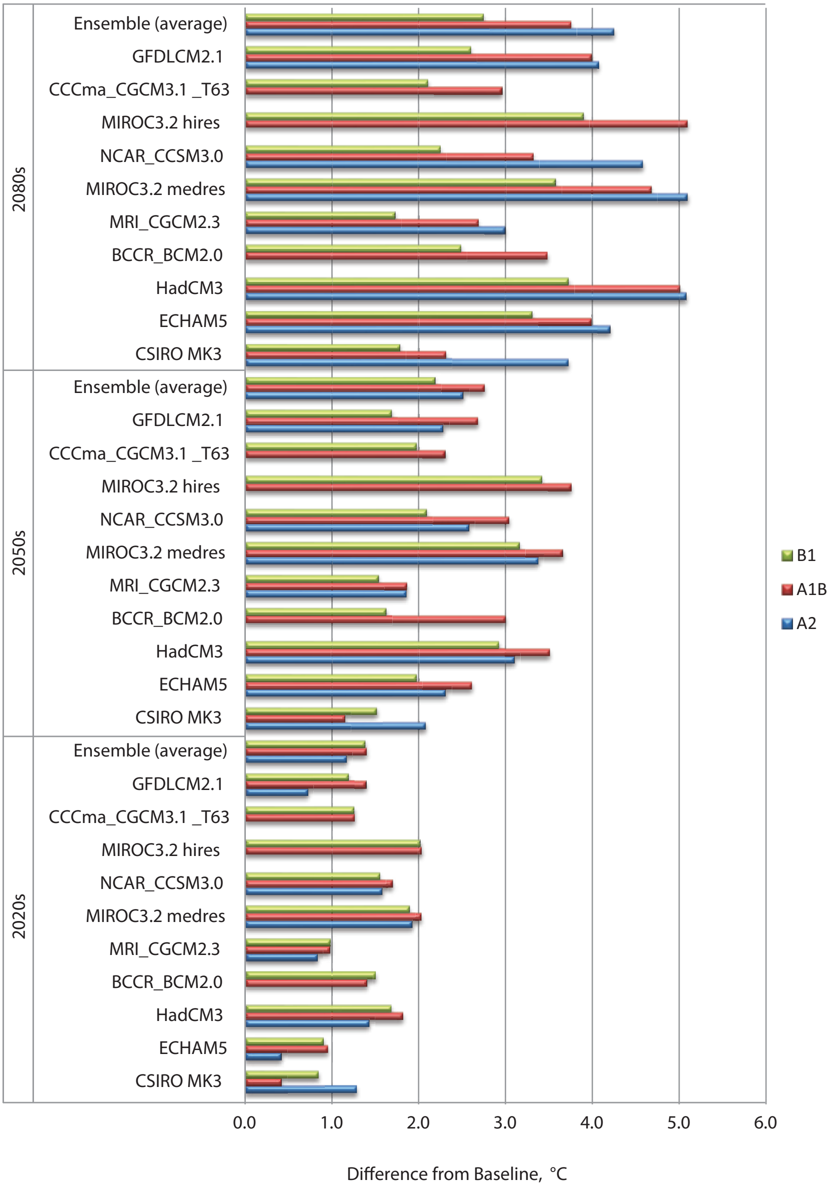


Figure 2-13: Projected Ensemble and Individual GCMs Annual Mean Air Temperature Changes (ΔT, °C) Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s for SRES A2, A1B and B1 Emission Scenarios Relative to the Climatological Baseline Period (1961-1990) in the Southern AEZ

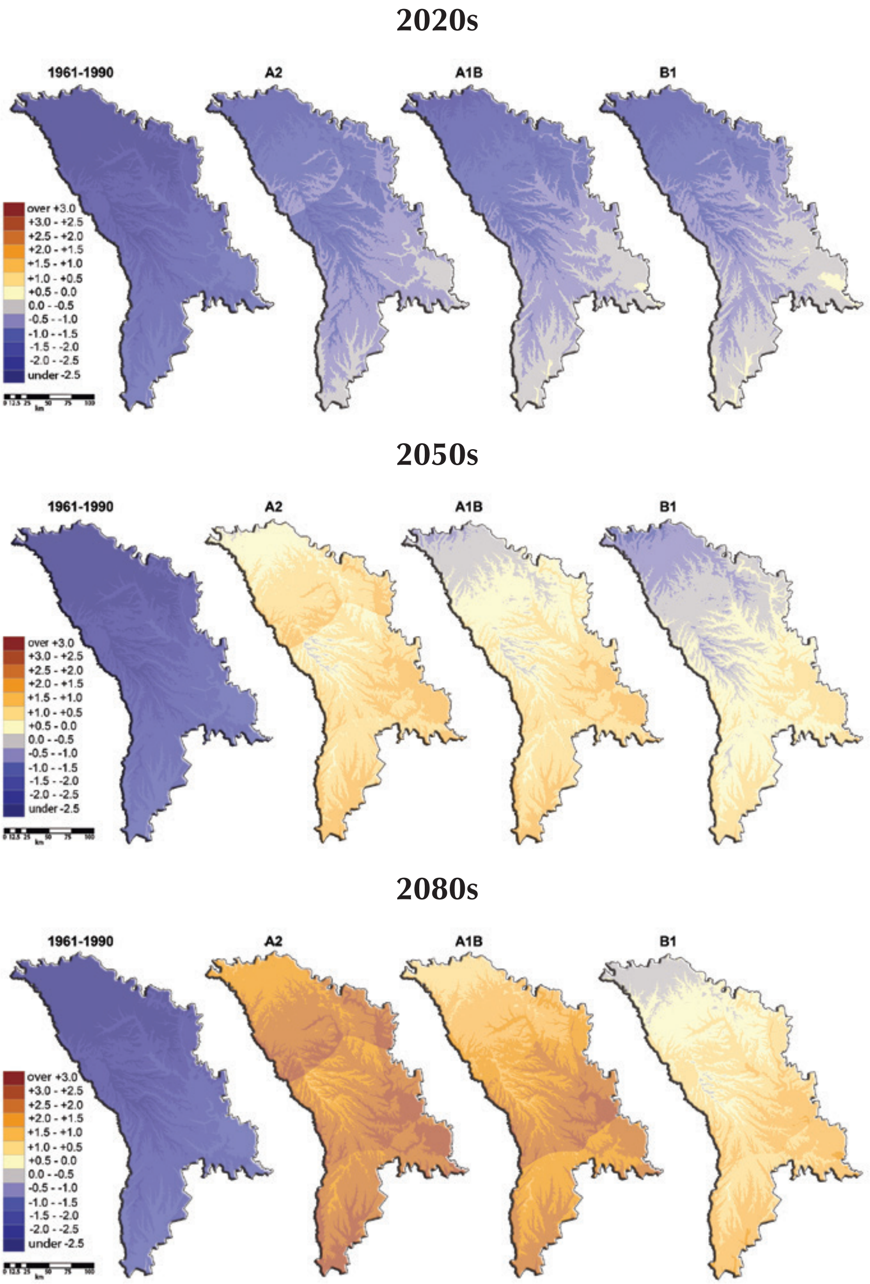


Figure 2-14: Projected Multi - Model Ensemble DJF Mean Air Temperature throughout the Republic of Moldova[2]

[2] Climate Change Office, 2012: http://www.clima.md/public/files/ProiectiiClima/en/ClimateMaps.html

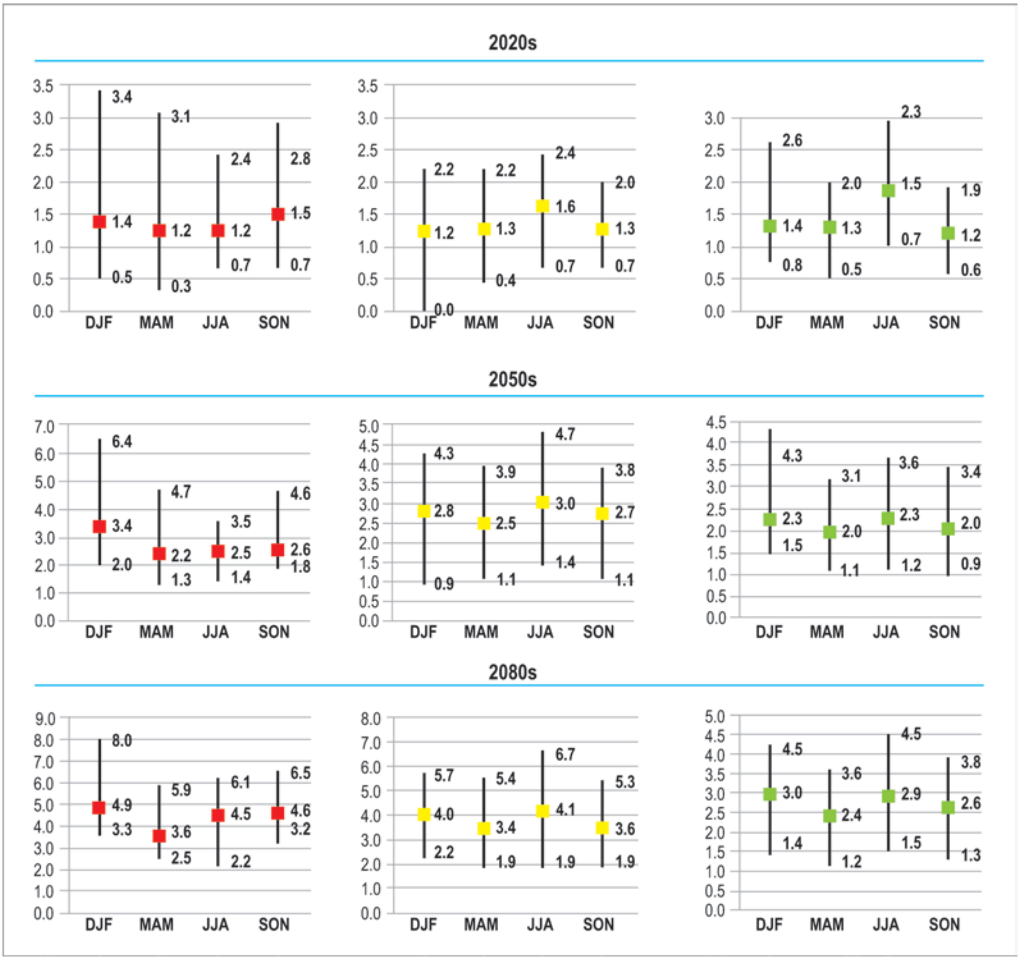


Figure 2-15: Projected Ensemble Seasonal Mean Air Temperature Changes (ΔT°C) Average, Maximum and Minimum Value Averaged over Four Seasons December-February (DJF), March-May (MAM), June-August (JJA) and September-November (SON) Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s for SRES A2 (Red), A1B (Orange) and B1 (Green) GCMs Experiments Relative to the Climatological Baseline Period (1961-1990) in the Northern AEZ

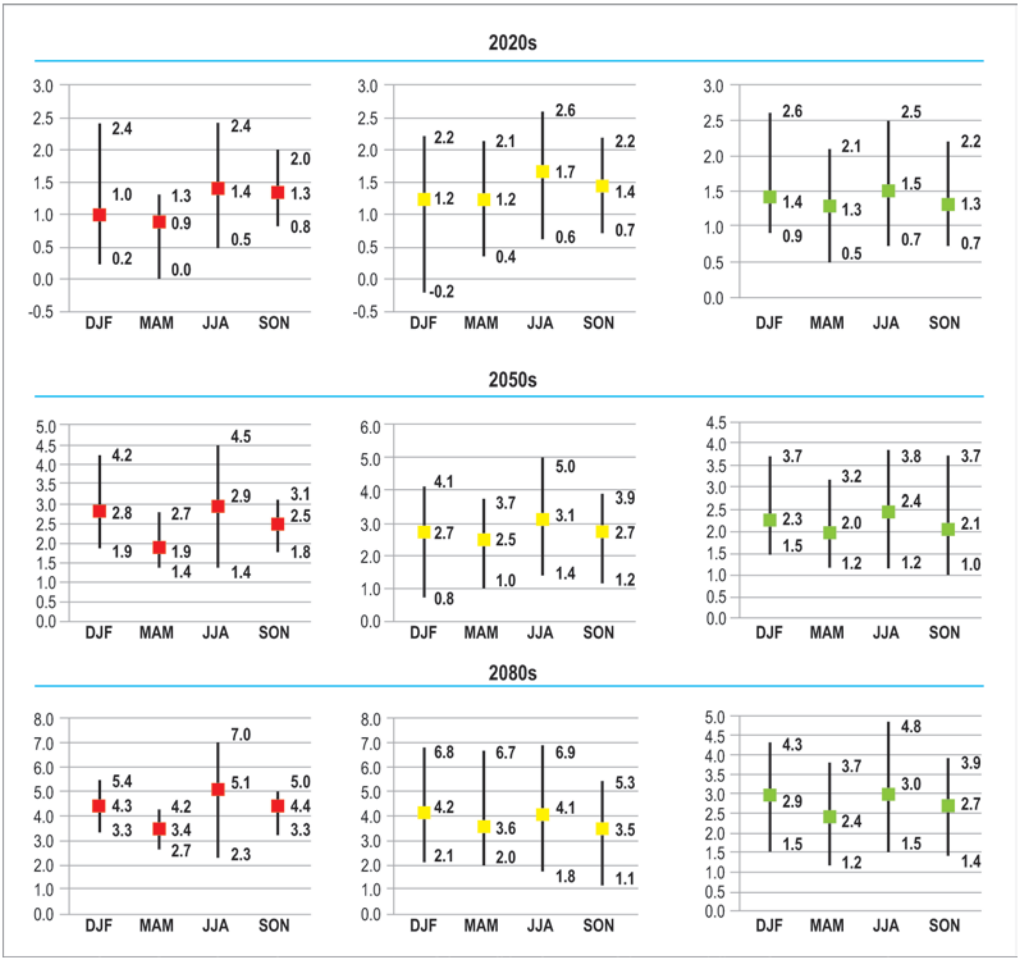


Figure 2-16: Projected Ensemble Seasonal Mean Air Temperature Changes (ΔT°C) Average, Maximum and Minimum Value Averaged over Four Seasons December-February (DJF), March-May (MAM), June-August (JJA) and September-November (SON), Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s, for SRES A2 (Red), A1B (Orange) and B1 (Green) GCMs Experiments Relative to the Climatological Baseline Period (1961-1990) in the Central AEZ

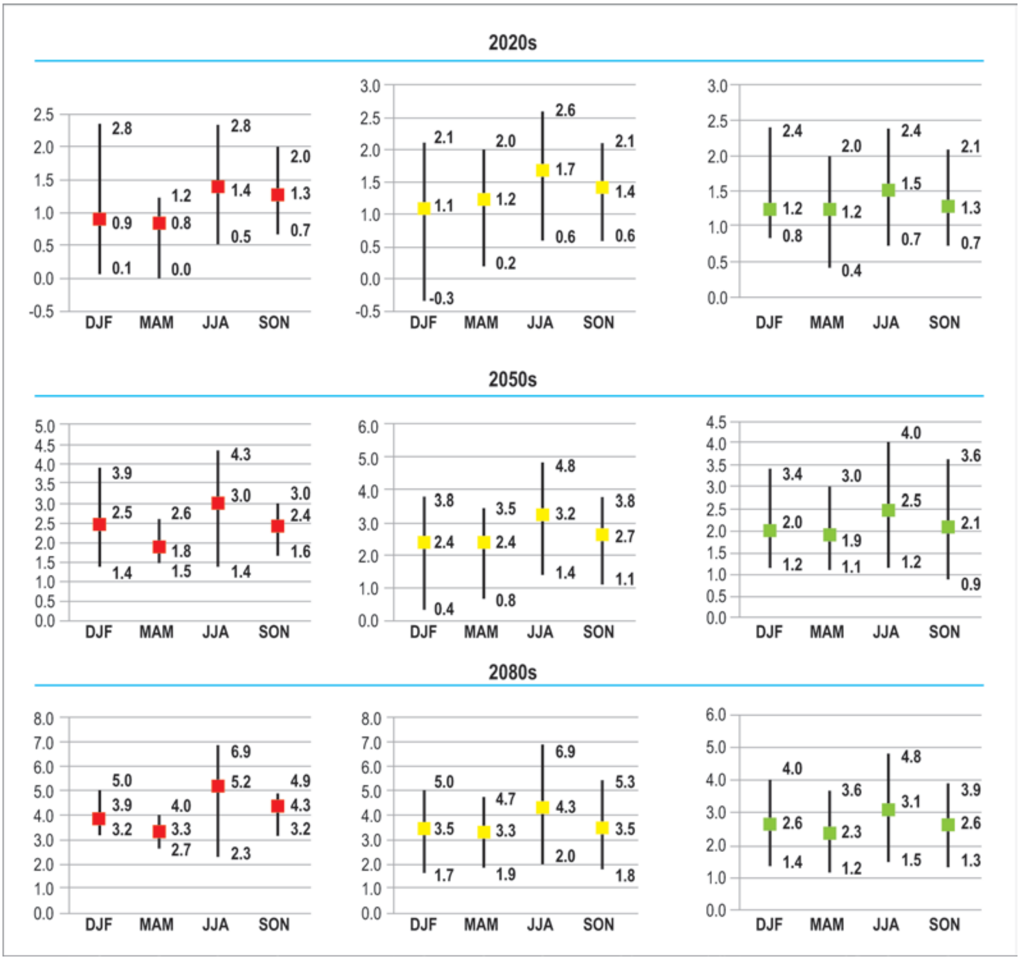


Figure 2-17: Projected Ensemble Seasonal Mean Air Temperature Changes (ΔT°C) Average, Maximum and Minimum Value Averaged over Four Seasons December-February (DJF), March-May (MAM), June-August (JJA) and September-November (SON), Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s for SRES A2 (Red), A1B (Orange) and B1 (Green) GCMs Experiments, Relative to the Climatological Baseline Period (1961-1990) in the Southern AEZ

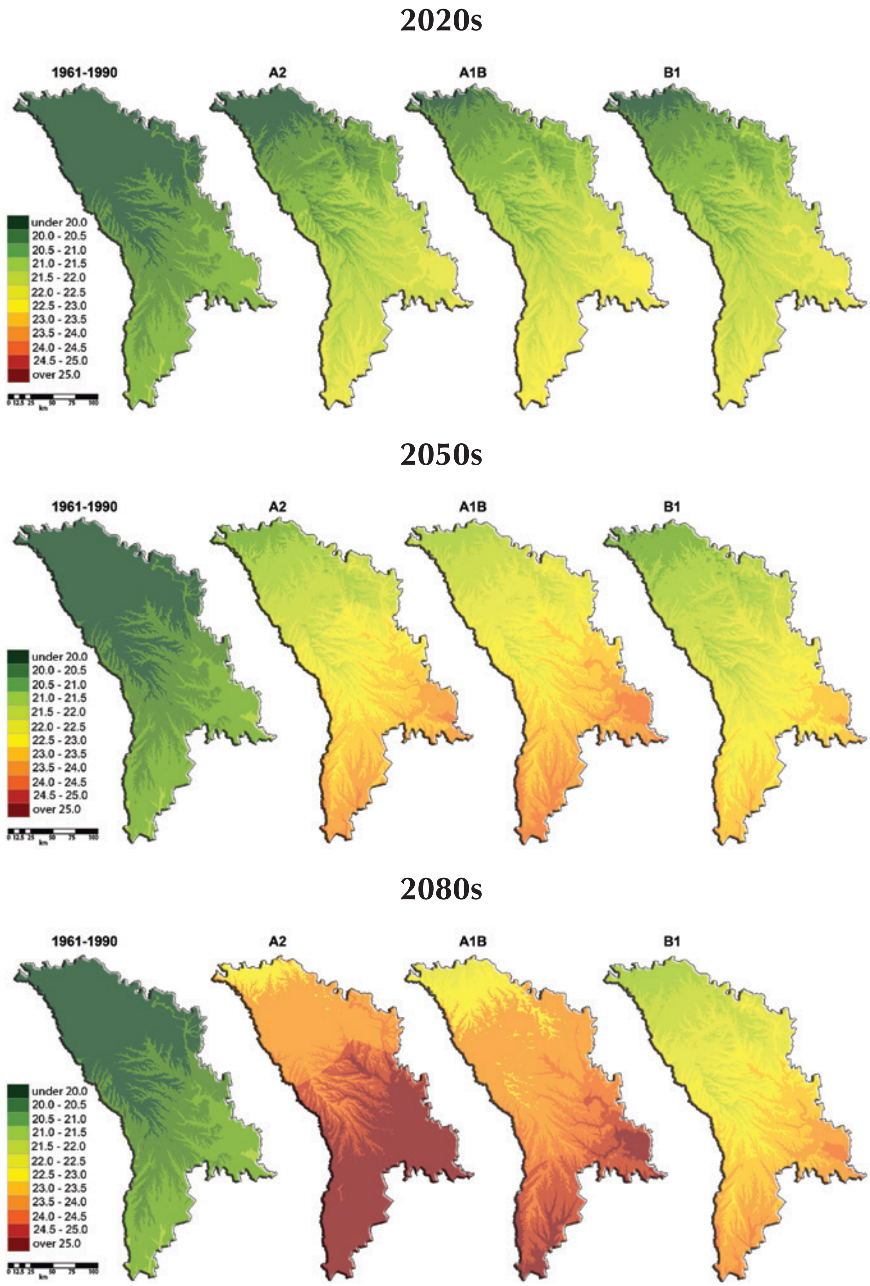


Figure 2-18: Projected Multi - Model Ensemble JJA Mean Air Temperature throughout the Republic of Moldova

All the assessments are in agreement with an overall season warming of Europe continent during the winter (**Figure 2-19**) and summer (**Figure 2-20**) months.

A) **B)**

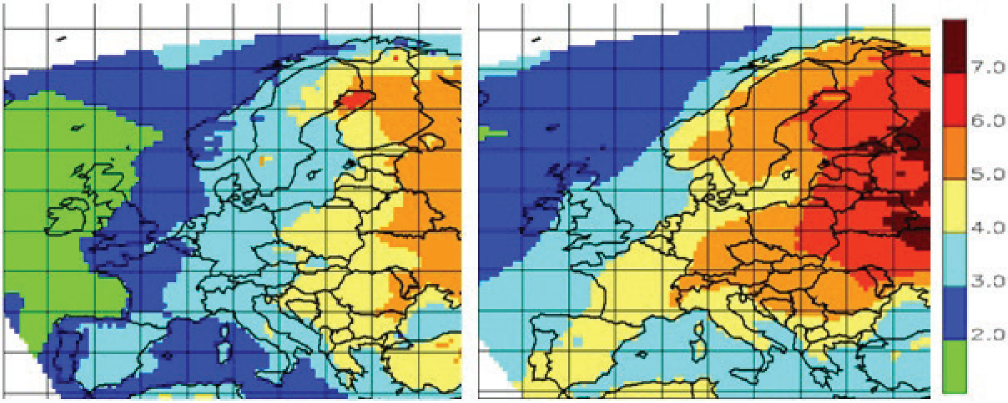


Figure 2-19: Change in winter temperature (°C) for different global and regional models for (A) HIRHAM/HadAM3H 2071- 2100; (B) RCAO/ECHAM4 2071-2100

Source: PRUDENCE project (downloaded from: http://peseta.jrc.ec.europa.eu/docs/ClimateModel.html).

A) **B)**

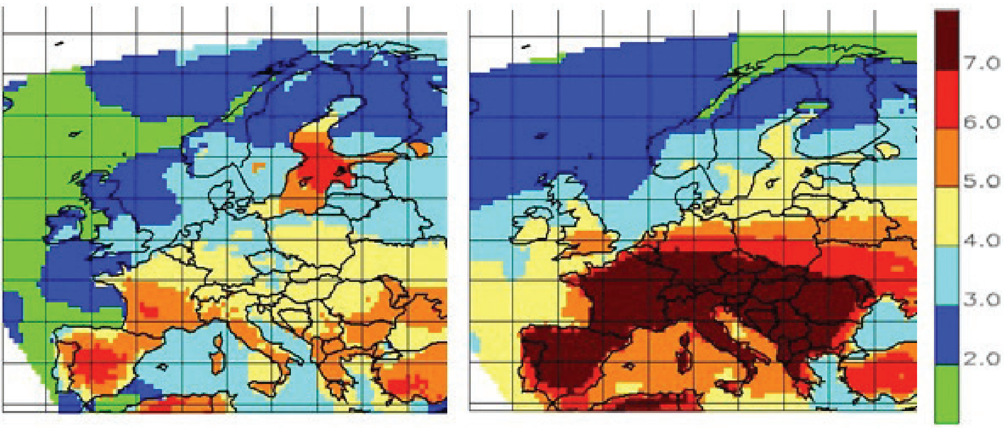


Figure 2-20: Change in summer temperature (°C) for different global and regional models for (A) HIRHAM/HadAM3H 2071- 2100; (B) RCAO/ECHAM4 2071-2100

Source: PRUDENCE project (downloaded from: http://peseta.jrc.ec.europa.eu/docs/ClimateModel.html).

2.2.3.2. Precipitation

A south-north contrast in precipitation changes across Europe is indicated by AOGCMs, with increases in the north and decreases in the south. The annual area-mean change from 1980 to 1999 to 2080 to 2099 in the multi-model SRES A1B projections varies from 0 to 16% in NEU and from –4 to –27% in SEM. The largest increases in northern and central Europe are simulated in winter. In summer, the NEU area mean changes vary in sign between models, although most models simulate increased (decreased) precipitation north (south) of about 55°N. In SEM, the most consistent and, in percentage terms, largest decreases, occur in summer, but the area mean precipitation in the other seasons also decreases in most or all models (IPCC, 2007a). For spatial distribution of EU absolute change in mean precipitation between control period (1961-1990) and 2071-2100, under regional model HIRHAM/HadCM3 IPCC SRES A2 scenario (see **Figure 2-9**), based on data from EC-funded project PRUDENCE (http://prudence.dmi.dk/).

The SRES A2, A1B and B1 emissions scenarios project similar slight precipitation increase around 2% over all of the Republic of Moldova's AEZs. But beginning from 2050s the three emissions scenarios project annual precipitation patterns that are distinguishable from each other. Annual changes for precipitation became much differentiated over the Republic of Moldova's AEZs. The multi-model projections from the SRES A2 and A1B forcing scenarios show that the domain of study would exhibit a general annual decrease in precipitation. Accordingly, the rate of decreasing in precipitation is higher under SRES A2 ensembles average varying from -13.5% over the southern to -5.7% over the northern AEZs, and smaller under the SRES A1B scenario from -4.4% in the southern to -1.5% in the northern AEZs.

Controversially, according to SRES B1 scenario slight decrease in precipitation by -1.8% is projected only for southern area while moderate increases by +0.6-1.7% are expected in the central and northern AEZs in comparison to the reference time period (1961-1990) by 2080s (**Table 2-4** and **Figures 2-21, 2-22, 2-23** and **2-24**).

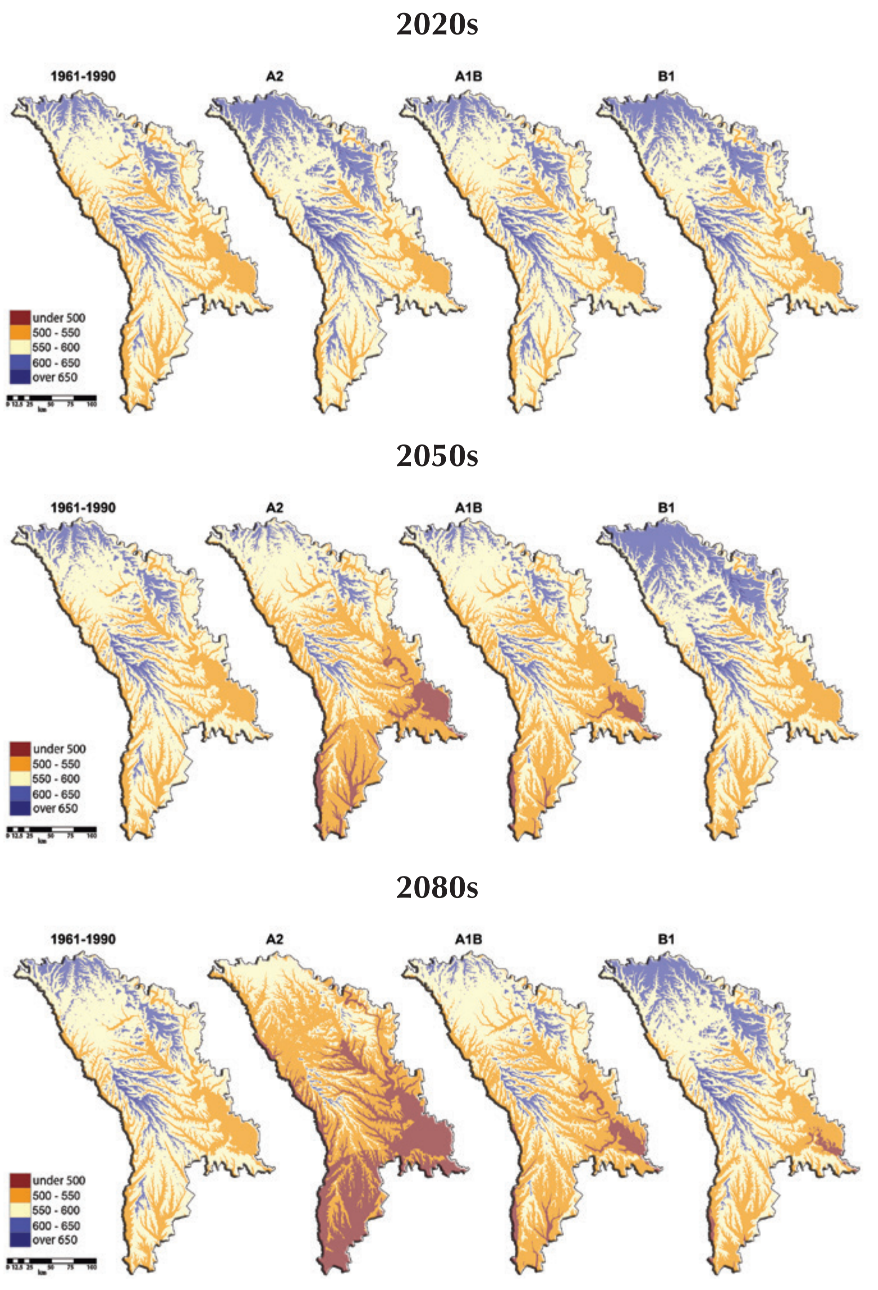


Figure 2-21: Projected Multi - Model Ensemble Annual Precipitation over the Republic of Moldova[3]

3 http://www.clima.md/public/files/ProiectiiClima/ro/ClimateMaps.html

Table 2-4: Projected Ensemble Annual and Seasons Total Precipitation Changes (ΔP, mm) Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s for SRES A2, A1B and B1 GCMs Experiments Relative to the Climatological Baseline Period (1961-1990)

Season	Average 1961-1990	SRES	Projected changes by the 2020s			Projected changes by the 2050s			Projected changes by the 2080s		
			Min	Average	Max	Min	Average	Max	Min	Average	Max
Northern AEZ											
Annual	612.7	**A2**	-6.8	**2.1**	7.2	-16.8	**-1.4**	7.0	-26.2	**-5.7**	4.0
		A1B	-9.1	**0.2**	8.2	-11.0	**-1.0**	9.4	-23.0	**-1.5**	16.2
		B1	-4.4	**2.0**	6.6	-7.5	**3.1**	16.7	-8.2	**1.7**	12.7
DJF	110.3	**A2**	-0.5	**4.5**	9.0	-29.0	**-0.5**	18.7	0.7	**7.5**	20.0
		A1B	-18.8	**3.6**	32.8	-22.8	**6.2**	44.7	-14.9	**6.5**	40.8
		B1	-18.3	**2.2**	10.3	-17.2	**2.2**	10.0	-22.5	**5.3**	17.6
MAM	154.3	**A2**	-3.0	**5.3**	17.6	-39.6	**1.7**	21.9	-14.0	**6.8**	33.1
		A1B	-2.2	**4.1**	10.6	-12.7	**1.7**	11.6	-7.0	**8.5**	23.6
		B1	-0.1	**5.0**	11.9	1.2	**8.6**	16.6	1.1	**10.9**	19.9
JJA	238.3	**A2**	-15.6	**0.6**	10.9	-30.8	**-2.7**	7.5	-46.4	**-16.1**	2.1
		A1B	-40.6	**-4.9**	31.8	-45.5	**-7.3**	37.8	-46.7	**-10.1**	35.2
		B1	-13.0	**3.2**	25.4	-28.0	**1.5**	28.8	-36.6	**-4.6**	34.7
SON	109.8	**A2**	-9.6	**1.2**	4.8	-21.5	**-3.8**	15.2	-33.3	**-13.7**	8.3
		A1B	-9.0	**2.8**	47.3	-15.4	**2.0**	37.0	-22.7	**-5.3**	24.4
		B1	-18.1	**-5.3**	7.2	-24.3	**0.1**	22.8	-11.2	**-1.2**	22.0
Central AEZ											
Annual	544.2	**A2**	-6.5	**2.0**	6.9	-12.2	**3.2**	2.8	-34.5	**-9.2**	1.3
		A1B	-12.4	**1.1**	10.0	-13.5	**-1.9**	10.3	-30.1	**-3.1**	13.4
		B1	-8.1	**0.7**	6.4	-9.8	**0.6**	9.8	-13.0	**0.6**	14.2
DJF	114.1	**A2**	2.8	**7.0**	11.3	-11.9	**2.4**	11.6	-4.7	**4.4**	21.3
		A1B	-12.1	**4.2**	29.6	-18.7	**4.6**	35.6	-8.3	**4.3**	33.6
		B1	-7.8	**3.3**	9.1	-12.5	**1.3**	10.7	-18.0	**3.6**	15.7
MAM	128.0	**A2**	-6.9	**4.0**	16.4	0.2	**6.3**	20.6	-20.0	**3.1**	31.0
		A1B	-6.9	**5.3**	13.3	-11.4	**3.3**	14.7	-17.6	**5.8**	27.4
		B1	-6.9	**4.1**	12.5	-2.3	**7.3**	18.5	-4.1	**9.3**	25.2
JJA	189.6	**A2**	-17.3	**-1.1**	11.0	-35.1	**-11.0**	1.6	-60.2	**-21.9**	0.7
		A1B	-31.9	**-4.8**	37.7	-36.6	**-7.9**	48.6	-57.6	**-11.3**	46.2
		B1	-17.5	**0.1**	28.8	-33.0	**-2.3**	19.9	-38.5	**-5.8**	34.4
SON	112.5	**A2**	-7.8	**0.1**	7.2	-17.6	**-6.3**	6.0	-37.8	**-15.5**	5.2
		A1B	-8.5	**3.2**	45.2	-19.1	**-4.1**	34.0	-23.2	**-6.9**	17.5
		B1	-22.2	**-4.6**	15.6	-26.0	**-2.8**	22.6	-12.8	**-1.7**	17.9

Season	Average 1961-1990	SRES	Projected changes by the 2020s			Projected changes by the 2050s			Projected changes by the 2080s		
			Min	Average	Max	Min	Average	Max	Min	Average	Max
Southern AEZ											
Annual	550.2	**A2**	-7.9	**2.0**	8.4	-16.3	**-6.9**	1.9	-35.9	**-13.5**	-1.2
		A1B	-11.6	**2.4**	26.4	-16.3	**-3.3**	19.6	-31.6	**-4.4**	13.3
		B1	-9.5	**-0.1**	6.1	-13.6	**-1.1**	6.5	-12.8	**-1.8**	14.5
DJF	113.2	**A2**	4.7	**7.0**	9.6	-7.3	**-0.3**	11.4	-6.6	**1.5**	18.7
		A1B	-19.6	**4.5**	27.9	-28.5	**1.2**	30.1	-19.4	**0.3**	27.4
		B1	-14.8	**1.0**	8.2	-15.9	**-1.3**	11.8	-25.0	**0.2**	13.4
MAM	127.9	**A2**	-13.8	**1.6**	13.0	-3.6	**0.8**	5.6	-21.9	**-2.7**	15.3
		A1B	-6.1	**5.8**	24.8	-11.8	**3.0**	20.9	-22.1	**3.1**	25.2
		B1	-7.3	**3.7**	12.3	-11.3	**6.2**	21.6	-6.4	**7.3**	22.1
JJA	195.8	**A2**	-17.9	**-0.6**	14.6	-37.6	**-15.9**	3.0	-57.9	**-26.4**	-2.7
		A1B	-25.8	**-1.4**	33.3	-38.5	**-8.4**	40.5	-54.9	**-9.1**	37.7
		B1	-21.3	**-1.0**	22.1	-35.2	**-3.3**	13.3	-40.6	**-8.4**	23.2
SON	113.3	**A2**	-9.0	**1.7**	27.4	-21.4	**-6.6**	4.4	-48.3	**-23.8**	1.8
		A1B	-11.1	**3.1**	46.3	-22.1	**-6.2**	33.9	-24.9	**-9.6**	12.2
		B1	-20.9	**-5.1**	9.2	-29.2	**-4.3**	11.3	-14.0	**-2.8**	13.0

The multi-model projections from the A2, A1B and B1 forcing scenarios show that the Republic of Moldova would exhibit a general increase of precipitation during winter and spring. This increase becomes progressively more intense towards the north. In details, the ensemble models simulate the largest increase in precipitation from 5.3 % (B1) to 7.5% (A2) in winter and from 6.8% (A2) to 10.9% (B1) in spring over the northern and the lowest ones from 1.5% (A2) to 0.2% (B1) and/or from -2.7% (A2) to 7.3% (B1) respectively over the southern parts of the country in comparison to the reference time period 1961-1990 by 2080s (**Table 2-4** and **Figure 2-25**).

Conversely, it can be noted that the individual model's climate signal, forced by the SRES A2, A1B and B1 emission scenarios, presented quite different estimations. For example, it can be seen that the individual models estimate of precipitation change in winter over North AEZ varying from +0.7% (CSIRO Mk3) to +20.0% (HadCM3) for the A2 emission scenario, from -14.9% (MIROC3.2 hires) to +40.8% (MRI_CGCM2.3) for A1B and from -22.5 (MIROC3.2 hires) to +17.6% (MRI_CGCM2.3) for the SRES B1 scenario in comparison to the control time period (1961-1990) by 2080s. The range of the changes projected over the southern AEZ is higher varying from -6.6 (GFDLCM2.1) to +18.7% (HadCM3) for the A2 emission scenario, from -19.4 (MIROC3.2 hires) to +27.4% (MRI_CGCM2.3) for A1B and from -25.3 (MIROC3.2 hires) to +13.4% (CCCma_CGCM3.1_T63) for the SRES B1 scenario (**Figures 2-26, 2-27** and **2-28**).

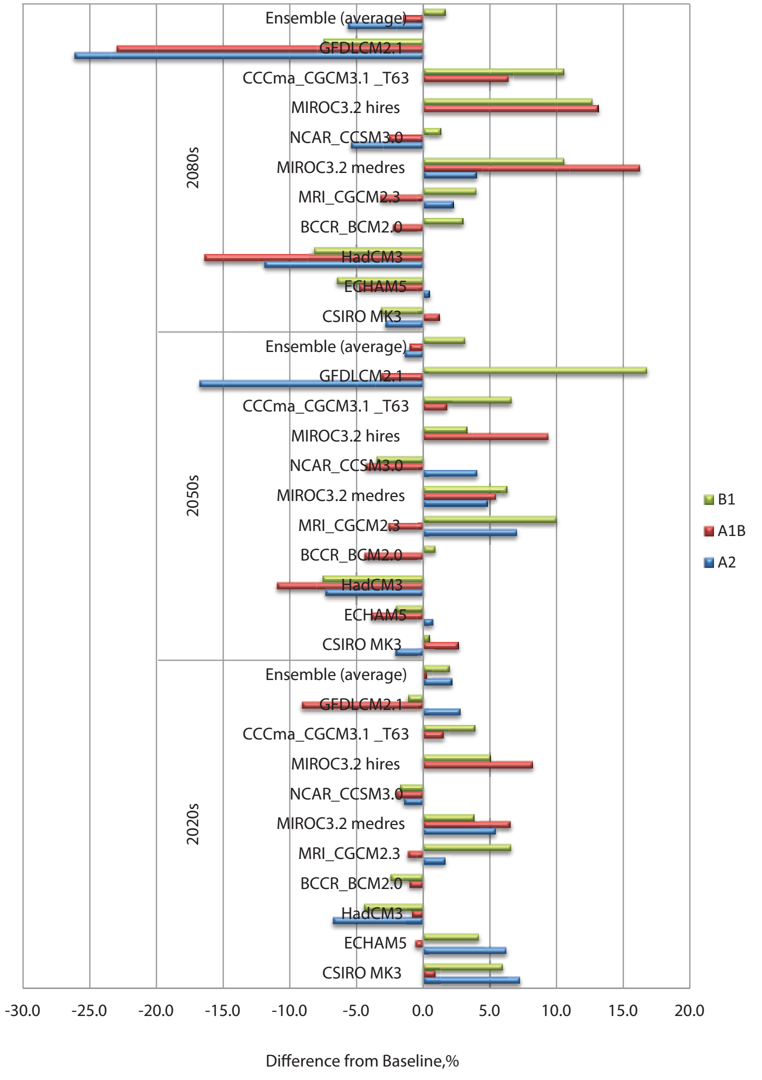


Figure 2-22: Projected Ensemble and 10 Individual GCMs Annual Precipitation Changes (ΔP, %) Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s for SRES A2, A1B and B1 Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990) in the northern AEZ

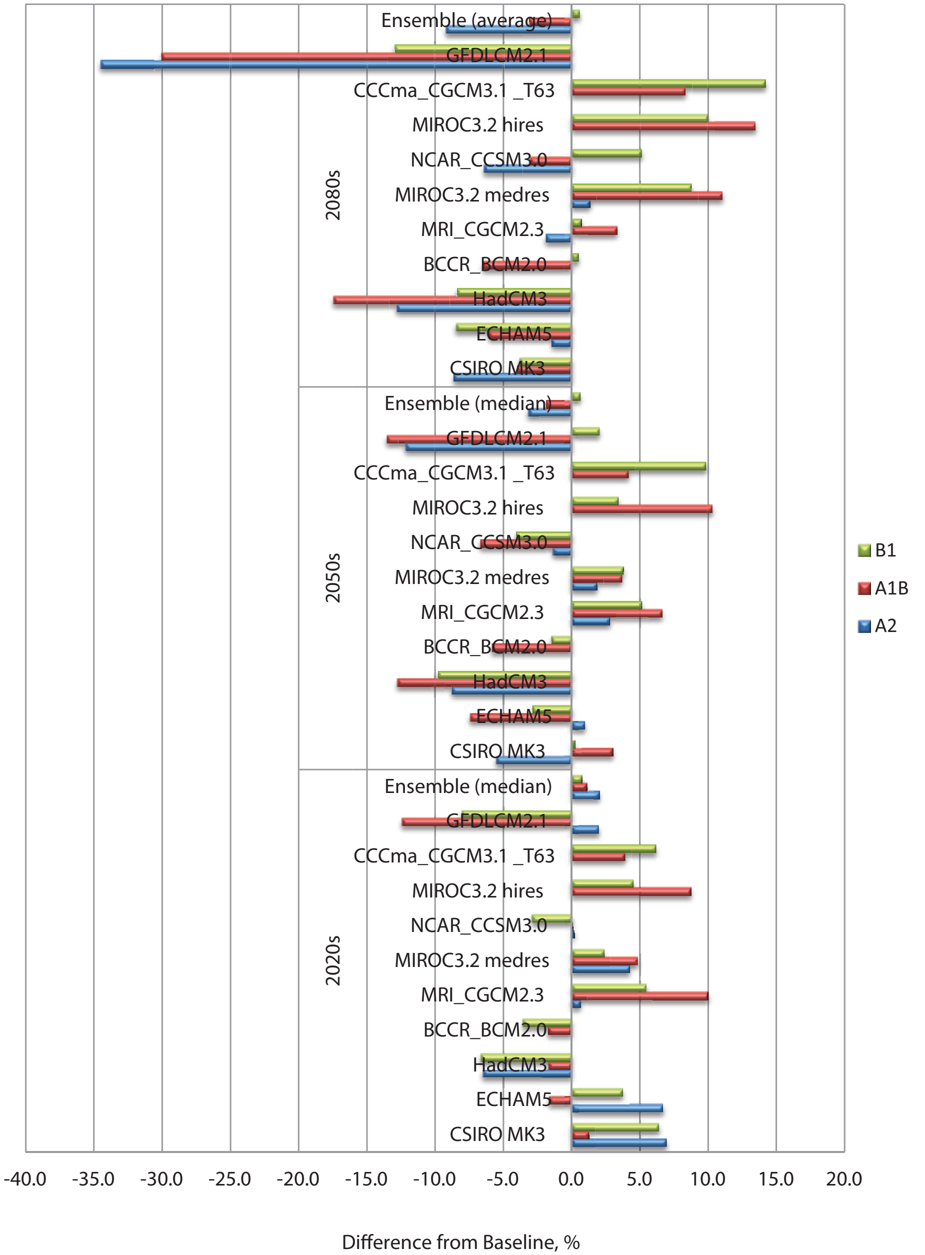


Figure 2-23: Projected Ensemble and 10 Individual GCMs Annual Precipitation Changes (ΔP, %) Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s for SRES A2, A1B and B1 Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990) in the central AEZ

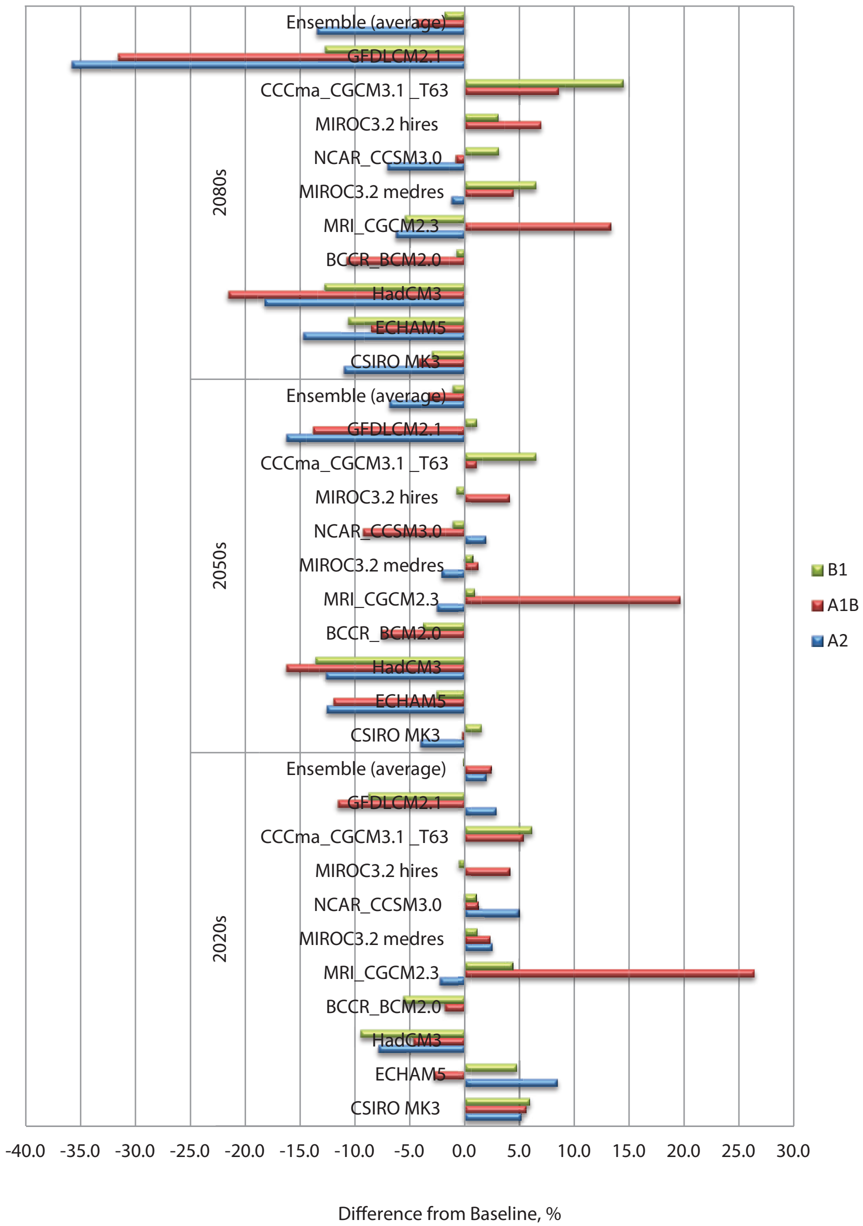


Figure 2-24: Projected Ensemble and 10 Individual GCMs Annual Precipitation Changes (ΔP, %) Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s for SRES A2, A1B and B1 Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990) in the southern AEZ

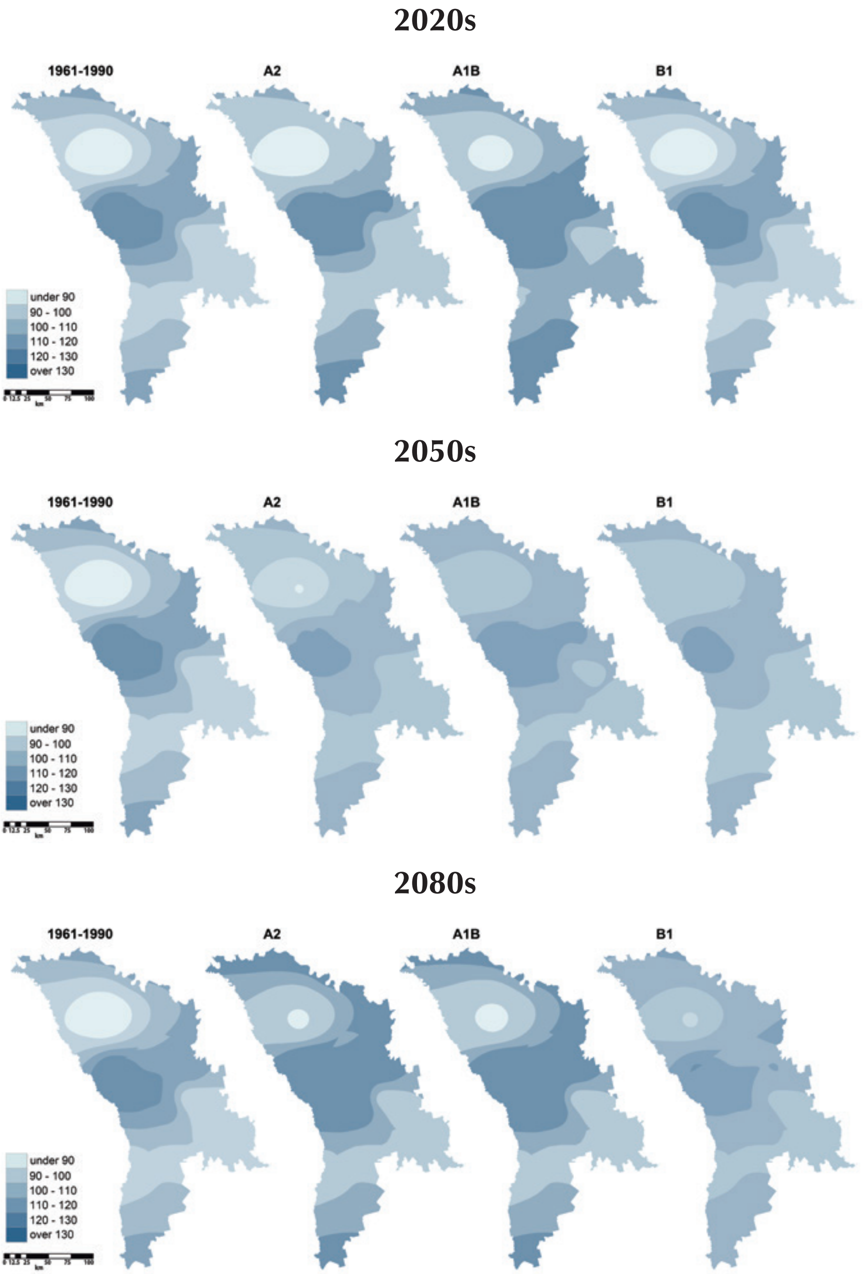


Figure 2-25: Projected Multi - Model Ensemble DJF Precipitation over the Republic of Moldova[4]

4 http://www.clima.md/public/files/ProiectiiClima/ro/ClimateMaps.html

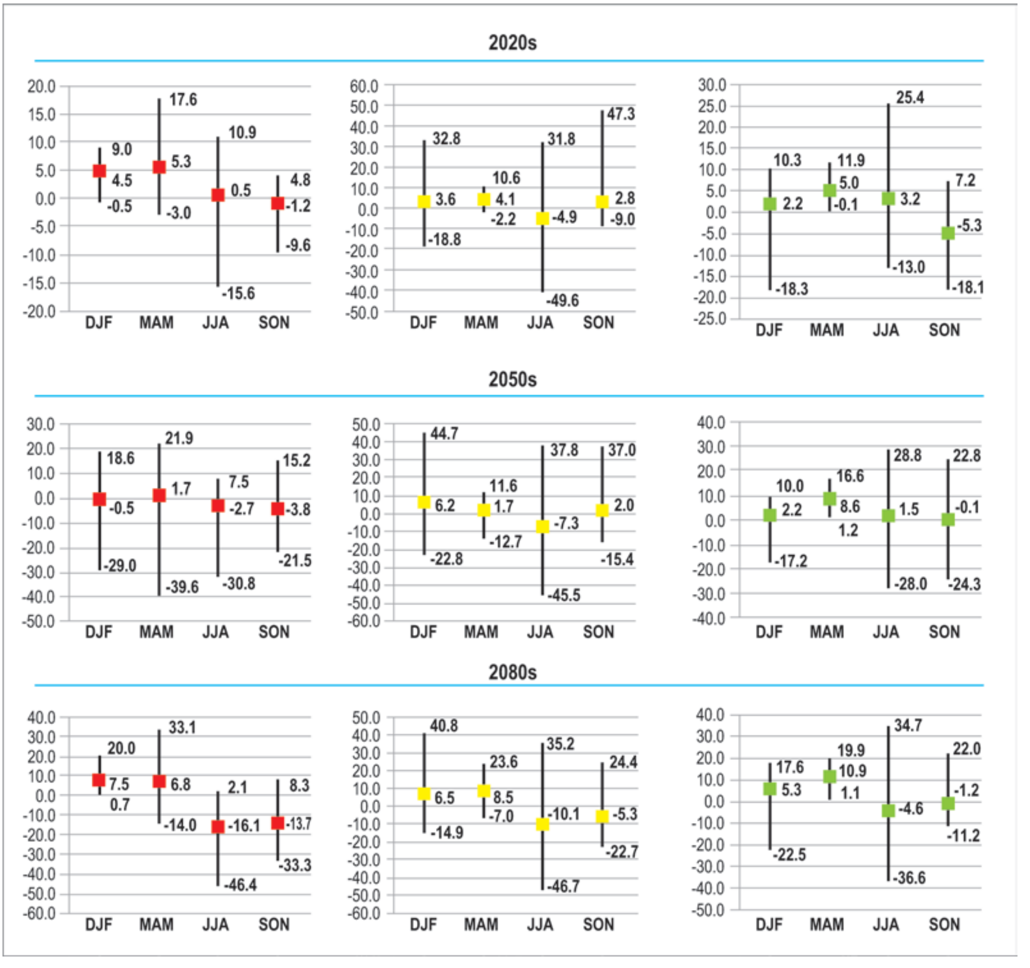


Figure 2-26: Projected Ensemble Seasonal Precipitation Changes (ΔP, %) Average, Maximum and Minimum Value Averaged over Four Seasons December-February (DJF), March-May (MAM), June-August (JJA) and September-November (SON), Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s, for SRES A2 (Red), A1B (Orange) and B1 (Green) Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990) in the Northern AEZ

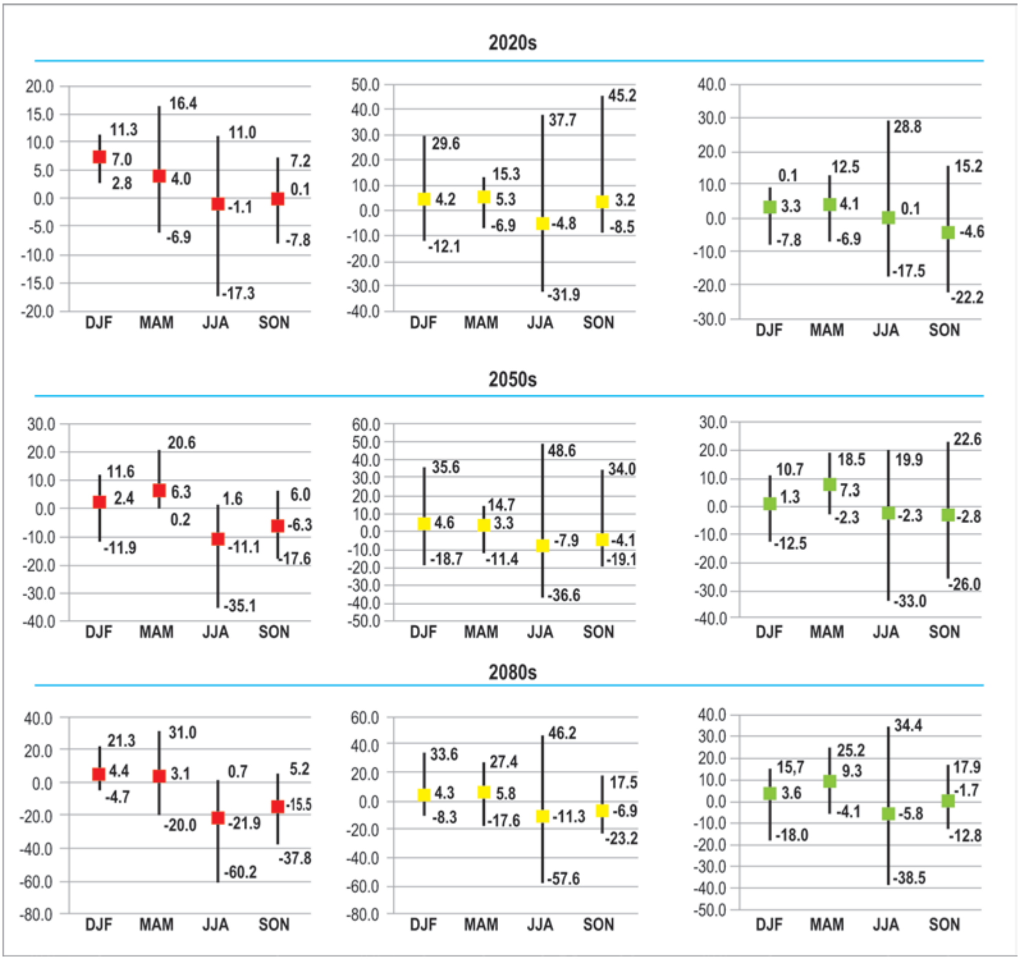


Figure 2-27: Projected Ensemble Seasonal Precipitation Changes (ΔP, %) Average, Maximum and Minimum Value Averaged over Four Seasons December-February (DJF), March-May (MAM), June-August (JJA) and September-November (SON), Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s, for SRES A2 (Red), A1B (Orange) and B1 (Green) Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990) in the Central AEZ

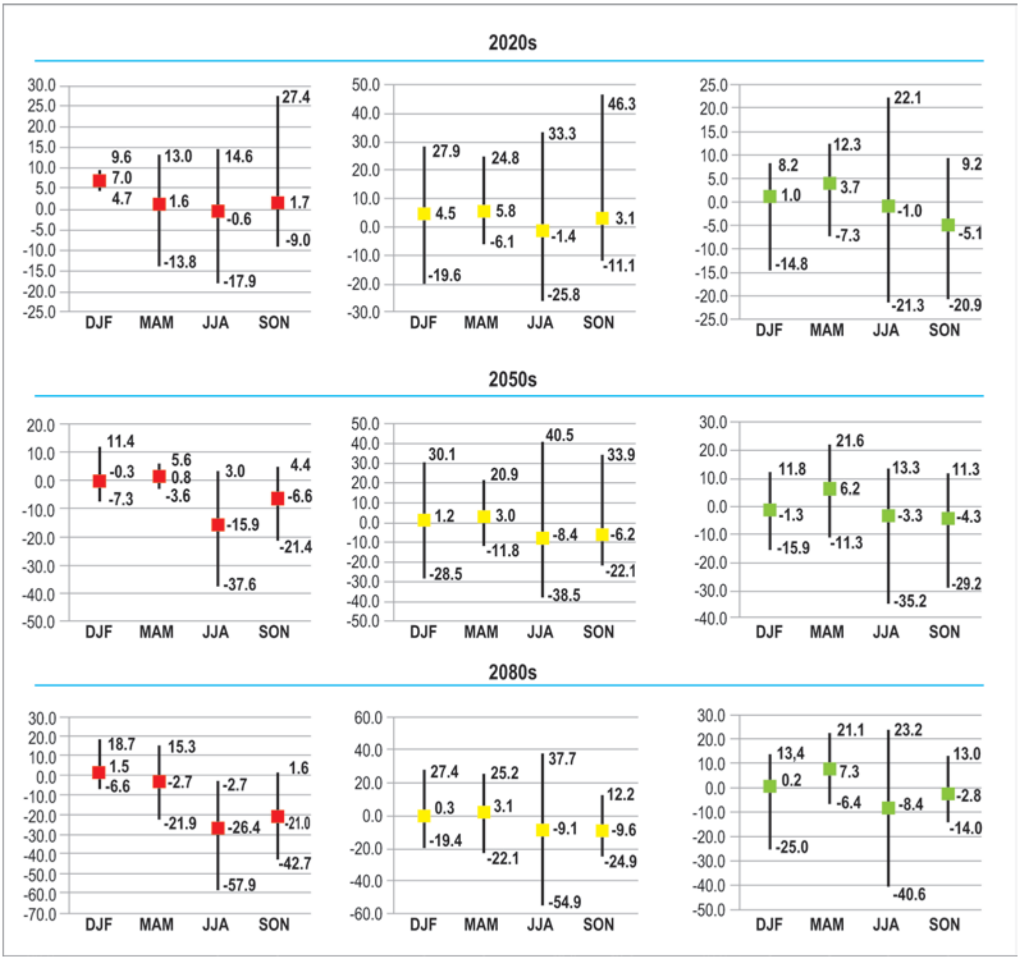


Figure 2-28: Projected Ensemble Seasonal Precipitation Changes (ΔP, %) Average, Maximum and Minimum Value Averaged over Four Seasons December-February (DJF), March-May (MAM), June-August (JJA) and September-November (SON), Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s, for SRES A2 (Red), A1B (Orange) and B1 (Green) Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990) in the Southern AEZ

The ensemble averages for the three SRES scenarios agree that the precipitation reduction will be much more extended in the Republic of Moldova during summer and autumn. The drying conditions are expected to characterize the all parts of the country. The ensemble projections forced by SRES A2 emission scenario project the greatest summer rainfall reduction by 26.4% in the southern and the lowest one by 16.1% in the northern areas. The pattern for ensemble projection forced by SRES B1 is quite similar but the magnitude of changes is lower decrease from 8.4% to 4.6% with maximum seen again over the southern and the minimum one over northern AEZs in comparison to the reference time period (1961-1990) by 2080s (**Table 2-4** and **Figure 2-29**).

It is worth mentioning that across all AEZs for the three SRES scenarios some individual models (e.g., HadCM3, MRI_CGCM2.3, GFDLCM2.1) simulate extremely high decrease in precipitation about/or more than 50%. As shown above, large uncertainties are associated with changes in the winter precipitation patterns over the Republic of Moldova climate persist also for summer pattern since model agreement is poor compared to temperature. As example can serve the ensembles members individual *max* and *min* estimates of precipitation change in summer over northern AEZ (the least vulnerable region conform projections for all SRES scenarios), varying from -46.4% (GFDLCM2.1) to +2.1%-18.6% (MRI_CGCM2.3) for the SRES A2 emission scenario; from -46.7% (GFDLCM2.1) to +35.2% (MIROC3.2 hires) for SRES A1B; and from -36.6% (HadCM3) to +34.7% (MIROC3.2 hires) for the SRES B1 scenario, in comparison to the reference time period (1961-1990) by 2080s. The range of the changes projected over the southern AEZ the most vulnerable area is higher varying from -57.9% (GFDLCM2.1) to -2.7% (MRI_CGCM2.3) for the SRES A2 emission scenario; from -54.9% (GFDLCM2.1) to +37.7% (MIROC3.2 hires) for SRES A1B; and from -40.6% (HadCM3) to +23.2% (MIROC3.2 hires) for the SRES B1 scenario (**Figures 2-26, 2-27** and **2-28**).

In comparison to the European SEM region (IPCC, 2007a), the Republic of Moldova is expected to have larger future precipitation change than other parts of the region. Under the SRES A1B scenario the simulated annual area and multi-model average precipitation range from 1961-1990 to 2080s varies from -23.0% to +16.5% in the northern AEZ; from -30.1% to 13.4% in the central AEZ; and from -31.6% to 13.3% in the southern AEZ. However, the central tendency (multi-model ensemble averages) in precipitation pattern is in agreement with precipitation trends over of European continent.

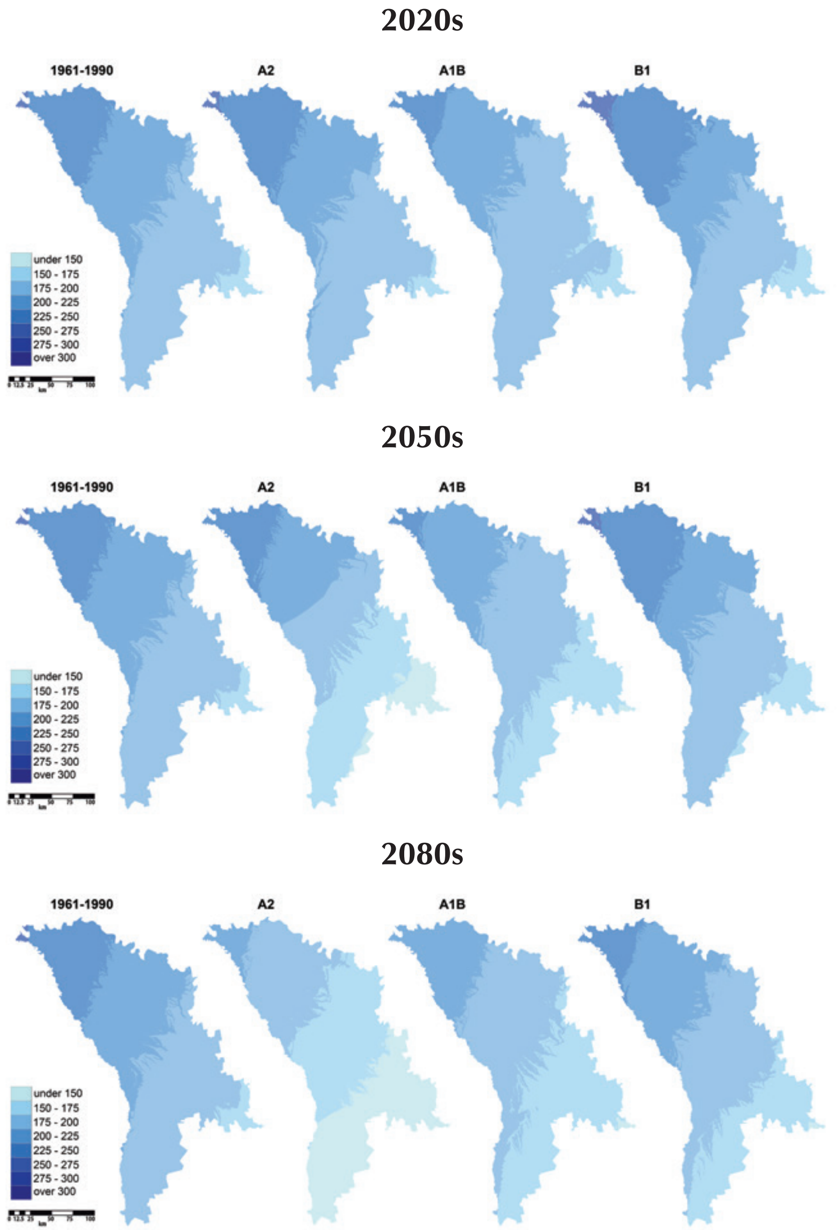


Figure 2-29: Projected Multi - Model Ensemble JJA Precipitation over the Republic of Moldova[5]

5 http://www.clima.md/public/files/ProiectiiClima/ro/ClimateMaps.html

CONCLUSIONS

In the present study we assessed the potential annual and seasonal (winter and summer) future changes in temperature and precipitation conditions over the Republic of Moldova AEZs as a consequence of the increased greenhouse gases concentrations until the end of the 21st century. Totally 37 simulations from 10 global coupled atmosphere ocean general circulation models (AOGCMs) were downloaded and assessed. The GCM simulations were grouped into three multi-model ensembles (averages) depending on the different IPCC emission scenarios (SRES A2, A1B and B1) and the climatic changes over the domain of study were computed for tree different future periods (2020s, 2050s and 2080s) with respect to the control period (1961-1990).

The main conclusions are the following:

1. The first feature to highlight is that, both for temperature and precipitation, the multi-model ensemble average changes consistently have the same sign across scenarios and their magnitude increases from the low GHG emissions scenario (SRES B1) to the higher emissions scenarios (SRES A1B and A2), as we move into the later decades of the 21st century.
2. Annual changes for temperatures are very homogeneous over the Republic of Moldova's AEZs. Accordingly, the rate of warming by the 2080s is higher under SRES A2 ensemble (+4.3°C); medium under SRES A1B (+3.8°C); and smaller under SRES B1 scenario ensemble (+2.7°C); individual GCMs show an increase of up to 5.1-6.2°C.
3. The seasonality of the warming signal is different in the Republic of Moldova's AEZs, over central and southern AEZs with a pronounced summer maximum by 5.1-5.2°C. Conversely, over northern AEZ the warming is larger in winter, +4.9°C by the 2080s.
4. The ensemble, driven by the SRES A2 emission scenario, estimate that the northern AEZ will experience the most significant warming during winter, with temperatures rising by up to 5.2°C by the 2080s. For the rest of the Republic of Moldova the temperature increase will be by 0.5 to 1.0°C lower. The pattern of change derived from the ensemble SRES B1 models is quite similar, but the magnitude of change is lower increase about 2.6 to 3.2°C, with the maximum warming seen again in northern and central AEZs.
5. The warming would be even higher during summer. The climate change simulations project an increase by up to 5.1-5.2°C in the central and

southern AEZs, while in the northern AEZ's temperature rise will be lower by up to 4.5^{0}C according to the SRES A2 scenario. The SRES B1 scenario reveals less intense and more uniform warming over the Republic of Moldova's AEZs (by 2.9-3.1°C). This kind of intense warming especially when it is accompanied by low precipitation would have severe impacts on human activities. Similar conditions during the extremely warm year of 2007 in Republic of Moldova resulted in serious consequences for national economy, specifically for agriculture sector, as well as for human health.

6. The multi-model projections from the SRES A2 and A1B forcing scenarios show that the domain of study would exhibit a general annual decrease in precipitation. Accordingly, the rate of decreasing in precipitation is higher under SRES A2 scenario, varying from -13.5% over the southern, to -5.7% over the northern AEZs, and smaller under the SRES A1B scenario, from -4.4% in the southern to -1.5% in the northern AEZs. Controversially, according to SRES B1 scenario slight decrease in precipitation by -1.8% is projected only for the southern AEZ, while moderate increases by 0.6-1.7% are expected in the central and northern AEZs by 2080s.
7. A strong seasonality is also evident in the precipitation change signal. Winters and springs are estimated to be wetter by the end of the 21st century. The ensemble models simulate the largest increase in precipitation from 5.3% (SRES B1) to 7.5% (SRES A2) in winter and from 6.8% (SRES A2) to 10.9% (SRES B1) in spring over the northern and the lowest ones from 1.5% (SRES A2) to 0.2% (SRES B1) and/or from -2.7% (SRES A2) to 7.3% (SRES B1) respectively over the southern AEZ by 2080s.
8. The precipitation reduction will be much more extended in the Republic of Moldova during summer. The ensemble projections forced by SRES A2 emission scenario project the greatest rainfall reduction by 26.4% in the southern AEZ and the lowest one by 16.1% in the northern AEZ. The pattern for ensemble projection forced by SRES B1 is quite similar, but the magnitude of changes is lower, decreasing from 8.4% to 4.6% with maximum seen again over the southern AEZ and the minimum one over northern AEZs, in comparison to the reference time period (1961-1990) by 2080s.

2.3. Generating High Resolution Climate Change Scenario for the Republic of Moldova

2.3.1. Data and Methods

A regional climate model PRECIS (Providing Regional Climates for Impacts Studies), developed by the UK Met Office Hadley Centre (Jones et al., 2004) was used to provide detailed maps and statistics of climate change across the Republic of Moldova during the 2020s, 2050s and 2080s.

Three experiments were designed for our work in close collaboration with PRECIS team: two experiments were aimed to simulate present day climate (1961-1990): the first experiment was driven by **ERA-40_re-analyses, from ECMWF** and the second one by **ECHAM5 GCM**; another experiment planned for 21 century future climate simulation was driven with boundary conditions from **SRES A1B** - medium emission scenario**.** The **Figure 2-30** shows the main PRECIS window (A) and domain of study resolution 0.22° x 0.22° giving grid boxes of approximately 25 km x 25 km (B).

Figure 2-30: The main PRECIS window (A) and domain of study resolution 0.22° x 0.22° giving grid boxes of approximately 25 km x 25 km (B)

2.3.2. Projections of Changes in Seasonal Temperature and Precipitation

Annual temperature: all zones of the Republic of Moldova will get warmer. Under the PRECIS/ECHAM5 SRES A1B medium emission scenario mean annual temperature are projected to increase by 1.2-1.6°C during the 2020s, 2.5-2.9°C by the 2050s and 4.1-4.5°C by the 2080s. Although mean annual temperatures will probably increase in all AEZs, the increase is likely to be the greatest in the southern AEZ (**Table 2-5**; **Figure 2-31 A**).

Table 2-5: Projected PRECIS/ECHAM5 Annual and Seasons Air Temperature (°C) and Precipitation (%) Changes Presented for Three 30 Year Time Slices in the Future, Centered on the 2020s, 2050s and 2080s for SRES A1B Emission Scenario Relative to the Climatological Baseline Period (1961-1990)

Season	Projected changes by the 2020s		Projected changes by the 2050s		Projected changes by the 2080s	
	T	*P*	*T*	*P*	*T*	*P*
Northern AEZ						
Annual	1.2	1.8	2.5	7.8	4.1	-2.5
DJF	2.2	3.1	4.0	10.4	5.3	0.7
JJA	0.3	-7.4	1.5	-4.3	3.8	-22.7
Central AEZ						
Annual	1.4	-8.1	2.7	-5.0	4.4	-17.7
DJF	2.2	-11.5	3.8	-5.8	5.1	-14.0
JJA	0.6	-7.7	1.9	-11.0	4.2	-30.5
Southern AEZ						
Annual	1.6	-12.0	2.9	-9.5	4.5	-21.5
DJF	2.3	-17.5	3.8	-12.3	5.1	-20.9
JJA	0.9	-16.8	2.3	-25.3	4.5	-34.2

Annual Precipitation: annual precipitation tends to decrease across the Republic of Moldova. Across the Republic of Moldova regional average annual precipitation decrease are projected to be between 2.5-21.5% by the 2080s (**Table 2-5**). **Figure 2-31B** shows estimates of annual precipitation change at the 25x25 km spatial resolution for the 2080s. Projections of average annual precipitation change in the RM get lower over time. Projected changes in average annual precipitation are from +1.8 % to -12.0% during the 2020s, from +7.8% to – 9.5% by the 2050s and from -2.5% to -21.5% by the 2080s.

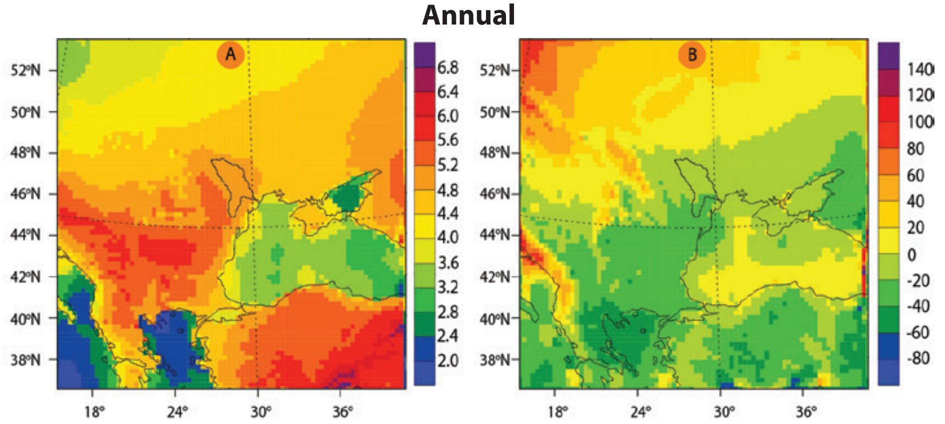


Figure 2-31: Projected PRECIS/ECHAM5 SRES A1B Future Changes in Annual (A) Mean Air Temperature (°C) and (B) Precipitation (%) by 2080s, relative to baseline period (1961-1990)

Temperatures in winter can increase faster than those in summer for all climate zones. Projections of seasons average temperature change also get larger over time. Projected increases in average summer temperature are between 0.3-0.9°C during the 2020s, 1.5-2.3°C by the 2050s and 3.8-4.5°C by the 2080s (**Table 2-5**; **Figure 2-32A**).

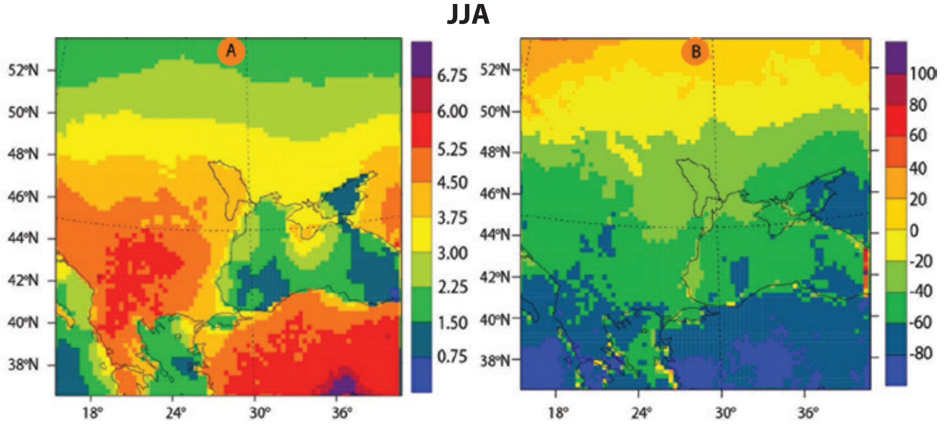


Figure 2-32: Projected PRECIS/ECHAM5 SRES A1B Future Changes in JJA (A) Mean Air Temperature (°C) and (B) Precipitation (%) by 2080s, relative to baseline period (1961-1990)

The winter warming according to PRECIS/ECHAM5 SRES A1B medium emission scenario excepted to be even larger than summer, the projected increases in average winter temperatures are between 2.2-2.3°C during the 2020s; 3.8-4.0°C by 2050s and 5.1-5.3°C by the 2080s. The spatial distribution of the changes is quite different, the strongest temperature rise occurring over the northern AEZ (**Table 2-5**; **Figure 2-33A**).

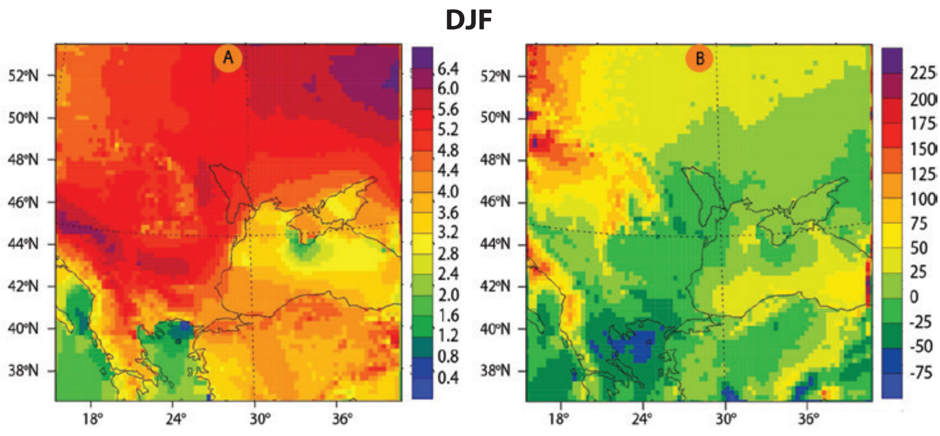


Figure 2-33: Projected PRECIS/ECHAM5 SRES A1B Future Changes in DJF (A) Mean Air Temperature (°C) and (B) Precipitation (%) by 2080s, relative to baseline period (1961-1990)

Season Precipitation: winter and summer precipitation tends to decrease across the Republic of Moldova. Regional average summer precipitation decrease is projected to be between 22.7-34.2% by the 2080s. **Figure 2-32B** shows estimates of summer precipitation changes at the 25 x 25 km spatial resolution for the 2080s. The summer precipitation changes according to PRECIS/ECHAM5 SRES A1B medium emission scenario are expected to be larger than in the winter season, projected decrease in average summer precipitation being between 7.4-16.8% by the 2020s; from 4.3% to 25.3% by 2050s; and from 22.7% to 34.2% by the 2080s. The spatial distribution of changes is quite similar, the strongest seasonal precipitation decrease occurring over the central and southern AEZs.

Regional average winter precipitation decrease is projected to be between 14.0-20.9% by the 2080s (see **Table 2-5**). **Figure 2-33B** shows estimates of winter precipitation change at the 25 x 25 km spatial resolution for the 2080s. Projections of average winter precipitation changes in the Republic of Moldova differ over time. Projected changes in average winter precipitation are ranged from +3.1 % to -17.5% by the 2020s; from +10.4% to -12.3% by 2050s; and from +0.7% to -20.9% in by the 2080s.

2.3.3. Projections of Future Extreme Temperature Events

Extreme high temperatures across Europe are projected to become more frequent and last longer during this century (IPCC, 2007 a, b; Haylock et al., 2008; Sillman and Roeckner, 2008; Seneviratne et al., 2012). These changes are consistent with projections of future average warming as well as observed trends over recent decades. The number of days that combine a hot summer day (defined as having a temperature exceeding 35°C) and a tropical night (defined as having a minimum temperature higher than 20°C) is a basic indicator of human comfort due to heat stress. Model projections project the number of such combined heat stress days to double across most parts of southern Europe by 2071 to 2100 (**Figure 2-34**). The most severe increases, of about 25 days per year, are projected in low-altitude river basins and along the Mediterranean coasts where many densely populated urban centers are located (Fischer and Schär, 2010).

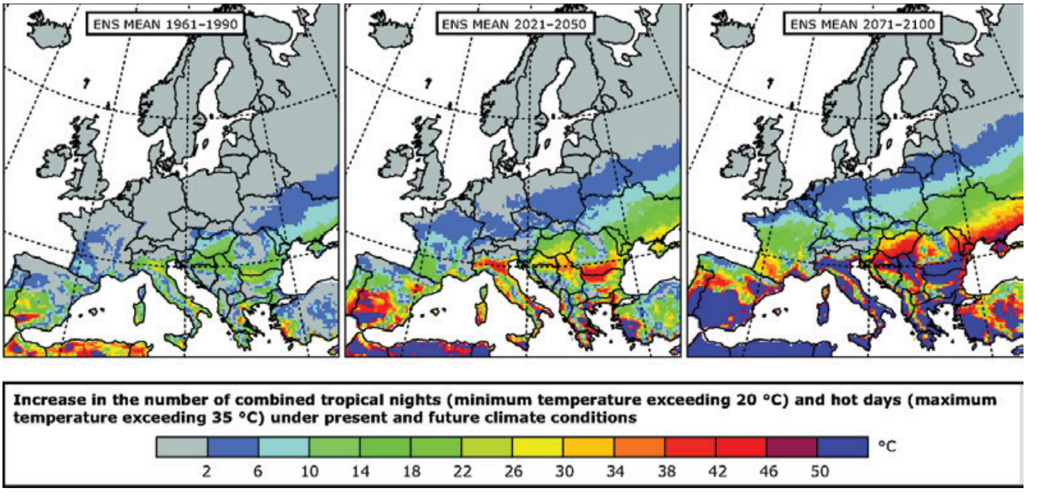


Figure 2-34: Number of combined tropical nights (T>20°C) and hot days (T>35°C) for the period 2071 to 2100.

Source: EEA, 2012: Urban adaptation to climate change in Europe. Report No 2/2012

Heat waves in Europe are very likely to become more frequent and longer-lasting, mainly following an increase in seasonal mean temperatures (Barnett *et al.*, 2006; Fischer and Schär, 2009, 2010). As a result, the probability of occurrence of recent events such as the 2010 Russian heat wave would increase substantially – by a factor of 5–10 by the mid-century (Barriopedro et al., 2011; Dole et al., 2011). Extremely hot summer temperatures, as seen in 2003, are projected to be exceeded every second to third summer by the end of the 21st century (Schär *et al.*, 2004; Fischer and Schär, 2010). The temperature departures during the hottest days are expected to increase substantially more than the corresponding mean local temperatures in central and southern Europe as a result of enhanced temperature variability on inter-annual to intra-seasonal time scales (Schär et al., 2004; Alexander et al., 2006; Clark et al., 2006; Fischer et al., 2007a; Kjellström et al., 2007; Vidale et al., 2007; Fischer and Schär, 2009; 2010; Nikulin et al., 2011).

Climate models and observational studies suggest that this amplification occurs through soil moisture-temperature feedbacks (Seneviratne et al., 2006; Fischer et al., 2007a, 2007b; Lenderink et al., 2007; Vidale et al., 2007; Fischer and Schär, 2010; Hirschi et al., 2011). Clark et al. (2010) demonstrate that even in scenarios where the global temperature change is limited to 2°C above pre-industrial levels, the intensity of temperature extremes in Europe may change by more than 6°C. Surface temperatures, from a multi-model ensemble, downscaled and gridded based on geographical information, suggest the strongest increases in the mean June-August temperatures in regions that already are characterised by hot, dry summer conditions (Benestad, 2011). Similarly, using a regional climate multi-model experiment, Fischer and Schär (2010) projected that under SRES A1B emission scenario the maximum heat wave intensity would increase by 4–6°C in the central and southern Europe, which is substantially more than the projected change in mean summer temperatures. The greatest changes in heat-wave frequency are projected for Southern Europe (Fischer and Schär, 2009) where the frequency of hot summer days would increase from 5% at the end of the 20th century (per definition) to about 65% at the end of the 21st century – 40% in Central Europe, under SRES A2 emissions scenario.

According to the IPCC SREX report (Field et al., 2012), some projections of future global warming suggest that the most substantial increase in the high temperature percentiles may take place over Western Europe, specifically France, even if the largest mean warming is expected for the Mediterranean region. Furthermore, for Central and Eastern Europe, changes in extremes may be due to changes both in the mean and the variability. However, these results have to be treated with caution as much remains to be done to validate such detailed output from the models used.

Relative to the reference period (1961-1990), there is a general increase in the annual minimum of TN and the annual maximum of TX values of daily temperatures over the Republic of Moldova AEZs in the 21st century. The increase in TX is greater than in TN for central and southern AEZs. In the middle of the 21st century the PRECIS/ECHAM5 A1B projected increase in annual TN and TX respectively over the Republic of Moldova AEZs, which will be 2.5°C and 2.6°C in northern AEZ, 2.6°C and 2.8°C in central AEZ, respectively 2.8°C and 3.0°C in southern AEZs. By the end of the 21st century them could rise up to 4.1°C in northern AEZ; 4.2°C and 4.5°C in central AEZ; and 4.3°C and 4.7°C in southern AEZ (**Table 2-6**).

Table 2-6: PRECIS/ECHAM5 SRES A1B Projected Future Changes in Minimum and Maximum Temperatures over the Republic of Moldova AEZs in 2020s, 2050s, and 2080s, as Differences Relative to Reference Period (1961-1990)

Season	Projected changes by the 2020s			Projected changes by the 2050s			Projected changes by the 2080s		
	Tavg	*Tmin*	*Tmax*	*Tavg*	*Tmin*	*Tmax*	*Tavg*	*Tmin*	*Tmax*
Northern AEZ									
Annual	1.2	1.2	1.2	2.5	2.5	2.6	4.1	4.2	4.1
DJF	2.2	2.4	2.0	3.9	4.0	3.7	5.3	5.4	5.2
JJA	0.3	0.4	0.3	1.5	1.6	1.6	3.8	4.2	3.5
Central AEZ									
Annual	1.4	1.3	1.6	2.7	2.6	2.8	4.4	4.2	4.5
DJF	2.2	1.8	2.5	3.8	3.5	4.1	5.1	4.8	5.3
JJA	0.6	0.5	0.8	1.9	1.8	2.1	4.2	3.8	4.6
Southern AEZ									
Annual	1.6	1.4	1.7	2.9	2.8	3.0	4.5	4.3	4.7
DJF	2.3	2.0	2. 6	3.8	3.5	4.1	5.1	4.8	5.3
JJA	0.9	0.6	1.2	2.3	2.0	2.6	4.5	4.0	5.0

The projected changes in extreme temperatures exhibit different warming throughout seasons in the 21st century. It is clear from the simulations that the most parts of changes in annual warming are mainly attributable to warming changes in DJF rather than those in JJA.

By the end of the 21st century the PRECIS/ECHAM5 A1B projected increase in winter TN and TX respectively over the Republic of Moldova AEZs, which will be 5.4°C and 5.2°C in northern AEZ; respectively 4.8°C and 5.3°C in central and southern AEZs; while summer increase TN and TX could be 4.2°C and 3.5 °C in northern AEZ; 3.8°C and 4.6°C in central AEZ; and 4.0°C and 5.0°C in southern AEZ.

Warm nights and days (TN90p and TX90p, respectively) show a general increase toward the end of the 21st century, the increase is more pronounced for TN90p than for TX90p. According to PRECIS/ECHAM5 A1B emission scenario the number of warm days will increase by between 36 and 46 days across the Republic of Moldova's AEZs, and the number of warm nights will increase by between 43 and 49 days. Southern AEZ will show the largest increase in warm days/nights, while northern AEZ will have the largest warming in cool days/nights.

Summer days, and ND_{35} based on the fixed 25°C and 35°C threshold, will increase over the Republic of Moldova AEZs. By the end of the 21st century the PRECIS/ECHAM5 A1B projected increase in SU and ND_{35} respectively by 36-43 and 19-33 days, the increase in summer days and number of days with temperature above 35°C will be more pronounced in Southern AEZ (**Table 2-7**).

Table 2-7: PRECIS/ECHAM5 SRES A1B Projected Future Changes in Temperature Extremes Indices over 2020s, 2050s, and 2080s, as Differences Relative to Reference Period (1961-1990)

AEZ	Cold temperature indices			Warm temperature indices			
	FD	TNp10%	TXp10%	SU	TNP90%	TXP90%	ND35
Projected changes by the 2020s							
Northern	-24	-12	-13	3	5	4	5
Central	-23	-12	-13	10	7	9	7
Southern	-23	-12	-13	13	10	14	9
Projected changes by the 2050s							
Northern	-42	-20	-19	15	19	13	8
Central	-40	-20	-19	23	23	19	12
Southern	-40	-20	-20	26	29	25	15
Projected changes by the 2080s							
Northern	-59	-29	-28	36	43	36	19
Central	-55	-27	-27	42	47	39	27
Southern	-55	-27	-28	43	49	46	33

A number of studies suggest that winter cold extremes are expected to become rarer (Tebaldi et al., 2006; Nikulin et al., 2011; Orlowsky and Seneviratne, 2012).

Interestingly, cold extremes are also expected to warm more than the local mean temperatures as a result of reduced temperature variability related to declining snow cover (Kjellström et al., 2007; Fischer et al., 2011).

Nevertheless, recent studies suggest that in Europe some intense cold winter spells may still occur in the second half of the 21st century (Sillmann and Croci-Maspoli, 2009; Kodra et al., 2011).

Cohen et al. (2012), on the other hand, suggest that a reduction in the Arctic sea-ice extent may lead to more cold spells, arguing that the sea-ice cover affects the Eurasian November snow-cover extent, which subsequently affects stratospheric conditions that later affect atmospheric circulation and atmospheric blocking.

Frost days (FD) gradually will decrease over the Republic of Moldova AEZs, the strongest decrease with reductions of 59 frost days is projected in northern AEZ and lowest of 55 frost days in the central and southern AEZs by the end of the 21st century.

An overall decrease in cold nights and days (TN10p and TX10p, respectively) is expected in the Republic of Moldova. By the end of the 21st century the PRECIS/ECHAM5 A1B projected decrease in cold nights and days respectively over all AEZs is 27-29 and 27- 28 days, the reduction in cold nights and days will be more pronounced in the northern AEZ.

Recent analyses (Benestad, 2011) suggest a reduced likelihood of below freezing mean winter, characterised by the temperature as measured at an altitude of 2 m T over Europe.

The high mountain regions will still have below-freezing temperatures in 2100 given the SRES A1B scenario, and the greatest reduction in the probability for below freezing mean winter temperature is expected in areas where the present winter conditions are around freezing – southern Sweden and Eastern Europe.

The areas with current climatological temperature a few degrees below 0°C can expect to see more 0°C crossings in the future.

The most likely cause of changes in temperature extremes is climate change. However, a recent model-based study by Deser et al. (2012) suggested that, at a regional level and over a 50-year time horizon, changes in extremes may be substantially higher or lower than the long-term warming caused by greenhouse gases because the large scale atmospheric flow also changes irrespective of the long-term warming.

Higher annual mean temperatures are expected to lead to more hot and fewer cold extremes. However, the magnitude of the changes and agreement among models varies with the definition used to describe the extreme and the characteristics of the event being considered – its time-scale, intensity, length and spatial extent, for example.

Petoukhov and Semenov (2010) also suggested that reduced Arctic sea-ice cover could lead to more cold spells. They used a GCM to study the atmospheric response to retreating sea-ice, and observed that the exposed sea had a tendency to give rise to high-pressure systems that are responsible for extreme cold winter conditions over Europe.

2.3.4. Projections of Future Extreme Precipitation Events

Model-based projections for the 21st century show a reduction in the contribution of low rainfall days to total annual precipitation, and an increase in the contribution of high rainfall days in most parts of Europe, with the exception of the Iberian Peninsula and Mediterranean regions (Boberg et al., 2009).

The recurrence time of intense precipitation is reduced from 20 years in the 1961–1990 periods to 6–10 years in the 2071–2100 period over northern and eastern central Europe in summer (**Figure 2-35 left**) and to 2–4 years in Scandinavia in winter (**Figure 2-35 right**) (Haugen and Iversen, 2008; Nikulin et al., 2011; Seneviratne et al., 2012).

Extreme precipitation events are likely to become more frequent in Europe (Solomon et al., 2007). Changes in extreme precipitation depend on the region, with a *high confidence* of increased extreme precipitation in northern, Atlantic (all seasons) and central Europe (except in summer) (Seneviratne et al., 2012).

Future projections are inconsistent in southern Europe (all seasons) (Sillman and Roeckner, 2008; Boberg et al., 2009; Seneviratne et al., 2012). The number of consecutive dry days is projected to increase significantly in southern and central Europe, in particular in summer, and to decrease in northern Europe, in particular in winter (IPCC, 2012).

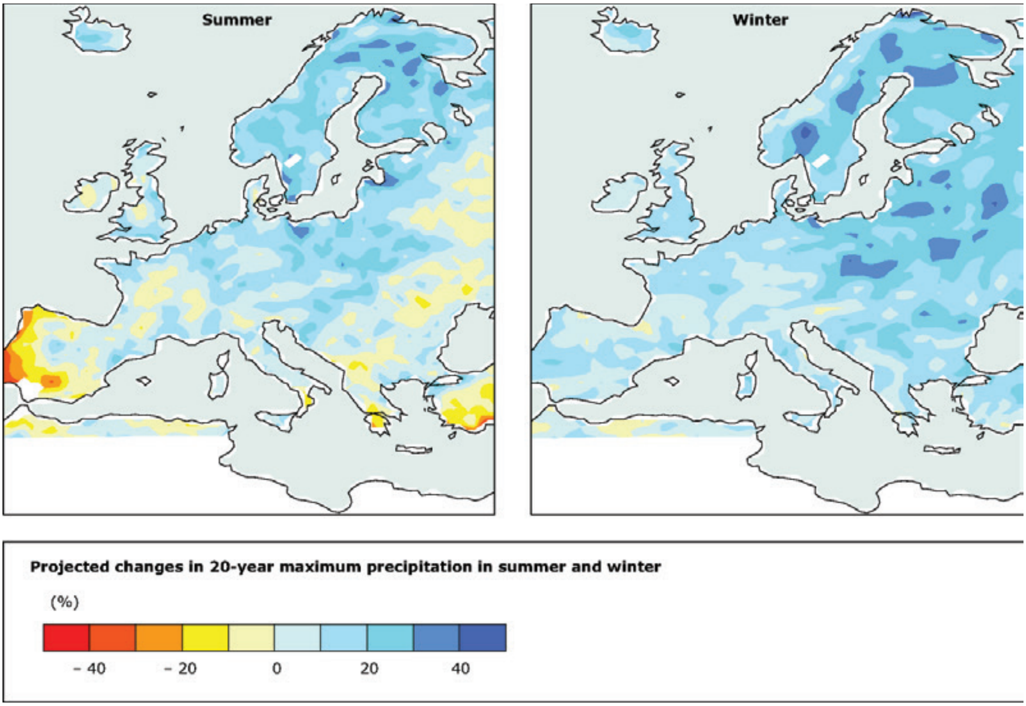


Figure 2-35: Projected changes in 20-year maximum precipitation in summer and winter

Note: Projected changes in 20-year maximum daily precipitation in summer (left) and winter (right) from 1961–1990 to 2071–2100 based on the ensemble mean using a regional climate model (RCM) nested in 6 general circulation model (GCMs). Changes that approximately lie outside of ± 10 % for the ensemble average are significant at the 10 % significance level.

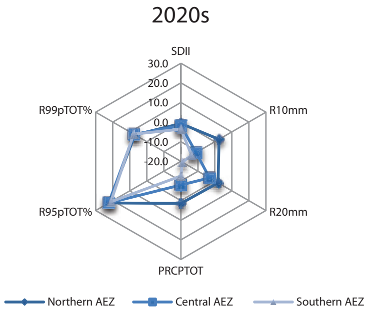
Source: Nikulin et al., 2011.

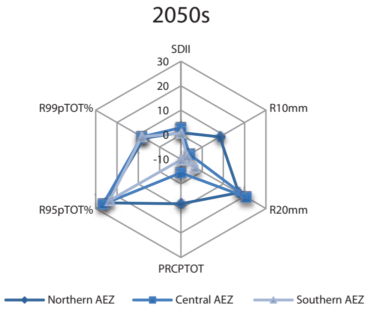
The patterns of future changes in precipitation extreme indices appear spatially more heterogeneous across the Republic of Moldova than the consistent warming pattern seen in the temperature extreme indices (**Table 2-8**; **Figure 2-36**).

Relative to the reference period (1961-1990) by the middle of the 21st century, in the northern AEZ it is projected a general increase in annual total wet day precipitation (PRCPTOT), maximum one day precipitation (RX1-day), number of heavy precipitation days (R10mm), number of very heavy precipitation days (R20mm), and simple daily intensity index (SDII), contribution from very wet days (R95pTOT%) and contribution from extremely wet days (R99pTOT%). While for southern AEZ it is expected a general decrease in PRCPTOT, RX1day, R10mm, R20mm, and an increase in SDII, R95pTOT% and R99pTOT%.

Table 2-8: PRECIS/ECHAM5 SRES A1B Projected Future Changes in Precipitation Extreme Indices (%), as Differences Relative to Reference Period (1961-1990)

AEZ	RX1day	SDII	R10mm	R20mm	PRCPTOT	R95pTOT%	R99pTOT%
Projected changes by the 2020s							
Northern	3	-1	2	2	1	22	7
Central	-21	-2	-11	-3	-8	22	8
Southern	-44	-4	-14	-19	-12	21	8
Projected changes by the 2050s							
Northern	-11	1	8	17	8	25	7
Central	-26	3	-6	21	-5	27	8
Southern	-28	1	-7	-3	-10	24	8
Projected changes by the 2080s							
Northern	104	0	-7	13	-3	27	10
Central	26	-1	-20	-12	-18	23	7
Southern	-26	-2	-21	-34	-22	18	7





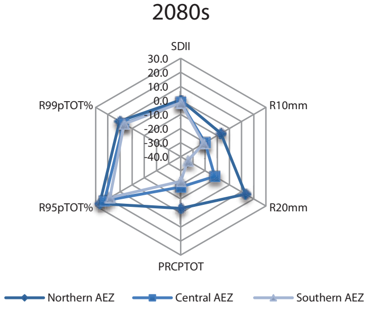


Figure 2-36: PRECIS/ECHAM5 SRES A1B Projected Future Changes in Precipitation Extreme Indices, as Differences Relative to Reference Period (1961-1990)

In the middle of the 21st century the PRECIS/ECHAM5 A1B projected decrease in PRCPTOT over the Republic of Moldova AEZs will be 5% in central AEZ, 10% in southern AEZ, while in northern AEZ is expected a small increase by 8%.

By the end of the 21st century total wet day precipitation could down up by 3% in northern AEZ, by 18% in central AEZ and by 22% in southern AEZ.

The PRECIS/ECHAM5 A1B projected increase in R10mm over the Republic of Moldova AEZs will be 5% in central AEZ and 10% in southern AEZ, while in northern AEZ is expected a small increase by 8% in the middle of the 21st century.

Contribution from very and extremely wet days and contribution from wet days (R95pTOT% and R99pTOT%, respectively) show a general increase toward the end of the 21st century, the increase is more pronounced for R95pTOT% than for R99pTOT%.

According to PRECIS/ECHAM5 A1B emission scenario the contribution from very wet days will increase by between 18 and 27% across the Republic of Moldova's AEZs and the contribution from extremely wet days will increase by between 7 and 10%.

Northern AEZ will show the largest increase in contribution from very/extremely wet days, while southern AEZ will have the lowest increase.

CONCLUSIONS

The main conclusions are as following:

1. Under the PRECIS/ECHAM5 SRES A1B medium emission scenario mean annual temperature are projected to increase by 1.2-1.6°C during the 2020s, by 2.5-2.9°C during the 2050s and by 4.1-4.5°C during the 2080s. Although mean annual temperatures will probably increase in all AEZs, the increase is likely to be the greatest in the southern AEZ.
2. Projections of average annual precipitation change in the RM get lower over time. Projected changes in average annual precipitation are from +1.8 % to -12.0% during the 2020s, from +7.8% to – 9.5% by the 2050s and from -2.5% to -21.5% by the 2080s.
3. Temperatures in winter can increase faster than those in summer for all AEZs.

   a. Projected increases in average summer temperature are between 0.3-0.9°C during the 2020s, 1.5-2.3°C during the 2050s and 3.8-4.5°C during the 2080s.

   b. The winter warming according to PRECIS/ECHAM5 SRES A1B medium emission scenario is excepted to be even larger than the summer warming, the projected increases in average winter temperatures are between 2.2-2.3°C during the 2020s; 3.8-4.0°C during the 2050s and 5.1-5.3°C during the 2080s. The spatial distribution of the changes is quite different, the strongest temperature rise occurring over the northern AEZ.

4. Season Precipitation: winter and summer precipitation tends to decrease across the Republic of Moldova.

   a. Projected changes in average winter precipitation are ranged from +3.1% to -17.5% by the 2020s; from +10.4% to -12.3% by 2050s; and from +0.7% to -20.9% by the 2080s.

   b. The summer precipitation changes according to PRECIS/ECHAM5 SRES A1B medium emission scenario are expected to be larger than in the winter season, projected decrease in average summer precipitation being between 7.4-16.8% by 2020s; from 4.3% to 25.3% by 2050s; and from 22.7% to 34.2% by 2080s. The spatial distribution of changes is quite similar, the strongest seasonal precipitation decrease occurring over the central and southern AEZs.

5. In the middle of the 21st century the PRECIS/ECHAM5 A1B projected increase in annual TN and TX respectively over the Republic of Moldova AEZs will be 2.5°C and 2.6°C in northern AEZ, and 2.6°C and 2.8°C in central AEZ, and 2.8°C and 3.0°C in southern AEZ. By the end of the 21st century they could rise up to 4.1°C in northern AEZ, to 4.2°C and 4.5°C in central AEZ, and to 4.3°C and 4.7°C in southern AEZ.

6. It is clear from the simulations that most parts of changes in annual warming are mainly attributable to warming changes in DJF rather than those in JJA. By the end of the 21st century the PRECIS/ECHAM5 A1B projected increase in winter TN and TX respectively over the Republic of Moldova AEZs is 5.4°C and 5.2°C in northern AEZ, 4.8°C and 5.3°C in central and in southern AEZs, while summer increase TN and TX could be 4.2°C and 3.5 °C in northern AEZ, 3.8°C and 4.6°C in central AEZ, and 4.0°C and 5.0°C in southern AEZ.

7. Warm nights and days (TN90p and TX90p, respectively) show a general increase toward the end of the 21st century, the increase is more pro-

nounced for TN90p than for TX90p. According to PRECIS/ECHAM5 A1B emission scenario the number of warm days will increase by between 36 and 46 days across the Republic of Moldova's AEZs, and the number of warm nights will increase by between 43 and 49 days. Southern AEZ will show the largest increase in warm days/nights, while northern AEZ will have the largest warming in cool days/nights.

8. Summer days, and ND_{35} based on the fixed 25°C and 35°C threshold, will increase over the Republic of Moldova AEZs. By the end of the 21st century the PRECIS/ECHAM5 A1B projected increase in SU and ND_{35} respectively is 36-43 and 19-33 days, the increase in summer days and number of days with temperature above 35°C will be more pronounced in southern AEZ.

9. Frost days (FD) gradually will decrease over the Republic of Moldova AEZs, the strongest decrease with reductions of 59 frost days is projected in northern AEZ and lowest of 55 frost days in the central and southern AEZs by the end of the 21st century.

10. An overall decrease in cold nights and days (TN10p and TX10p, respectively) is expected. By the end of the 21st century the PRECIS/ECHAM5 A1B projected decrease in cold nights and days respectively over the Republic of Moldova AEZs is 27-29 days, the reduction in cold nights and days will be more pronounced in northern AEZ.

11. Relative to the 1961-1990 reference period by the middle of the 21st century, in northern AEZ it is projected a general increase in annual total wet day precipitation (PRCPTOT), maximum one day precipitation (RX1day), number of heavy precipitation days (R10mm), number of very heavy precipitation days (R20mm), and simple daily intensity index (SDII), contribution from very wet days (R95pTOT%) and contribution from extremely wet days (R99pTOT%). While for southern AEZ it is expected a general decrease in PRCPTOT, RX1day, R10mm, R20mm, and an increase in SDII, R95pTOT% and R99pTOT%.

12. In the middle of the 21st century the PRECIS/ECHAM5 A1B projected decrease in PRCPTOT over the Republic of Moldova AEZs will be 5% in central AEZ and 10% in the southern AEZ, while in northern AEZ is expected a small increase by 8%. By the end of the 21st century total wet day precipitation could down up by 3% in northern AEZ, by 18% in central AEZ and by 22% in southern AEZ.

13. The PRECIS/ECHAM5 A1B projected increase in R10mm over the Republic of Moldova AEZs will be 5% in central AEZ and 10% in southern

AEZ, while in northern AEZ is expected a small increase by 8% in the middle of the 21st century. By the end of the 21st century total wet day precipitation could down up by 3% in the northern AEZ, by 18% in central AEZ and by 22% in southern AEZ.

14. According to PRECIS/ECHAM5 A1B emission scenario the contribution from very wet days will increase by 18 to 27% across the Republic of Moldova's AEZs and the contribution from extremely wet days will increase by 7 to 10%. Northern AEZ will show the largest increase in contribution from very/extremely wet days, while southern AEZ will have the lowest increase.

Bibliography

1. **Alexander, L.V., Zhang, X., Peterson, T.C., Caesar, J., Gleason, B., Klein Tank, A.M.G., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F., Tagipour, A., Rupa Kumar, K., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D.B., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M., Vazquez-Aguirre, J.L., 2006,** *Global observed changes in daily climate extremes of temperature and precipitation.* Journal of Geophysical Research: Atmospheres 111, DOI: 10.1029/2005JD006290.
2. **Araya, A., Keesstra, S.D., Stroosnijder, L., 2010,** *A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia.* Agric. Forest Meteorology, 150, 1057–1064.
3. **Arnell, N.W., Cannell, M.G.R., Hulme, M., Kovats, R.S., Mitchell, J.F.B., Nicholls, R.J., Parry, M.L., Livermores, T.J., White, A. 2002,** *The consequences of CO_2 stabilization for the impacts of climate change.* Climatic Change 53, 413–446.
4. **Arnell, N.W.**, **2003b,** *Relative effects of multi-decadal climatic variability and changes in the mean and variability of climate due to global warming: future stream flows in Britain.* Journal of Hydrology, 270, 19-213.
5. **Arnell, N., Reynard, N., 1996,** *The Effects of Climate Change Due to Global Warming on River Flows in Great Britain.* Journal of Hydrology, 183 (3-4), 397-424. Available online at: http://www.sciencedirect.com/science
6. **Arnell, N.W. 2003a,** *Effects of climate change on river flows and groundwater recharge using the UKCIP02 scenarios.* Report to UK Water Industry Research Limited. University of Southampton.
7. **Barnett, D.N., Brown, S.J., Murphy, J.M., Sexton, D.M.H., Webb, M.J., 2 Barnett, D.N., Brown, S.J., Murphy, J.M., Sexton, D.M.H., Webb, M.J., 2006,** *Quantifying uncertainty in changes in extreme event frequency in response to doubled CO2 using a large ensemble of GCM simulations.* Clim Dyn, 26, 489–511.
8. **Barriopedro, D., Fischer, E.M., Luterbacher, J., Trigo, R.M., García-Herrera, R., 2011,** *The Hot Summer of 2010: Redrawing the Temperature Record Map of Europe.* Science, 332, 220–224.

9. **Benestad, R.E., 2004,** *Tentative probabilistic temperature scenarios for northern Europe.* Tellus A, 56, 89–101, DOI: 10.1111/j.16000870.2004.00039.x.

10. **Benestad, R.E., 2011,** *A new global set of downscaled temperature scenarios.* Journal of Climate, 24, 2080-2098.

11. **Beniston, M., Stephenson, D.B., Christensen, O.B., et al. 2007,** *Future extreme events in European climate: an exploration of regional climate model projections.* Climatic Change, 81, 71–95.

12. **Boberg, F., Berg, P., Thejll, P., Gotowski, W.J., Christensen, J.H., 2009,** *Improved confidence in climate change projections of precipitation further evaluated using daily statistics from ENSEMBLES models.* Climate Dynamics, 35, 1509-1520. DOI: 10.1007/s00382-009-0683-8.

13. **Boe´, J., Terray L., Habets F., Martin E., 2006,** *A simple statistical dynamical downscaling scheme based on weather types and conditional resampling.* Journal of Geophysical Research, 111, D23106, DOI: 10.1029/2005JD006889.

14. **Calanca, P., Kaifez Bogataj L., Halenka, T., Cloppet, E., Mika, J., 2008,** *Use of climate change scenarios in agrometeorological studies: past experiences and future needs.* COST Action 734: Impact of climate change and variability on European Agriculture: survey of agrometeorological practices and applications in Europe regarding climate change impacts, 237–266.

15. **Caldiz, D.O., Haverkort, A.J., Struik, P.C., 2002,** *Analysis of a complex crop production system in interdependent agro-ecological zones: a methodological approach for potatoes in Argentina.* Agric. Syst, 73, 297–311.

16. **Carter, T., 2007,** *General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment, Version 2, Task Group on Data and Scenario Support for Impact and Climate Assessment (TGICA).* Intergovernmental Panel on Climate Change (IPCC), Geneva, 66p. Available online at: http://www.ipcc-data.org/guidelines/TGICA_guidance_sdciaa_v2_final.pdf

17. **Challinor, A.J., Wheeler, T., Hemming, D., et al. 2009,** *Ensemble yield simulations: crop and climate uncertainties, sensitivity to temperature and genotypic adaptation to climate change.* Climate Research, 38, 117–127.

18. **Challinor, A.J., Wheeler, T.R., Craufurd, P.Q., et al. 2007,** *Adaptation of crops to climate change through genotypic responses to mean and extreme temperatures.* Agriculture Ecosystems and Environment, 119, 190–204.

19. **Challinor, A.J., Wheeler, T.R., Slingo, J.M., Hemming, D., 2005c,** *Quantification of physical and biological uncertainty in the simulation of the yield of a tropical crop using present day and doubled CO2 climates.* Philos. Trans. Roy. Soc., 360B, 1981–2194.

20. **Challinor, A.J., 2009,** *Developing adaptation options using climate and crop yield forecasting at seasonal to multi-decadal timescales.* Environ. Sci. and Policy, v.12, 453-465.

21. **Challinor, A.J., Osborne, T., Shaffrey, L., Weller, H., Morse, A., Wheeler, T., Vidale, P.L., 2009,** *Methods and Resources for Climate Impacts Research.* Bull. Amer. Meteor. Soc., 90, 836–848. DOI: http://dx.doi.org/10.1175/2008BAMS2403.1

22. **Clark, R.T., Brown, S.J., Murphy, J.M., 2006,** *Modeling Northern Hemisphere Summer Heat Extreme Changes and Their Uncertainties Using a Physics Ensemble of Climate Sensitivity Experiments.* Journal of Climate, 19, 4418–4435.

23. **Clark, R.T., Murphy, J.M., Brown, S.J., 2010,** *Do global warming targets limit heat wave risk?* Geophysical Research Letters, 37, DOI: 10.1029/2010GL043898.
24. **Cohen, J.L., Furtado, J.C., Barlow, M.A., Alexeev, V.A., Cherry, J.E., 2012,** *Arctic warming, increasing snow cover and widespread boreal winter cooling.* Environmental Research Letters 7, 014007, DOI: 10.1088/1748-9326/7/1/014007.
25. **Collins, M., and S. Knight, Eds., 2007,** *Ensembles and probabilities: A new era in the prediction of climate change.* Philos. Trans. Roy. Soc., 365A, 1955–2191.
26. **Cornwell, A.R., Harvey, A.D.D., 2007,** *Soil moisture: a residual problem underlying AGCMs.* Climatic Change, 84, 313–336.
27. **Covey, C., Achuta Rao K.M., Cubasch, U., Jones, P., Lambert, S.J., Mann, M.E., Phillips, T.J., Taylor, K.E., 2003,** *An overview of results from the coupled model intercomparison project.* Global and Planetary Change, 37, 103–133, DOI: 10.1016/S0921-8181(02)00193-5.
28. **Cox, P., Stephenson, D., 2007,** *A changing climate for prediction.* Science, 317, 207–208.
29. **Cruz, R. V., and Co authors, 2007,** Asia. *Climate Change 2007: Impacts, Adaptation and Vulnerability,* M. L. Parry et al., Eds., Cambridge University Press, 469–506.
30. **De´que´, M., Jones, R.G., Wild, M., Giorgi, F., et al. 2005,** *Global high resolution versus Limited Area Model climate change projections over Europe: quantifying confidence level from PRUDENCE results.* Climate Dynamics, 25, 653–670, DOI 10.1007/s00382-005-0052-1.
31. **Deser, C., Knutti, R., Solomon, S., Phillips, A.S., 2012,** Communication of the role of natural variability in future North American climate. Nature Climate *Change,* 2, 775–779, DOI: 10.1038/nclimate1562.
32. **Diaz-Nieto, J., Wilby, R., 2005,** *A Comparison of Statistical Downscaling and Climate Change Factor Methods: Impacts on Low Flows in the River Thames, United Kingdom.* Climatic Change, 69 (2), 245-268
33. **Dole, R., Hoerling, M., Perlwitz, J., Eischeid, J., Pegion, P., Zhang, T., Quan, X.-W., Xu, T., Murray, D., 2011,** *Was there a basis for anticipating the 2010 Russian heat wave?* Geophysical Research Letters 38, DOI: 10.1029/2010GL046582.
34. **Easterling, W. E. and coauthors, 2007,** *Food, fibre and forest products.* Climate Change 2007: Impacts, Adaptation and Vulnerability, M. L. Parry et al., Eds., Cambridge University Press, 273–313.
35. **Eckhardt, K., Ulbricht, U., 2003,** Potential impacts of climate change on groundwater recharge and stream flow in a central European low mountain range. // Journal of Hydrology, 284, p.244-252.
36. **Fischer, E., Schär, C., 2010,** *Consistent geographical patterns of changes in high-impact European heat waves.* Nature Geoscience, 3, 398–403. DOI: 10.1038/ngeo866.
37. **Fischer, E.M., Lawrence, D.M., Sanderson, B.M., 2011,** *Quantifying uncertainties in projections of extremes - a perturbed land surface parameter experiment.* Clim. Dyn, 37, 1381–1398.
38. **Fischer, E.M., Schär, C., 2009,** *Future changes in daily summer temperature variability: driving processes and role for temperature extremes.* Clim. Dyn, 33, 917–935.
39. **Fischer, E.M., Seneviratne, S.I., Lüthi, D., Schär, C., 2007a,** *Contribution of land-atmosphere coupling to recent European summer heat waves.* Geophysical Research Letters, 34, L06707, DOI: 10.1029/2006GL029068.

40. **Fischer, E.M., Seneviratne, S.I., Vidale, P.L., Lüthi, D., Schär, C., 2007b,** Soil Moisture–Atmosphere Interactions during the 2003 European Summer Heat Wave. *Journal of Climate* 20, 5081–5099.

41. **Fischer, G., Shah, M., Tubiello, F.N., Van Velhuizen, H., 2005,** *Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080.* Phil. Trans. R. Soc. Lond., B 360, 2067–2083.

42. **Food and Agricultural Organization (FAO), 1978,** *Report on the agro-ecological zones project.* FAO, Rome.

43. **Gallup, J.L., Sachs, J.D., 2000,** *Agriculture, climate, and technology: why are the tropics falling behind?* Am. J. Agric. Econ., 82, 731–737.

44. **Geerts, S., Raes, D., Garcia, M., Del Castillo, C., Buytaert, W., 2006,** *Agro-climatic suitability mapping for crop production in the Bolivian Altiplano: a case study for quinoa.* Agric. Forest Meteorology, 139, 399–412.

45. **Giorgi, F., Mearns, L.O. 1999,** *Regional climate modeling revisited. An introduction to the special issue.* Journal of Geophysical Research, 104, 6335–6352.

46. **Giorgi, F., 2005,** *Climate change prediction.* Climatic Change, 73, 239–265, DOI: 10.1007/s10584-005-6857-4.

47. **Hagedorn, R., Doblas-Reyes, F. J., Palmer, T.N., 2005,** *The rationale behind the success of multi-model ensembles in seasonal forecasting. I. Basic concept.* Tellus, 57A, 219–233.

48. **Hansen, J.W., Jones, J.W., 2000,** *Scaling-up crop models for climatic variability applications.* Agric. Syst., 65, 43–72.

49. **Haugen, J.E., Iversen, T., 2008,** *Response in extremes of daily precipitation and wind from a downscaled multi-model ensemble of anthropogenic global climate change scenarios.* Tellus Series A - Dynamic Meteorology and Oceanography, 60 (3), 411–426.

50. **Haylock, M.R., Hofstra, N., Klein Tank, A.M.G., Klok, E.J., Jones, P.D., New, M., 2008,** *A European daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006.* Journal of Geophysical Research 113, D20, DOI:10.1029/2008JD010201

51. **Hellström, C., Chen., D. 2003**, *Statistical downscaling based on dynamically downscaled predictors: Application to monthly precipitation in Sweden.* Advances in Atmospheric Sciences, 20, 951–958.

52. **Hirschi, M., Seneviratne, S.I., Alexandrov, V., Boberg, F., Boroneant, C., Christensen, O.B., Formayer, H., Orlowsky, B., Stepanek, P., 2011.** *Observational evidence for soil-moisture impact on hot extremes in southeastern Europe*. Nature Geoscience, 4, 17–21, DOI: http://dx.doi.org/10.1038./NGEO1032.

53. **Horton, R., et al. 2010,** *"New York City Panel on Climate Change 2010 Report, Chapter 3: Climate Observations and Projections."* New York Academy of Sciences 1196, p.41–62. Available online at: http://onlinelibrary.wiley.com/doi/10.1111/j.1749-6632.2009.05314.x/full.

54. **Intergovernmental Panel on Climate Change (IPCC), 2001a,** *Climate change 2001: The scientific basis.* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

55. **Intergovernmental Panel on Climate Change (IPCC), 2001b,** *Climate change 2001: Impacts, adaptation, and vulnerability.* Contribution of Working Group II to the Third Assess-

ment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

56. **IPCC, 2007a,** *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. (Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis M., Averyt, K. B., Tignor, M., Miller, H.L. eds.). Cambridge University Press, Cambridge, http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html.

57. **IPCC, 2007b,** *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Report of the Intergovernmental Panel on Climate Change. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis M., Averyt, K. B., Tignor, M., Miller, H.L. eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

58. **Jones, R.N., 2000,** *Managing uncertainty in climate change projections–Issues for impacts assessments.* Climatic Change, 45, 403–419, DOI: 10.1023/A: 1005551626280.

59. **Jones, R.G., Noguer, M., Hassell, D.C., et al. 2004,** *Generating high resolution climate change scenarios using PRECIS*. Met Office Hadley Centre, Exeter, UK, 40pp.

60. **Kjellström, E., Bärring, L., Jacob, D., Jones, R., Lenderink, G., Schär, C., 2007,** *Modelling daily temperature extremes: recent climate and future changes over Europe. Climatic Change* 81, 249–265.

61. **Kodra, E., Steinhaeuser, K., Ganguly, A.R., 2011,** *Persisting cold extremes under 21st-century warming scenarios*. Geophysical Research Letters 38, L08705, DOI: 10.1029/2011GL047103.

62. **Lejenäs, H., Ed., 2005,** *Development of a European Multi-Model Ensemble System for Seasonal to Interannual Prediction (DEMETER)*. Tellus, 57A, 217–512.

63. **Lenderink, G., Ulden, A. van, Hurk, B. van den, Meijgaard, E. van, 2007,** *Summertime inter-annual temperature variability in an ensemble of regional model simulations: analysis of the surface energy budget*. Climatic Change, 81, 233–247.

64. **Machenhauer, B., Windelband, M., Botzet, M., Christensen, J.H., De´ que´, M., Jones, J., Ruti, P.M., Visconti, G., 1998,** *Validation and analysis of regional present-day climate and climate change simulations over Europe*. Max-Planck Institutfuür Meteorologie. 87pp.

65. **McAveney, B.J., Covey, C., Joussaume, S., Kattsov, V., Kitoh, A., Ogana, W., Pitman, A.J., et al., 2001,** *Model evaluation*. In Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., Johnson, C.A. eds). Cambridge University Press: Cambridge and New York, 881p.

66. **Mearns, L.O., Bogardi, I., Matyasovsky, I., Palecki, M., 1999,** *Comparison of climate change scenarios generated from regional climate model experiments and statistical downscaling*. Journal of Geophysical Research, 104, 6603–6621.

67. **Mearns, L. O., Ed., 2003,** *Issues in the Impacts of Climate Variability and Change on Agriculture: Applications to the Southeastern United States*. Kluwer Academic, 216 pp.

68. **Mearns, L.O., Hulme, M., Carter, T.R., Leemans, R., Lal, M., Whetton, P., 2001**, *Climate scenario development*. In Climate Change 2001: The Scientific Basis, (Houghton, J.T., Ding,

Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Xiaosu, D., Maskell, K., eds.). Cambridge University Press, New York, 2001. Available at http://www.grida.no/climate/ipcc_tar/wg1/pdf/TAR-13.PDF.

69. **Meehl, G. A., Covey, C., Delworth, T., Latif, M., McAvaney, B. Mitchell, J.F.B., Stouffer, R.J., Taylor, K. E., 2007a,** *The WCRP CMIP3 multi-model dataset - A new era in climate change research.* Bull. Am. Meteorology Soc., 88, 1383–1394, DOI: 10.1175/BAMS-88-9-1383.
70. **Ministry of Ecology, Construction and Territory Development/UNDP Moldova, 2000,** *First National Communication of the Republic of Moldova developed under the United Nations Framework Convention on Climate Change.* Coord.: Bobeica, V., Petrusevschi, M., Synthesis Team: Ciubotaru, V., Scorpan, V., Taranu, M., Perciun, A. Chisinau, 74 p.
71. **Ministry of Environment and Natural Resources / United Nations Environment Programme, 2009**, *Second National Communication of the Republic of Moldova under the United Nations Framework Climate Change Convention.* Coord.: Ivanov, V., Manful, G. Synthesis Team: Scorpan, V., Taranu, M., Todos P., Boian, I. Chisinau, 316 p.
72. **Murphy, J.M., Sexton, D.M.H., Barnett, D.N., Jones, G.S., Webb, M.J., Collins, M., Stainforth, D.A., 2004,** *Quantification of modelling uncertainties in a large ensemble of climate change simulations.* Nature, 430, 768–772.
73. **Nakicenovic, N., et al. 2000,** *Special Report on Emissions Scenarios.* A Special Report of Working Group III of the IPCC. Cambridge University Press, 599p.
74. **Nikulin, G., Kjellstrom, E., Hansson, U., Stanberg, G., Ullestrig, A., 2011,** *Evaluation and future projections of temperature, precipitation and wind extremes over Europe in an ensemble of regional climate simulations.* Tellus Series, A 64, 41–55. DOI:10.1111/j.1600-0870.2010.00466.x.
75. **Orlowsky, B., Seneviratne, S.I., 2012,** *Global changes in extreme events: regional and seasonal dimension.* Climatic Change, 110, 669–696.
76. **Palmer, T.N., and Coauthors, 2004,** *Development of a European Multi-Model Ensemble System for Seasonal to Inter-Annual Prediction (DEMETER).* Bull. Amer. Meteor. Soc., 85, 853–872.
77. **Palmer, T.N., Doblas-Reyes, F.J., Hagedorn, R., Weisheimer, A., 2005,** *Probabilistic prediction of climate using multimodel ensembles: From basics to applications.* Philos. Trans. Roy. Soc., 360B, 1991–1998, DOI: 10.1098/ rstb.2005.1750.
78. **Parry, M., Rosenzweig, C., Livermore, M., 2005,** *Climate change and risk global food supply and hunger.* Philosophical Transactions of the Royal Society B-Biological Sciences, 360, 2125–2138.
79. **Petoukhov, V., Semenov, V.A., 2010,** *A link between reduced Barents-Kara sea ice and cold winter extremes over northern continents.* Journal of Geophysical Research: Atmospheres, 115, D21111, DOI: 10.1029/2009JD013568.
80. **Prudhomme, C., Reynard, N., Crooks, S., 2002,** *Downscaling of global climate models for flood frequency analysis: where are we now?* Hydrological Processes, 16, 1137-1150.
81. **Randall, D.A., Ringler, T.D., Heikes, R.P., Jones, P., Baumgardner, J., 2002,** *Climate modeling with spherical geodesic grids.* Comput. Sci. Eng., 4, 32–41.

82. **Reilly, J., Tubiello, F.N., McCarl B., Melillo, J., 2001,** *Climate change and agriculture in the United States.* In: Melillo, J., Janetos, G., Karl T., eds. Climate change impacts on the United States. Foundation, United States Global Change Research Program. Cambridge: Cambridge University Press.

83. **Schär, C., Vidale, P.L., Lüthi, D., Frei, C., Häberli, C., Linger, M.A., Appenzeller, C., 2004,** *The role of increasing temperature variability in European summer heat waves. Nature* 427, 332–336.

84. **Schellnhuber, J., Cramer, W., Nakicenovic, N., Wigley, T. M. L., Yohe, G. Eds., 2006,** *Avoiding Dangerous Climate Change.* Cambridge University Press, 392 pp.

85. **Seneviratne, S.I., Nicholls, N., Easterling, D., Goodess, C.M., Kanae, S., Kossin, J., Luo, Y., Marengo, J., McInnes, K., Rahimi, M., Reichstein, M., Sorteberg, A., Vera, C. and Zhang, X., 2012,** *Changes in Climate Extremes and their Impacts on the Natural Physical Environment.* In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC), 109–230. Cambridge University Press, Cambridge. http://ipccwg2.gov/SREX/contributors/chapter/chapter-3.

86. **Seneviratne, S.I., Lüthi, D., Litschi, M., Schär, C., 2006,** *Land–atmosphere coupling and climate change in Europe.* Nature, 443, 205–209.

87. **Seppelt, R., 2000,** *Regionalised optimum control problems for agroecosystem management.* Ecol. Model., 131, 121–132.

88. **Sillman, J., Roeckner, E., 2008,** *Indices of extreme events in projections of anthropogenic climate change.* Climatic Change, 86 (1), 83–104. DOI: 10.1007/s10584-007-9308-6.

89. **Sillmann, J., Croci-Maspoli, M., 2009,** *Present and future atmospheric blocking and its impact on European mean and extreme climate.* Geophysical Research Letters, 36, DOI: 10.1029/2009/GL038259.

90. **Stainforth, D.A., and Coauthors, 2005,** *Uncertainty in predictions of the climate response to rising levels of greenhouse gases.* Nature, 433, 403–406.

91. **Taranu Lilia, 2012,** *Constructing Regional Climate Scenarios for Vulnerability and Adaptation Assessment.* Report of National Consultant prepared for UNEP/GEF Project: "Enabling Activities for the preparation of the Third National Communication under the United Nations Framework Climate Change Convention." 75p (unpublished).

92. **Taylor, K.E., 2001,** *Summarizing multiple aspects of model performance in a single diagram.* Journal of Geophysical Research, 106, 7183–7192, DOI: 10.1029/2000JD900719.

93. **Tebaldi, C., Hayhoe, K., Arblaster, J.M., Meehl, G.A., 2006,** *Going to the extremes; An intercomparison of model-simulated historical and future changes in extreme events.* Climatic Change, 79, 185–211.

94. **Troccoli, A., Palmer, T.N. 2007,** *Ensemble decadal prediction from analysed initial conditions.* Philos. Trans. Roy. Soc., 365A, 2179–2191, DOI:10.1098/rsta.2007.2079.

95. **Tubiello, F.N., Fischer, G., 2007,** *Reducing climate change impacts on agriculture: global and regional effects of mitigation, 2000–2080.* Technological Forecasting and Social Change, 74, 1030–1056.

96. **UNDP, 2009/2010 National Human Development Report, 2010,** "Climate Change in Moldova: Socioeconomic Impact and Policy Options for Adaptation". 224p.

97. **UNDP, 2010,** *Mapping Climate Change Vulnerability and Impact Scenarios: A Guidebook for Sub-National Planners.* 91p.

98. **Vidal, J.-P., Wade, S., 2008,** *A framework for developing high-resolution multi-model climate projections: 21st century scenarios for the UK.* Int. J. Climatology, 28, 843–858, DOI: 10.1002/joc.1593.

99. **Vidale, P.L., Lüthi, D., Wegmann, R., Schär, C., 2007,** *European summer climate variability in a heterogeneous multi-model ensemble.* Climatic Change, 81, 209–232.

100. **WCRP, 2007,** *World Climate Research Programme Workshop WCRP, 2007*: *World Climate Research Programme Workshop on Seasonal Prediction.* Position Paper. Available online at www.clivar.org/organization/wgsip/spw/spw_position.php.

101. **Wilby, R.L, Charles, S.P., Zorita, E., Timbal, B., Whetton, P., Mearns, L.O., 2004,** *Guidelines for Use of Climate Scenarios Developed from Statistical Downscaling Methods*. IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA), Available online at: http://www.ipcc-data.org/guidelines/dgm_no2_v1_09_2004.pdf.

102. **Williams, C.L., Liebman, M., Edwards, J.W., James, D.E., Singer, J.W., Arritt, R., Herzmann, D., 2008,** *Patterns of regional yield stability in association with regional environmental characteristics.* Crop Sci., 48, 1545–1559.

103. **World Meteorological Organization, 1989,** *Calculation of Monthly and Annual 30-Year Standard Normals.* WCDP-No. 10, WMO-TD/No. 341, Geneva: World Meteorological Organization.

Chapter 3: Climate Change and Agroclimatic Condition in the Republic of Moldova

3.1. Temperature – Based Agroclimatic Indices

Climate change is expected to affect both regional and global food production through changes in overall agroclimatic conditions (Fischer et al., 2005; Solomon et al., 2007). The observed warming trend throughout Europe (+0.90°C from 1901 to 2005) is well established (Alcamo et al., 2007). 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 (Easterling et al., 2007). Several climate projections for 2050 exceed this 2°C threshold (Giorgi & Lionello, 2008; Taranu et al., 2012). 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 (Ciscar et al., 2009; COM, 2009; NCCAS, 2012).

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 (Jones et al., 2003; Porter & Semenov, 2005; Lavalle et al., 2009; Quiroga & Iglesias, 2009; Iglesias et al., 2010). Technological development (e.g., new crop varieties and improved cropping practices) could ameliorate the effects of climate change (Ewert et al., 2005; Peltonen-Sainio et al., 2009a). 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 (e.g., Cassman et al., 2003; Ewert et al., 2005; Lobell et al., 2009), or due to policies such as stricter environmental regulation (e.g., Finger, 2010). To date, there have been a limited number of reports (Kenny & Harrison, 1993; Trnka, 2011) dealing with the changes expected in agroclimatic parameters at the pan-European scale, and many of these are review articles (Olesen & Bindi, 2002; Lavalle et al., 2009; Olesen et al., 2011). Most studies of climate change impacts on crop yields apply either statistical models (Lobell and Burke 2010) or process-based crop simulation models (Rötter et al., 2011b; White et al., 2011; Osborne et al., 2013). 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 (Nelson et al., 2009; Ewert et al., 2011;

Angulo et al., 2013). 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 (Semenov and Halford 2009; Rötter et al., 2011 a, b; Rosenzweig et al., 2013). 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 (Harrison and Butterfield, 1996; Ramankutty et al., 2002; Fisher et al., 2005; Trnka et al., 2011; Rötter et al., 2013).

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 and 2080s) and space (northern, central and southern AEZs) under an ensemble of 10 GCM for three SRES A2 (high), A1B (medium) and B1 (low) emission scenarios.

3.1.1. 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 **Table 3-1** are presented the definitions of the agro-climatic indices analyzed in this study.

Table 3-1: The definitions of agro-climatic indices have been used in the assessment

Indices	Abbrevia-tion	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	**$GSS_{5, 10, 15°C}$**	The earliest date of series of days with the mean daily air temperature of ≥ 5, 10 and 15°C that is the beginning of such cumulated series of daily mean temperature deviations from the threshold value of 5, 10 and 15°C that do not have negative values up to the end of the first 6 month of the year.	Date
End of Growing Season	**$GSE_{5, 10, 15°C}$**	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 ≤ 5, 10 and 15°C that is the beginning of such cumulated series of daily mean temperature deviations from the threshold value of 5, 10 and 15°C that do not have positive values up to the end of a year.	Date
Length of Growing Season	**$LGS_{5, 10, 15°C}$**	Number of days between $GSS_{5, 10, 15°C}$ and $GSE_{5, 10, 15°C}$	Days
Active Growing Degree Days	**$AGDD_{5, 10°C}$**	Accumulated sum of temperature degrees above 5°C and 10°C	°C
Effective Growing Degree Days	**$EGDD_{5, 10°C}$**	Accumulated sum of temperature degrees above 5°C and 10°C minus T_{base}	°C

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 0°C 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 0°C is considered a frost-free day, as frost often occurs when daily average temperature is below 0°C. The length of the growing season (LGS) is another widely used index. In general, the 5°C mean temperature (T_{avg}) threshold is widely accepted for determining the thermal growing season, in particular for mid and high latitudes (Carter 1998; Frich et al., 2002; Jones et al., 2002, Menzel et al., 2003). 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 ≥ 5, 10 and 15°C that is the beginning of such cumulated series of daily mean temperature deviations from the threshold value of 5, 10 and 15°C 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 ≤ 5, 10 and 15°C that is the beginning of such cumulated series of daily mean temperature deviations from the threshold value of 5, 10 and 15°C 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. Different indices are used to quantify that process. 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 $AGDD_{Tb}$ for two different temperature thresholds (5 and 10°C) was computed according to:

$$AGDD_{T_b} = \sum_{k=1}^{n} T_{avg}\ , \quad (3.1)$$

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°C) was computed according to:

$$EGDD_{T_b} = \sum_{k=1}^{n} \left(T_{avg} - T_b\right), \quad (3.2)$$

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 $T_{avg} < T_b$.

3.1.2. Frost Indices

In the future, due to the FFD delay and earliest occurrence of LFD, in the Republic of Moldova can be expected a substantial decrease in the FP. The duration of the FP with temperatures below 0°C 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 SRES B1) to 17 days (under SRES A2) in the northern AEZ. In central and southern AEZs the duration of the FP will decrease in both scenarios by 9-11 days, respectively. To be noted, that actually observed decrease for FP over the last two decades (1991-2010) was in northern AEZ ↘ -18, in central AEZs ↘ -14, and in southern AEZs ↘ -11 days, compared to the baseline climate. By the end of 2080s, duration of the FP in central and southern AEZs will decrease significantly from 44-56 days (SRES B1) to 71-75 days (SRES A2). The lowest decrease is expected in northern AEZ from 33 to 68 days (**Table 3-2**).

Table 3-2: Projected Ensemble Changes of the $FFD_{0°C}$, $LFD_{0°C}$ Dates and FP when Average Daily Air Temperature is below 0°C (Days) in XXI Century for SRES A2, A1B and B1 Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990)

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).*

3.1.3. Growing Season and Frost Free Period

In the future, due to the earlier start of spring and autumn elongation, in the Republic of Moldova can be expected a substantial increase in the FFP.

The duration of the FFP with temperatures above 0°C 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 SRES B1) to 17 days (under SRES A2) in northern AEZ.

In central 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 across northern AEZ ↗ +18, central AEZ ↗ +14, and southern AEZ ↗+11 days, compared to baseline climate.

By the end of 2080s, duration of the FFP in central and southern AEZs will increase significantly from 44-56 days (SRES B1) to 71-75 days (SRES A2). The lowest growth is expected in northern AEZ, from 33 to 68 days (**Table 3-3**).

Table 3-3: Projected Ensemble Changes of the $LSF_{0°C}$, $FFD_{0°C}$, (Dates) and FFP (Days) in XXI Century for SRES A2, A1B and B1 Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990)

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 **Table 3-4**, reveal that the $LGS_{5°C}$ will elongate, and its increase by the 2020s in northern and southern AEZs can be from a week (SRES A2) up to 5-9 days (SRES B1), respectively. In central region the duration of 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 northern AEZ, ↗ +3 days in central AEZ, and ↗ +8 days in southern AEZ. By the end of the 21th century the $LGS_{5°C}$ will increase substantially from 14-21 (SRES B1) to 30-32 (SRES A2) days in northern and southern AEZs. The tendency to maximum increase of the $LGS_{5°C}$ in the central AEZ will persist, and by the 2080's is expected that such periods will be 24-36 days longer.

Table 3-4: Projected Ensemble Changes of the $GSS_{5°C}$, $GSE_{5°C}$ (Dates) and $LGS_{5°C}$ (Days) in XXI Century for SRES A2, A1B and B1 Emission Scenarios Relative to the Climatological Baseline Period (1961-1990)

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).*

For all AEZs 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 days in northern AEZ; 14 to 23 days in central AEZ and 14 to 20 days later in southern AEZ), while the spring vegetation will start earlier than usual from 7 to 12 days across northern AEZ, from 9 to 13 days in central AEZ and from 7 to 10 days before in southern AEZ.

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 southern and central AEZs. The lowest growth by 7-10 days is possible in northern AEZ. In fact, the observed changes in the $LGS_{10°C}$ over the last 20 years were as follows: in northern AEZ ↘ -1 day, in central AEZ ↗ +6 days, and ↗ +5 days in southern AEZ. By the end of 2080s the $LGS_{10°C}$ will increase substantially from 32-34 (SRES B1) to 41-42 (SRES A2) days in central and southern AEZs. The tendency to minimum increase of the $LGS_{10°C}$ in northern AEZ will persist, and by the 2080s would be expected that such periods will be only 25-37 days longer (**Table 3-5**).

Table 3-5: Projected Ensemble Changes of the $GSS_{10°C}$, $GSE_{10°C}$ (Dates) and $LGS_{10°C}$ (Days) in XXI Century for SRES A2, A1B and B1 Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990)

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).*

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 northern AEZ ↗ +1 day, in the central AEZ ↘ -6 days and in the southern AEZ ↗ +4 days. In connection to climate change is expected that the $LGS_{15°C}$ will increase by 2020s from 6 to 9 days in 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 (SRES B1) to 33-34 (SRES A2) days over central and southern AEZs. The tendency to maximum increase of the $LGS_{15°C}$ in northern areas will persist, and by the 2080s would be expected that such periods will be from 27 (SRES B1) to 40 (SRES A2) days longer (**Table 3-6**).

Table 3-6: Projected Ensemble Changes of the $GSS_{15°C}$, $GSE_{15°C}$ (Dates) and $LGS_{15°C}$ (Days) in XXI Century for SRES A2, A1B and B1 Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990)

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).*

According to (Rinaldi, 2004; Grassini *et al.,* 2011) 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 (Taranu et al., 2009).

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 (Taranu et al., 2009; Babinszky et al., 2011).

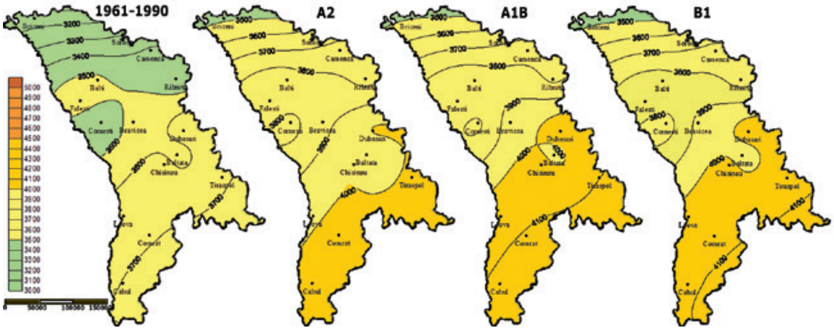
3.1.4. Growing Degree Days ($AGDD_{5,\ 10°C}$ and $EGDD_{5,\ 10°C}$)

The $AGDD_{5°C}$ and/or $EGDD_{5°C}$ for the baseline climate vary from 3105 and/or 1995°C in the northern AEZ up to 3652 and/or 2472°C in the southern AEZ. 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%[1], with maximum increase in northern AEZ.

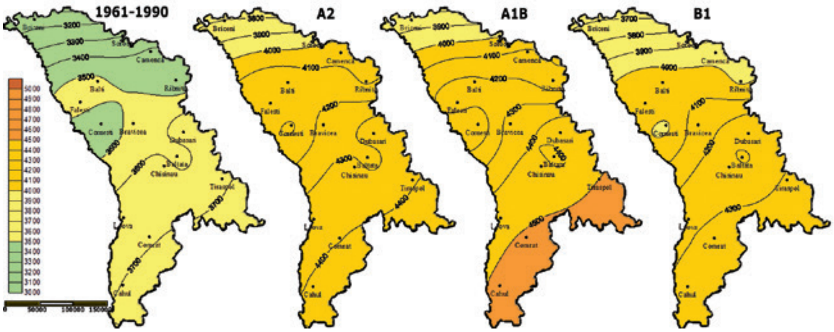
In fact, the observed changes in the $AGDD_{5°C}$ and/or $EGDD_{5°C}$ over the last 20 years were as follows: for northern AEZ +6.2 and/or 10.1 %, + 5.5 and/or 7.5% in central AEZ, and +4.6 and/or 6.6% in southern AEZ. By the end of 2080s the $AGDD_{5°C}$ and/or $EGDD_{5°C}$ would increase significantly under SRES A2 high emission scenario by 34-37%, respectively by 45-50%, and will make from 4267 and 2996°C over northern AEZ to 4911 and 3575°C in southern AEZ; slightly lower growth is expected according to SRES B1 low emission scenario by 21-23% and respectively by 28-30%, varying from 3779 and 2599°C across northern AEZ, to 4434 and 3155°C in southern AEZ, relative to the baseline climate (**Table 3-7** and **Figure 3-1**).

[1] Here and throughout the text the first pair of numbers corresponds to $AGDD_{5°C}$, the second one $EGDD_{5°C}$.

2020s



2050s



2080s

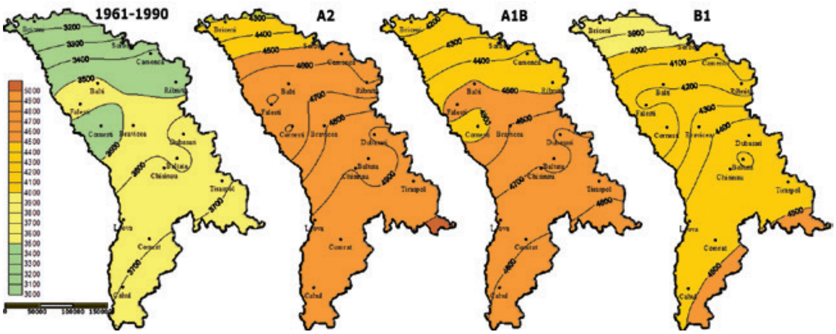


Figure 3-1: Projected Multi-Model Ensemble $AGDD_{5°C}$ Spatial Development throughout the Republic of Moldova

Table 3-7: Projected Ensemble Changes in the $AGDD_{5°C}$ and $EGDD_{5°C}$ in XXI Century for SRES A2, A1B and B1 Emission Scenarios, Relative to the Climatological Baseline Period

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).*

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%[2] under SRES A2 high emission scenario; and by 11-16 and/or 20-23% according to the SRES B1 low emission scenario. 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 northern, + 7.2 and/or 12.3% in central and +6.5 and/or 11.3 % in southern AEZs (**Table 3-8**).

[2] Here and throughout the text the first pair of number corresponds to $AGDD_{10°C}$, the second one $EGDD_{10°C}$.

Table 3-8: Projected Ensemble Changes in the $AGDD_{10°C}$ and $EGDD_{10°C}$ in XXI Century for SRES A2, A1B and B1 Emission Scenarios, Relative to the Climatological Baseline Period

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 (2745°C); Chisinau (3175°C); Cahul (3222°C);* $\Sigma T_{ef>10°C}$ *- Briceni (1025°C); Chisinau (1375°C); Cahul (1402°C).*

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 SRES A2 high emission scenario, and will make from 3930 and/or 1834°C for northern AEZ to 4600 and/or 2347°C in southern AEZ; slightly lower growth is projected according to the SRES B1 low emission scenario by 27-28 and/or 41-48%, and will make from 3481 and/or 1514°C for northern AEZ to 4128 and/or 1983°C in southern AEZ, relative to the baseline climate.

In **Figure 3-2** is presented the multi-model ensemble estimation of spatial distribution of the Republic of Moldova's $AGDD_{10°C}$ development in the XXI century, for SRES A2, A1B and B1 emission scenarios, relative to the baseline climate (1961-1990).

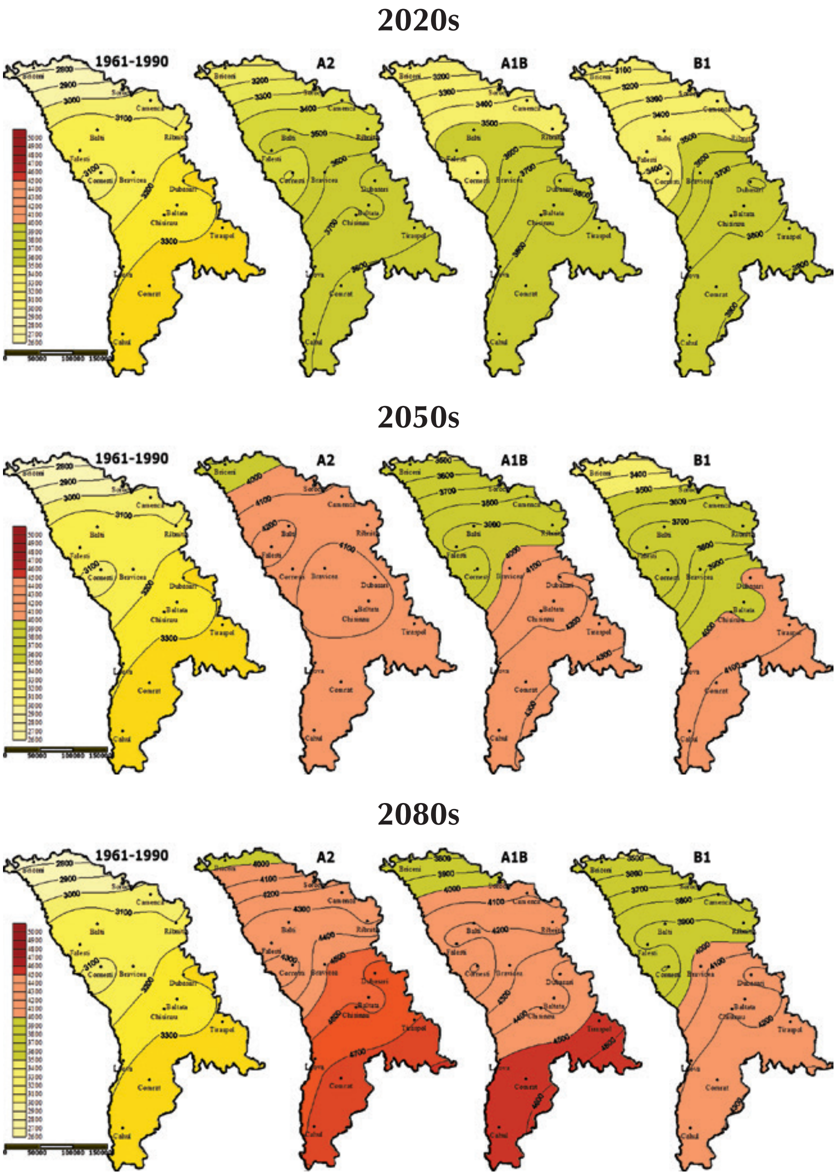


Figure 3-2: Projected Multi-Model Ensemble $AGDD_{10°C}$ Spatial Development throughout the Republic of Moldova

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 SRES A2 high emission scenario from 4000 to 4700°C and/or from 3500 to 4300°C under the SRES B1 low emission scenario.

CONCLUSIONS

In this chapter 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 5°C, 10°C and 15°C; 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's 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 (high), A1B (medium) and B1 (low) 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, regional and sectoral (specifically for agriculture sector) adaptation strategies and plans. 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.

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.

In the above mentioned context, the main conclusions are as following:

1. In the future, due to the earlier start of spring and autumn elongation, in the Republic of Moldova it can be expected a substantial increase in the FFP. By the end of 2080s, duration of the FFP in central and southern AEZs will increase significantly from 44-56 days (SRES B1) to 71-75 days (SRES A2). The lowest growth from 33 to 68 days is expected across the northern AEZ.
2. The $LGS_{5°C}$ will increase from 14-21 (SRES B1) to 30-32 (SRES A2) days in northern and southern AEZs, the maximum increase by 24-36 days is projected in 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 AEZ; from 14 to 23 days in the central AEZ and from 14 to 20 days later in the southern AEZ, while the spring vegetation will start earlier than usual from 7 to 12 days in the northern AEZ; from 9 to 13 days in the central AEZ and from 7 to 10 days before in the southern AEZ.
4. The $LGS_{10°C}$ will increase from 32-34 (SRES B1) to 41-42 (SRES A2) days in the central and southern AEZs, the minimum increase about 25-37 days is expected in northern areas of the Republic of Moldova by the 2080s.
5. The $LGS_{15°C}$ will increase from 21-25 (SRES B1) to 33-34 (SRES A2) days in the central and southern AEZs. The tendency to maximum increase of the $LGS_{15°C}$ in 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 SRES A2 high emission scenario by 34-37% and/or 45-50%, and will make from 4267 and/or 2996°C in the northern AEZ to 4911 and/or 3575°C in the southern AEZ; slightly lower growth is expected according to SRES B1 low emission scenario by 21-23% and/or 28-30%, varying from 3779 and/or 2599°C across the northern AEZ, to 4434 and/or 3155°C in southern AEZ 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 SRES A2, and will make from 3930 and/or 1834°C over the northern AEZ to 4600 and/or 2347°C in the southern AEZ; slightly lower growth is projected according SRES B1, by 27-28% and/or 48-41% and will make from 3481 and/or 1514°C across the northern AEZ to 4128 and/or 1983°C in the southern AEZ, relative to the baseline climate.

3.2. Humidity Indices

The warming trend and spatially variable changes in rainfall have already affected managed ecosystems (Easterling et al., 2007). For instance, the droughts and heat waves from 2007 and 2012 years in the Republic of Moldova had major impacts on agricultural systems and society by decreasing the quantity and quality of the harvests, particularly in central and southern AEZs. The very high air temperature and solar radiation resulted in a notable increase in the crops' water consumption. This, together with the summer dry spell, resulted in an acute depletion of soil water and lowered crop yields. Total agriculture damages in 2007 were estimated to 12 billion lei, while those in 2012 respectively to 5 billion lei. In 2012 the major damage (73% from the total) was for the group II crops (maize, sunflower, sugar beet). In the case of group I crops (winter wheat, barley, rape), the southern AEZ was the most affected region, accounting for 49% out of total damage caused to this group of crops.

Due to reduction in the level of fodder availability (by 60%), around 45% of the livestock (mainly, poultry and swine) was slaughtered in rural areas (UNDP, 2012). At the national level, the impact of the 2012 year drought on crop production was moderate in the northern AEZ; the central AEZ was very affected, while the southern AEZ was severely affected. Severely affected southern areas accounted for around 11.7% of the total population (420.000 residents) and 15.4% (5.217 km^2) of the total territory of Republic of Moldova (Drought Moldova MAFI Assessment Report, 2012).

Climate change in Republic of Moldova is very likely to reduce ecosystem services such as climate regulation potential, fresh water availability, water regulation, soil fertility, sustainable agricultural productivity, biodiversity, pest regulation, and etc. Furthermore, impacts may be unevenly distributed between northern (some positive, some negative), central and southern AEZs (nearly all negative) according to NCCAS (2012).

Taranu L. (2013) has revealed a sequential reduction in yield of major agricultural crops in the Republic of Moldova, under the IPCC SRES A2, A1B and B1 scenarios by 2020s, 2050s and 2080 under a changing climate, drier conditions and rising temperatures. Similar yield reductions have also been estimated for Eastern Europe, with increased variability in yield, especially in the steppe regions (Maracchi et al., 2004).

Over the last three years in the Republic of Moldova have been produced high-resolution maps representing the projected changes in climate variables, such as mean temperature and precipitation, and projected impacts as temperature-based agroclimatic indices (http://www.clima.md/public/files/ProiectiiClima/en/ClimateMaps.html). These maps are very useful for policy-making and awareness-raising purposes. They illustrate what can be expected in the Republic of Moldova by the end of the century, according to the IPCC4 SRES A2, A1B, and B1 scenarios. Maps with projections of future changes in temperature and precipitation are based on 10 global coupled atmosphere ocean general circulation models (AOGCMs) made available by the World Climate Research Program (WCRP) Coupled Models Intercomparison Program Phase 3 (CMIP3) downloaded from (http://

www.ipcc-data.org/gcm/monthly/SRES_AR4/index.html) and processed by the modeling team of the Climate Change Office within the TNC Project (TNC, 2013).

Changes are projected for 2020s, 2050s and 2080s relative to reference period (1961-1990). Uncertainties in the projection of future precipitation complicate the assessment of humidity agroclimatic indices and future crop yield losses. This is particularly true for the Republic of Moldova, where humidity supply is a critical factor for agriculture now and will remain in future. In such areas, model results diverge to a great extent, depending on the scenarios in use and the model itself (Taranu, 2012).

The main objective of this work was: (i) to develop a set of humidity 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 humidity agroclimatic indices is likely to change in time (by the 2020s, 2050s, 2080s) and space (northern, central and southern AEZs) under an ensemble of 10 GCM for three SRES A2 (high), A1B (medium) and B1 (low) emission scenarios.

3.2.1. Data and Methods

In this study, 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 10 GCMs for three SRES A2, A1B and B1 emission scenarios of greenhouse gases and aerosols see more in (Taranu et al., 2012).

Ivanov's aridity index (*AI*) (Иванов, 1962) was used to perform analysis of the temperature/humidity ratio development:

$$E = 0.0018(25 + T)^2(100 - \alpha), \quad (3.3)$$

$$AI = \frac{P}{E}, \quad (3.4)$$

where E - the potential evaporation (mm), T - is average monthly air temperature (°C), α – relative humidity (%), and P - the sum of precipitation values (mm).

Regression equations of relationship of Potential Evaporation (*E*, mm) and Aridity Index (*AI*) with average monthly air temperature and precipitation for baseline period (1960-1990) is presented in the **Tables 3-9** and **3-10**.

Table 3-9: The Relationship of Potential Evaporation *(E, mm)* with Average Air Temperature *(T, ^0C)* and Precipitation *(P, mm)*

Month	R-squared	P-value	Regression equation
Northern AEZ			
January	78.02	**0.0000**	$E_{Jan} = 18.85 + 1.06*T_{Jan} - 0.04*P_{Jan}$
February	57.83	**0.0000**	$E_{Feb} = 19.94 + 1.22*T_{Feb} - 0.03*P_{Feb}$
March	65.89	**0.0000**	$E_{Mar} = 27.25 + 3.07*T_{Mar} - 0.11*P_{Mar}$
April	82.92	**0.0000**	$E_{Apr} = 30.10 + 6.10*T_{Apr} - 0.35*P_{Apr}$
May	67.32	**0.0000**	$E_{May} = -36.56 + 9.84*T_{May} - 0.22*P_{May}$
June	80.27	**0.0000**	$E_{Jun} = -70.45 + 10.37*T_{Jun} - 0.16*P_{Jun}$
July	67.23	**0.0000**	$E_{Jul} = -84.72 + 10.25*T_{Jul} - 0.13*P_{Jul}$
August	59.44	**0.0000**	$E_{Aug} = -49.88 + 8.35*T_{Aug} - 0.12*P_{Aug}$
September	79.78	**0.0000**	$E_{Sep} = -60.58 - 0.21*P_{Sep} + 10.22*T_{Sep}$
October	47.85	**0.0002**	$E_{Oct} = 36.53 + 1.92*T_{Oct} - 0.29*P_{Oct}$
November	31.82	**0.0057**	$E_{Nov} = 24.25 + 1.36*T_{Nov} - 0.18*P_{Nov}$
December	16.80	0.0835	$E_{Dec} = 14.79 + 0.58*T_{Dec} - 0.02*P_{Dec}$
Central AEZ			
January	73.33	**0.0000**	$E_{Jan} = 23.88 + 1.25*T_{Jan} - 0.08*P_{Jan}$
February	61.43	**0.0000**	$E_{Feb} = 26.68 + 1.91*T_{Feb} - 0.09*P_{Feb}$
March	72.29	**0.0000**	$E_{Mar} = 27.13 + 5.24*T_{Mar} - 0.13*P_{Mar}$
April	70.13	**0.0000**	$E_{Apr} = 7.04 + 7.83*T_{Apr} - 0.16*P_{Apr}$
May	81.44	**0.0000**	$E_{May} = -14.69 + 9.65*T_{May} - 0.46*P_{May}$
June	73.67	**0.0000**	$E_{Jun} = -107.06 + 12.77*T_{Jun} - 0.16*P_{Jun}$
July	62.57	**0.0000**	$E_{Jul} = -67.27 + 10.33*T_{Jul} - 0.19*P_{Jul}$
August	70.54	**0.0000**	$E_{Aug} = -73,90 + 11,07*T_{Aug} - 0.28*P_{Aug}$
September	84.94	**0.0000**	$E_{Sep} = -67.21 + 11.51*T_{Sep} - 0.29*P_{Sep}$
October	34.13	**0.0036**	$E_{Oct} = 47,30 + 2,07*T_{Oct} - 0,26*P_{Oct}$
November	44.07	**0.0004**	$E_{Nov} = 27.00 + 2.60*T_{Nov} - 0.19*P_{Nov}$
December	29.01	**0.0098**	$E_{Dec} = 22.91 + 0.54*T_{Dec} - 0.10*P_{Dec}$
Southern AEZ			
January	54.54	**0.0000**	$E_{Jan} = 18.39 + 1.01*T_{Jan} - 0.03*P_{Jan}$
February	54.60	**0.0000**	$E_{Feb} = 23.20 + 1.77*T_{Feb} - 0.08*P_{Feb}$
March	76.99	**0.0000**	$E_{Mar} = 24.65 + 5.42*T_{Mar} - 0.20*P_{Mar}$
April	76.98	**0.0000**	$E_{Apr} = 13.85 + 7.28*T_{Apr} - 0.33*P_{Apr}$
May	85.65	**0.0000**	$E_{May} = -45.99 + 10.99*T_{May} - 0.43*P_{May}$
June	59.37	**0.0000**	$E_{Jun} = -135.09 + 13.69*T_{Jun} - 0.13*P_{Jun}$
July	62.14	**0.0000**	$E_{Jul} = -95.04 + 11.30*T_{Jul} - 0.14*P_{Jul}$
August	78.50	**0.0000**	$E_{Aug} = -77.87 + 11.10*T_{Aug} - 0.27*P_{Aug}$
September	68.93	**0.0000**	$E_{Sep} = -80.13 + 11.80*T_{Sep} - 0.17*P_{Sep}$
October	36.76	**0.0016**	$E_{Oct} = 42.69 + 2.59*T_{Oct} - 0.27*P_{Oct}$
November	43.76	**0.0003**	$E_{Nov} = 26.12 + 2.30*T_{Nov} - 0.24*P_{Nov}$
December	25.73	**0.0155**	$E_{Dec} = 17.37 + 0.55*T_{Dec} - 0.06*P_{Dec}$

As follows from the physical considerations, *E* is directly proportional to the air temperature and inversely proportional to precipitation, while for *AI* the dependence is reversed.

The regression coefficients show, in what direction and how much may be modified the *E* and *AI* in response to changes in the temperature and precipitation of the respective month.

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,* for assessing the AEZs climate was used also the Ivanov's Index of the Biological Effectiveness of the Climate (*IBEC*) (Костантинова et al., 1999). *IBEC* is a product of the sum of active temperatures above 10°C in hundreds of degrees:

$$IBEC = 0.01\sum T_{>10°C} AI, \quad (3.5)$$

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*) (Селянинов, 1928) 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 temperature above 10°C ($\sum T$) for the same period of time divided by 10, i.e.:

$$HTC = \frac{R}{0.1\sum T_{>10°C}}, \quad (3.6)$$

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 ≤ 0.7 - drought conditions; HTC = 0.6 - medium drought; HTC ≤ 0.5 - strong drought.*

Table 3-10: The Relationship of Aridity Index *(AI)* with Average Air Temperature *(T, ^0C)* and Precipitation *(P, mm)*

Month	R-squared	P-value	Regression equation
		Northern AEZ	
January	87.63	**0.0000**	$AI_{Jan} = -2.01 + 0.11*P_{Jan} - 0.37*T_{Jan}$
February	90.82	**0.0000**	$AI_{Feb} = -0.93 + 0.09*P_{Feb} - 0.20*T_{Feb}$
March	89.00	**0.0000**	$AI_{Mar} = 0.13 + 0.05*P_{Mar} - 0.16*T_{Mar}$
April	93.25	**0.0000**	$AI_{Apr} = 0.52 + 0.02*P_{Apr} - 0.08*T_{Apr}$
May	90.01	**0.0000**	$AI_{May} = 1.32 + 0.01*P_{May} - 0.09*T_{May}$
June	94.28	**0.0000**	$AI_{Jun} = 0.16 + 0.01*P_{Jun} - 0.02*T_{Jun}$
July	95.35	**0.0000**	$AI_{Jul} = 1.48 + 0.01*P_{Jul} - 0.09*T_{Jul}$
August	95.74	**0.0000**	$AI_{Aug} = 0.95 + 0.01*P_{Aug} - 0.07*T_{Aug}$
September	93.81	**0.0000**	$AI_{Sep} = 1.01 - 0.07*T_{Sep} + 0.02*P_{Sep}$
October	93.59	**0.0000**	$AI_{Oct} = 0.17 - 0.03*T_{Oct} + 0.03*P_{Oct}$
November	80.99	**0.0000**	$AI_{Nov} = -0.27 - 0.08*T_{Nov} + 0.07*P_{Nov}$
December	85.07	**0.0000**	$AI_{Dec} = -0.14 - 0.07*T_{Dec} + 0.08*P_{Dec}$
		Central AEZ	
January	93.20	**0.0000**	$AI_{Jan} = -1.44 - 0.19*T_{Jan} + 0.09*P_{Jan}$
February	79.39	**0.0000**	$AI_{Feb} = -0.59 - 0.18*T_{Feb} + 0.07*P_{Feb}$
March	90.34	**0.0000**	$AI_{Mar} = 0.22 - 0.11*T_{Mar} + 0.04*P_{Mar}$
April	89.51	**0.0000**	$AI_{Apr} = 0.68 - 0.06*T_{Apr} + 0.01*P_{Apr}$
May	96.44	**0.0000**	$AI_{May} = 0.77 - 0.05*T_{May} + 0.01*P_{May}$
June	95.43	**0.0000**	$AI_{Jun} = 1.00 - 0.05*T_{Jun} + 0.01*P_{Jun}$
July	97.73	**0.0000**	$AI_{Jul} = 0.87 - 0.04*T_{Jul} + 0.01*P_{Jul}$
August	97.37	**0.0000**	$AI_{Aug} = 0.59 - 0.03*T_{Aug} + 0.01*P_{Aug}$
September	95.82	**0.0000**	$AI_{Sep} = 0.73 - 0.05*T_{Sep} + 0.01*P_{Sep}$
October	92.69	**0.0000**	$AI_{Oct} = 0.44 - 0.05*T_{Oct} + 0.02*P_{Oct}$
November	88.79	**0.0000**	$AI_{Nov} = -0.20 - 0.02*T_{Nov} + 0.05*P_{Nov}$
December	87.90	**0.0000**	$AI_{Dec} = -0.29 - 0.04*T_{Dec} + 0.07*P_{Dec}$
		Southern AEZ	
January	96.78	**0.0000**	$AI_{Jan} = -0.58 - 0.20*T_{Jan} + 0.08*P_{Jan}$
February	81.89	**0.0000**	$AI_{Feb} = -0.77 - 0.24*T_{Feb} + 0.09*P_{Feb}$
March	88.96	**0.0000**	$AI_{Mar} = 0.37 - 0.13*T_{Mar} + 0.04*P_{Mar}$
April	92.91	**0.0000**	$AI_{Apr} = 0.55 - 0.06*T_{Apr} + 0.02*P_{Apr}$
May	94.02	**0.0000**	$AI_{May} = 0.63 - 0.04*T_{May} + 0.01*P_{May}$
June	94.21	**0.0000**	$AI_{Jun} = 1.68 - 0.09*T_{Jun} + 0.01*P_{Jun}$
July	97.51	**0.0000**	$AI_{Jul} = 0.90 - 0.05*T_{Jul} + 0.01*P_{Jul}$
August	95.47	**0.0000**	$AI_{Aug} = 0.55 - 0.03*T_{Aug} + 0.01*P_{Aug}$
September	95.53	**0.0000**	$AI_{Sep} = 0.69 - 0.04*T_{Sep} + 0.01*P_{Sep}$
October	95.38	**0.0000**	$AI_{Oct} = 0.25 - 0.04*T_{Oct} + 0.02*P_{Oct}$
November	89.90	**0.0000**	$AI_{Nov} = -0.40 + 0.01*T_{Nov} + 0.06*P_{Nov}$
December	87.51	**0.0000**	$AI_{Dec} = -0.38 - 0.06*T_{Dec} + 0.08*P_{Dec}$

3.2.2. 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 revealed in **Figure 3-3**. 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.

For all three SRES emission scenarios are expected worsening of the humidity conditions throughout the territory of the Republic of Moldova. 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 during the XXI century.

Potential evaporation is likely will increase by 9-13 per cent during the growing season over the 2020s, run up to 40-45 per cent by the 2080s and make from 810 mm across northern to 1074 mm in southern AEZs[3] under the SRES A2 high emission scenario; slightly lower growth is projected according to the SRES B1 low emission scenario, by 22-27 per cent, from 713 mm for northern AEZ, to 942 mm in southern AEZ, relative to the baseline climate (**Table 3-11**).

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 1961-1990 reference period (**Figure 3-4**). That phenomenon will be more pronounced during July to October.

[3] For comparison purposes, it is worth noting that the observed mean PE during the growing season in the reference period (1961-1990) was as following: Briceni – 562 mm; Chisinau – 770 mm; Cahul – 742 mm.

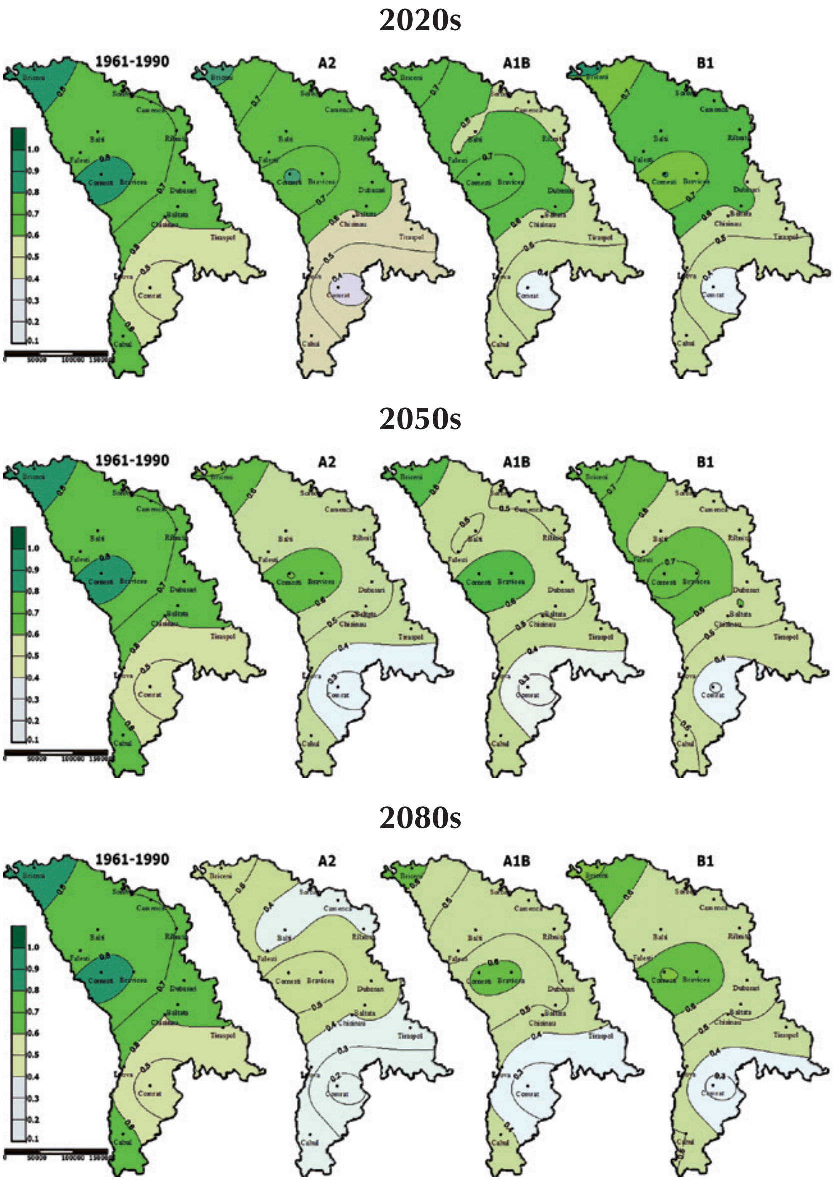


Figure 3-3: Projected Multi-Model Ensemble Annual Aridity Index *(AI)* Development throughout the Republic of Moldova

Table 3-11: Projected Ensemble Changes in the Potential Evaporation *(E)* and Ivanov's Aridity Index *(AI)* during the growing season in XXI Century for SRES A2, A1B and B1 Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990)

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)*

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 SRES A2 scenario, also in July, August and September), achieving in respective periods values characteristic to arid climate conditions (*AI* = 0.05-0.20).

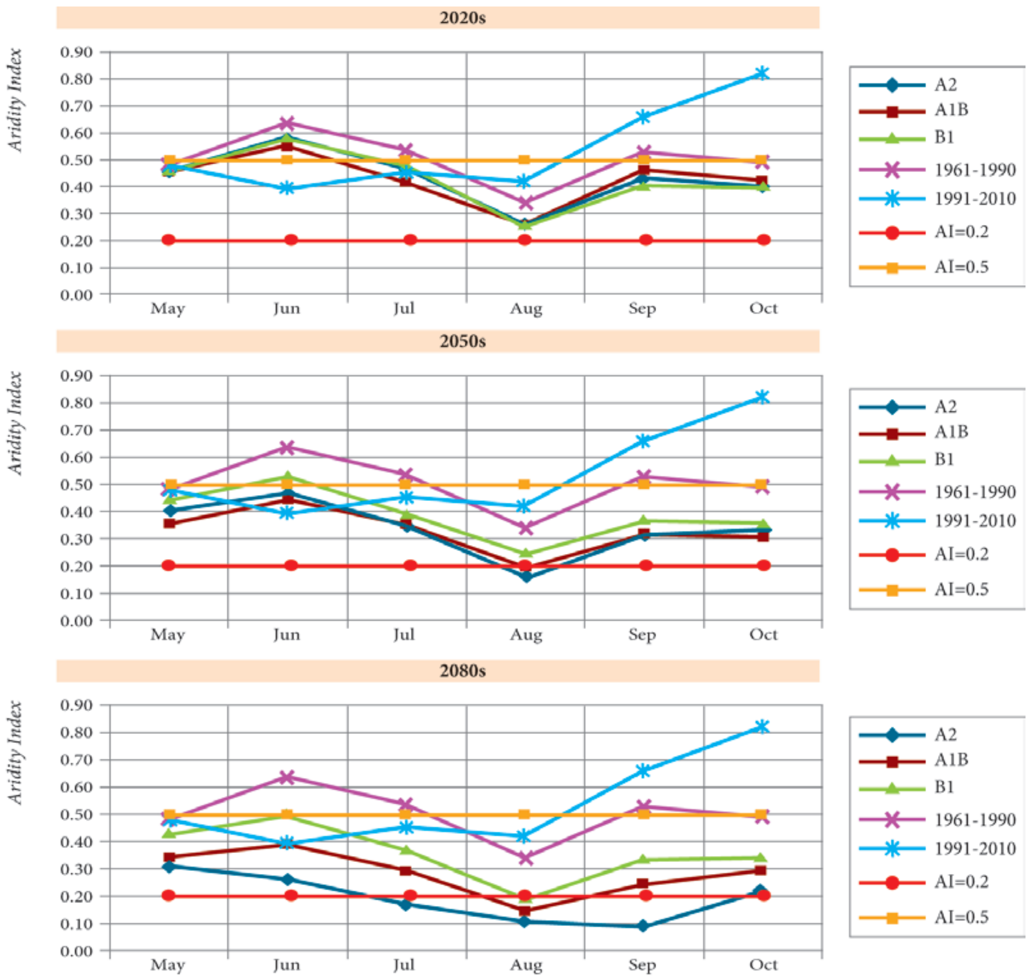


Figure 3-4: Projections of the Aridity Index *(AI)* Development Pattern for Central AEZ of the Republic of Moldova from an Ensemble of 10 Global Models for the SRES A2, A1B and B1 Emission Scenarios, as Compared to the Reference Period Climate (1961-1990)

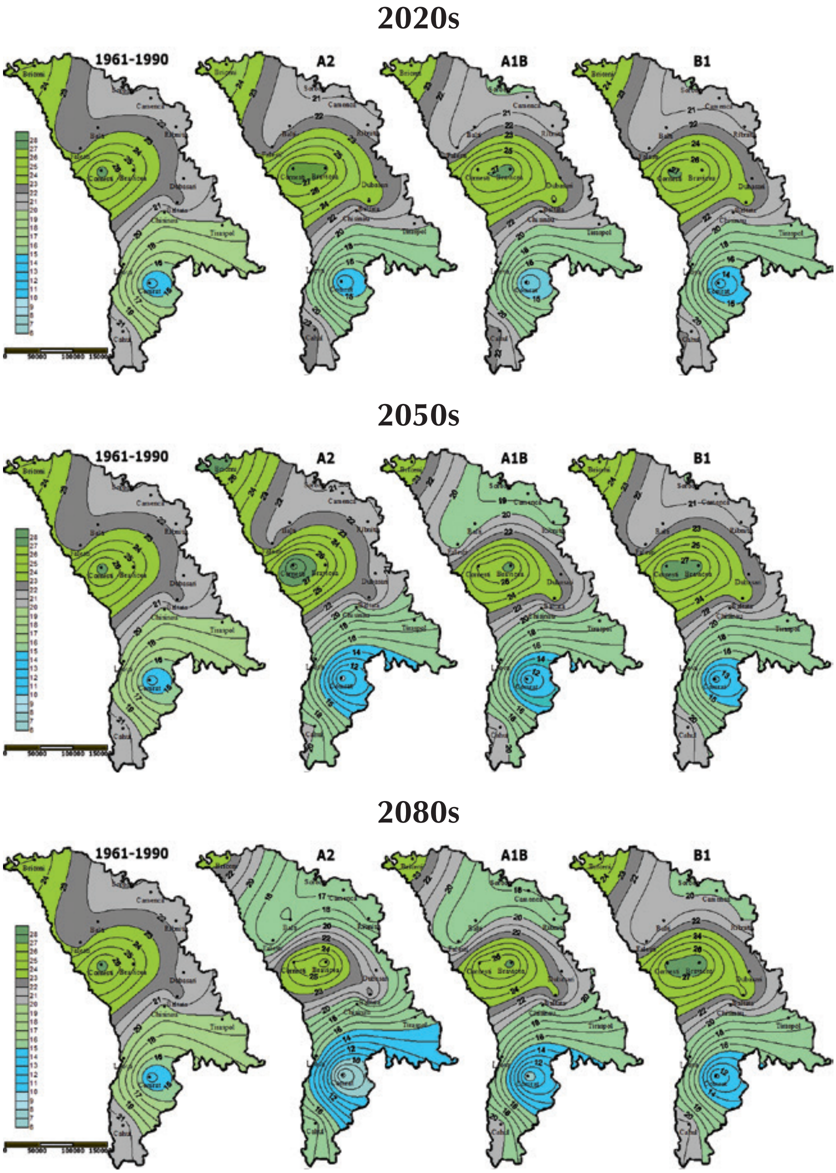


Figure 3-5: Projected Multi-Model Ensemble Ivanov Index of the Biological Effectiveness of Climate *(IBEC)* Spatial Development throughout the Republic of Moldova

3.2.3. 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 (**Figure 3-5**) 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.

3.2.4. Selianinov Hydro-Thermal Coefficient (HTC)

In the Republic of Moldova 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. The assessment of that 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 3-6 clearly demonstrates the gradual aridization of the Republic of Moldova territory, including northern areas, which today are still sufficiently wet.

In **Table 3-12** it is provided the characterization of humidity conditions during the plant vegetation period using the Selianinov Hydrothermal Coefficient (*HTC*) for the reference period, current climate and projected ensemble changes in the *HTC* during the growing season for SRES A2, A1B and B1 emissions scenarios relative to the 1961-1990 climatological baseline period in XXI century. Analysis of data shows that by 2080 the drought conditions of $HTC \leq 0.7$ will be observed on the whole territory of the Republic of Moldova under the SRES A2 high emission scenario; in July, August, September and October those levels can achieve even the values characteristic to the medium drought ($HTC = 0.6$) and strong drought ($HTC \leq 0.5$) conditions.

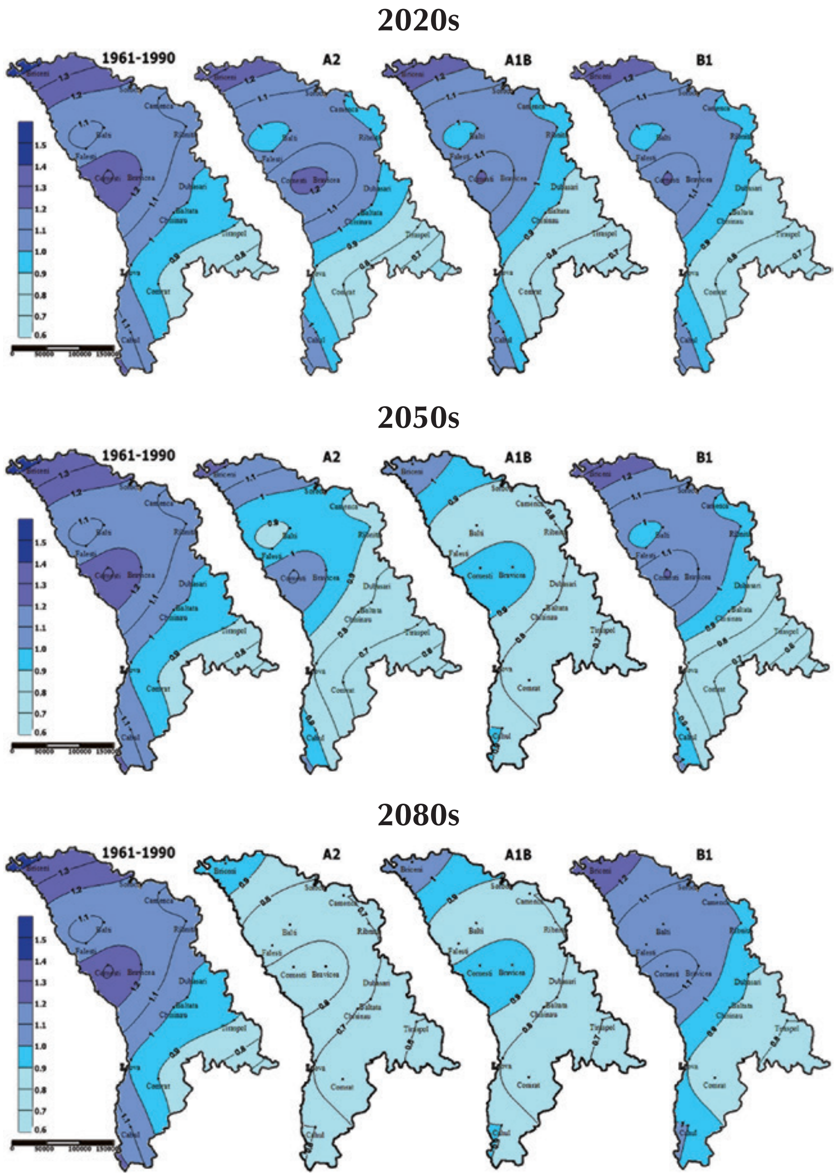


Figure 3-6: Projected Multi-Model Ensemble *HTC* Index Spatial Development for the Vegetation Period throughout the Republic of Moldova

Table 3-12: Projected Ensemble Changes in the Selianinov Hydrothermal Coefficient (HTC) during the growing season in XXI Century for SRES A2, A1B and B1 Emission Scenarios, Relative to the Climatological Baseline Period (1961-1990)

AEZ	Scenario	Month of the year							
		IV	V	VI	VII	VIII	IX	X	IV-X
1961-1990									
Northern	***Baseline climate***	1.9	1.6	1.7	1.5	1.1	1.1	1.0	**1.4**
Central		1.4	1.0	1.3	1.1	0.7	0.9	0.9	**1.0**
Southern		1.3	1.1	1.3	1.0	0.9	1.0	0.8	**1.1**
1991-2010									
Northern	***Current climate***	1.6	1.4	1.5	1.8	1.1	1.4	1.5	**1.5**
Central		1.2	1.0	0.9	1.0	0.9	1.2	1.3	**1.1**
Southern		1.2	0.9	1.1	0.9	0.8	1.0	1.2	**1.0**
2020s									
Northern	**A2**	1.8	1.6	1.7	1.4	1.0	0.9	0.8	**1.3**
	A1B	1.8	1.5	1.5	1.3	0.9	1.0	0.8	**1.3**
	B1	1.7	1.6	1.6	1.5	1.0	0.9	0.8	**1.3**
Central	**A2**	1.3	1.0	1.2	1.0	0.6	0.8	0.7	**1.0**
	A1B	1.3	1.0	1.2	0.9	0.6	0.9	0.8	**0.9**
	B1	1.2	1.0	1.2	1.0	0.6	0.8	0.7	**0.9**
Southern	**A2**	1.2	1.1	1.2	1.0	0.7	0.9	0.7	**1.0**
	A1B	1.2	1.1	1.3	0.9	0.7	0.9	0.7	**1.0**
	B1	1.2	1.1	1.3	0.9	0.7	0.9	0.7	**1.0**
2050s									
Northern	**A2**	1.5	1.4	1.5	1.3	0.9	0.8	0.7	**1.2**
	A1B	1.6	1.4	1.4	1.2	0.9	0.9	0.7	**1.1**
	B1	1.7	1.6	1.6	1.3	1.0	0.9	0.8	**1.3**
Central	**A2**	1.2	0.9	1.1	0.8	0.5	0.7	0.6	**0.8**
	A1B	1.2	0.9	1.0	0.9	0.6	0.7	0.6	**0.8**
	B1	1.2	1.0	1.2	0.9	0.6	0.8	0.7	**0.9**
Southern	**A2**	1.1	1.0	1.0	0.8	0.5	0.8	0.6	**0.8**
	A1B	1.1	1.0	1.1	0.8	0.6	0.8	0.6	**0.9**
	B1	1.1	1.1	1.2	0.9	0.7	0.8	0.7	**0.9**
2080s									
Northern	**A2**	1.5	1.4	1.3	1.0	0.7	0.6	0.6	**1.0**
	A1B	1.5	1.4	1.3	1.1	0.7	0.8	0.6	**1.1**
	B1	1.6	1.6	1.5	1.9	0.7	0.8	0.7	**1.3**
Central	**A2**	1.1	0.8	0.8	0.6	0.5	0.5	0.5	**0.7**
	A1B	1.1	0.9	1.0	0.8	0.5	0.7	0.6	**0.8**
	B1	1.2	1.0	1.1	0.9	0.5	0.8	0.7	**0.9**
Southern	**A2**	1.0	0.9	0.8	0.6	0.5	0.5	0.5	**0.7**
	A1B	1.0	1.0	1.0	0.8	0.6	0.7	0.6	**0.8**
	B1	1.1	1.1	1.1	0.8	0.6	0.8	0.6	**0.9**

For all three SRES emission scenarios are expected worsening of the humidity conditions throughout the territory of the Republic of Moldova'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* 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 AEZ by 2080s.

The obtained results may be useful further in developing national, regional and sectoral adaptation strategies and action plans. Farmers and policymakers may use the provided information to choose adaptation measures; 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.

Increased drought risk associated with global warming and impacts on water resources are among the main concerns in Europe now. Several recent studies highlight the challenges that result from changes in water availability and water quality (Schröter et al., 2005, 2007; EEA, 2012).

Under climate change conditions, it is expected that irrigation water demand will further increase; aggravating the competition with other sectors whose demand is also projected to increase. In addition, an expected lowering of the groundwater table will make irrigation more expensive, which, in turn might have to be limited to cash crops. Extreme weather events such as heat waves will impact on peak irrigation requirements. As the evaporative demand will increase due to higher temperatures, it is expected that capillary rise will increase the salinisation of soils, having a major impact on irrigation management.

The reduction of pressures on land and resources, obtained through restorations of natural processes and local attitudes and tradition can be a very powerful mean. Multifunctional agriculture may produce economic and high value commodities, allowing containing fast and large growing pressures, and appropriate land use may recover local vocationally and knowledge, as that linked to traditional no-food crops, as for example, fibers.

Emergence of ecological agriculture and precision production (information intensive) are likely to characterize twenty-first century. The management of production is expected to trend towards micromanagement of each specific production site, in order to lower impacts, reduce environment degradation, minimize costs, and enhance crop quality. Precision farming will allow to use crop models and monitoring technologies (including GPS, remote sensing) to apply correct inputs, adjusted to the ambient environment, including meteorological variables (Mc Bratney et al., 2005).

At the same time, awareness is increasing about the importance of ecological agriculture, that shifts management practices to apply low-input paradigms, as self-regulating pest management systems instead of pesticide applications, diverse crop or livestock instead of monocultures. The ecological management of agroecosystems that addresses energy flows, nutrient cycling, population regulating mechanisms and system resilience can lead to the redesign of agriculture at a landscape scale (Shennan, 2008).

Strategies in agricultural activities to help farmers to better – and less riskily produce in a climate change scenarios constitute a potentially great value for agriculture. At the same time, the adoption of environmentally sustainable practices in the field may positively reflect on climate, allowing agriculture itself to positively act to contrast climate change.

The concept of Good Agricultural Practices has evolved in recent years as a result of the concerns and commitments of a wide range of stakeholders about food production and security, and the environmental sustainability of agriculture. Correct knowledge and interpretation of climate urgencies may address on-farm and post-production processes less sensitive and decrease vulnerability (ACCRETE project, 2007).

Adequate land use and resource preservation policies must be coupled with appropriate energy saving actions. Biofuels are a potential low-carbon energy source, but whether biofuels offer carbon savings depends on how they are produced. Biofuels made from waste biomass or from biomass grown on degraded and abandoned agricultural lands planted with perennials incur little or no carbon debt and can offer immediate and sustained GHG advantages (Fargione et al., 2008; Cost action 734, 2008).

CONCLUSIONS

The main conclusions are as following:

1. For all three SRES A2, A1B, B1 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.
2. Potential evaporation is likely will increase by 9-13 per cent during the growing season over the 2020s, run up to 40-45 per cent by the 2080s and make from 810 mm for northern AEZ to 1074 mm in southern AEZ under the SRES A2 high emission scenario; slightly lower growth is projected according to the SRES B1 low emission scenario, by 22-27 per cent, from 713 mm across northern AEZ, to 942 mm in southern AEZ, relative to the baseline climate
3. 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 SRES A2 scenario, also in July, August and September), achieving in respective periods values characteristic to arid climate conditions (AI = 0.05-0.20).
4. *IBEC* shows the latitude-zonal pattern of climate variability and clearly demonstrates the gradual worsening of optimal ecological-climatic characteristics for plant growing throughout the Republic of Moldova's territory, including northern areas by 2080s.
5. Analysis of data shows that by 2080 the drought conditions ($HTC \leq 0.7$) will be observed on the whole territory of the Republic of Moldova, including northern AEZ, and what is more, in 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 ($HTC \leq 0.5$).
6. The obtained results may be useful in developing national, regional and sectoral (specifically, for agriculture sector) adaptation strategies and action plans.

Bibliography

1. **ACCRET-E, (2008),** *Code of attitudes to prevent impacts between agriculture and climate change*. Printed in English, Italian, German, Greek, Slovenian, Romanian, Czech versions, available on-line at http://www.accrete.eu/ and http://www.agrometeorology.org/
2. **Alcamo, J., Moreno, J.M., 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, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E.), pp. 541–580. Cambridge University Press, Cambridge, UK.
3. **Angulo, C., Rötter, R.P., Lock, R., Enders, A., Fronzek, S., Ewert, F. (2013),** *Implication of crop model calibration strategies for assessing regional impacts of climate change in Europe*. Agric. For. Meteorol, 170, 32-46.
4. **Babinszky, L., Halas, V., 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.
5. **Carter, T.R. (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.
6. **Cassman, K.G., Dobermann, A., Walters, D.T., Yang, H.S. (2003),** *Meeting cereal demand while protecting natural resources and improving environmental quality*. Annual Review of Environment and Resources, 28, 315–358.
7. **Ciscar, J.C., 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. **Cost action 734, (2008),** *Impact of climate change and variability on European agriculture*. Survey of Agrometeorological practices and applications in Europe regarding climate change impacts. Edited by: Pavol Nejedlik & Simone Orlandini. 329p.
10. **Easterling, W.E., Aggarwal, P.K., Batima, P., Brander, K.M., Erda, L., Howden, S.M., Kirilenko, A., Morton, J., Soussana, J.-F., Schmidhuber, J., Tubiello, F.N. (2007),** *Food, fibre and forest products. Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the IPCC, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, P. 273-313.
11. **EEA, (2012),** *Climate change impacts and vulnerability in Europe*. An indicator – based report. No 2/2012. 304p.

12. **Ewert, F., M.K. van Ittersum, Heckelei, T., Therond, O., Bezlepkina, I., Andersen, E., et al. (2011),** *Scale changes and model linking methods for integrated assessment of agri-environmental systems*. Agric. Ecosyst. Environ, 142, 6-17.
13. **Ewert, F., Rounsevell, M.D.A., Reginster, I., Metzger, M.J., Leemans, R. (2005),** *Future scenarios of European agricultural land use I. Estimating changes in crop productivity*. Agriculture, Ecosystems and Environment, 107, 101–116.
14. **Fargione, J., Hill J., Tilman, D., Polaski, S., Hawthorne, P. (2008),** *Land clearing and the biofuel carbon debt*. Science, 319, 5867, 1235-1238.
15. **Finger, R. (2010),** *Evidence of slowing yield growth – the example of Swiss cereal yields*. Food Policy, 35, 175–182.
16. **Fischer, G., Shah, M., Tubiello, F.N. 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.
17. **Frich, P., Alexander, L.V., 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.
18. **Giorgi, F., Lionello, P. (2008),** *Climate change projections for the Mediterranean region*. Global and Planetary Change, 63, 90–104.
19. **Grassini, P., Thorburn, J., Burr, C., Cassman, K.G. (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.
20. **Harrison, P.A., Butterfield R. (1996),** *Effects of climate change on Europe-wide winter wheat and sunflower productivity*. Clim. Res., 7, 225–241.
21. **Iglesias, A., Quiroga, S., Schlickenrieder, J. (2010),** *Assessing uncertainty to support climate change adaptation needs for Mediterranean crops*. Climate Research, 44, 83–94.
22. **IPCC, (2007),** *Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the IPCC [Solomon, S., D. Qin, M. Manning,Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA.
23. **Jones, P.D., Lister, D.H., Jaggard, K.W., Pidgeon, J.D. (2003),** *Future climate impact on the productivity of sugar beet (Beta vulgaris L.) in Europe*. Climatic Change, 58, 93–108.
24. **Kenny, G.J, Harrison, P.A. (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, G.J., Harrison, P.A., Parry, M.L.), pp. 201–224. University of Oxford, UK.
25. **Lavalle, C., Micale, F., Houston, T.D. et al. (2009),** Climate change in Europe. 3. Impact on agriculture and forestry. A review. Agronomy for Sustainable Development, 29, 433-446.
26. **Lobell, D.B. and Burke M.B. (2010),** *On the use of statistical models to predict crop yield responses to climate change*. Agric. For. Meteorol. 150, 1443-1452.

27. **Lobell, D.B., Cassman, K.G., Field, C.B. (2009),** *Crop yield gaps: their importance, magnitudes, and causes*. Annual Review of Environment and Resources, 34, 179-204.
28. **Maracchi, G., Sirotenko, O., Bindi, M. (2004),** *Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe*. *Climatic Change*, 70 (1), 117-135.
29. **Mc Bratney, A., Whelan, B., Ancev, T., Bouma, J. (2005),** *Future directions of precision agriculture*. Precision Agriculture, 6. (1), 7-23.
30. **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.
31. **National Climate Change Adaptation Strategy of the Republic of Moldova (NCCAS), (2012),** 83p. http://clima.md/lib.php?l=ro&idc=237&.
32. **Nelson, G.C., Rosegrant, M.W., Koo, J., Robertson, R., Sulser, T., Zhu, T., et al. (2009),** *Climate change: impact on agriculture and costs of adaptation*. Food Policy Report. International Food Policy Research Institute, Washington DC.
33. **Olesen, J.E., Bindi, M. (2002),** *Consequences of climate change for European agricultural productivity, land use and policy*. European Journal of Agronomy, 16, 239–262.
34. **Olesen, J.E., Trnka, M., Kersebaum, K.C. et al. (2011),** *Risk assessment and foreseen impacts on agriculture*. European Journal of Agronomy, 34, 96–112.
35. **Osborne, T., Rose, G., Wheeler, T. (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.
36. **Peltonen-Sainio, P., Jauhiainen, L., Laurila, I.P. (2009a),** *Cereal yield trends in northern European conditions: changes in yield potential and its realisation*. Field Crops Research, 110, 85–90.
37. **Porter, J.R., Semenov, M.A. (2005),** *Crop responses to climatic variation*. Philosophical Transactions of the Royal Society B, 360, 2021–2035.
38. **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.
39. **Ramankutty, N., Foley, J.A, 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.
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. **Rosenzweig, C., Jones, J.W., Hatfield, J.L., Ruane, A.C., Boote, K.J., Thorburn, P. et al. (2013),** *The Agricultural Model Intercomparison and Improvement Project (AgMIP): protocols and pilot studies*. Agric. For. Meteorology, 170, 166–182.
42. **Rötter, R.P., Carter, T.R., Olesen, J.E., Porter J.R. (2011b),** *Crop-climate models need an overhaul*. Nat. Clim. Change 1, 175–177.
43. **Rötter, R.P., Höhn, J., Trnka, M. et al. (2013),** *Modelling shifts in agroclimate and crop cultivar response under climate change*. Ecology and Evolution, 3 (13), 4620.

44. **Rötter, R.P., Palosuo, T., Pirttioja N.K., Dubrovsky, M., Salo, T., Fronzek S. 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.
45. **Schröter, D., Cramer, W., Leemans R., Prentice, I.C., Araujo, M.B. et al. (2005),** *Ecosystem service supply and vulnerability to global change in Europe*. Science, 310(5752), 1333-1337.
46. **Semenov, M.A., Halford, N.G. (2009),** *Identifying target traits and molecular mechanisms for wheat breeding under a changing climate*. J. Exp. Bot. 60, 2791-2804.
47. **Shennan, C. (2008),** *Biotic interactions, ecological knowledge and agriculture*. Phil. Trans. Royal Soc. B. Biol. Sci., 363, (1492), 717-739.
48. **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.
49. **Taranu, L. (2013),** *Projections of changes in productivity of major agricultural crops in the Republic of Moldova according to an ensemble from 10 GCMs for SRES A2, A1B and B1 emission scenarios in the XXI century*. Mediul Ambiant (In press).
50. **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. 3 (63), 33-42. http://clima.md/lib.php?l=ro&idc=250&year=2012.
51. **Taranu, L., Scorpan, V., Toderas, V., Mironova, T. (2009),** *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, 400-409. (In Russian) http://clima.md/lib.php?l=ro&idc=250&year=2009.
52. **Trnka, M., Olesen, J.E., Kersebaum, K.C., Skjelvag, A. O., Eitzinger, J. Seguin, B. et al. (2011),** *Agroclimatic conditions in Europe under climate change*. Glob. Change Biol. 17: 2298–2318.
53. **UNDP (2012),** *Drought: Snapshot Analysis,* August 2, 2012 (based on media reports, Government websites, information from the Ministry of Agriculture and Civil Protection). http://www.un.md/drought/2012/2012%20Drought_0208.pdf.
54. **White, J.W., Hoogenboom, G., Kimball, B.A., Wall, G.W. (2011),** *Methodologies for simulating impacts of climate change on crop production*. Field Crops Res. 124:357–368.
55. **Иванов Н.Н. (1962),** *Показатель биологической эффективности климата*. Изв. РГО. Т.94. Вып. 1. С. 65-70.
56. **Костантинова Т.С., Коробов Р.М., Николаенко А.В. (1999),** *Картографическое моделирование биологической эффективности климата Молдавии.* Изв. РАН. Сер. Геогр. №3. С. 86-92.
57. **Селянинов Г.Т. (1928),** *О сельскохозяйственной оценке климата.* Труды по сельскохозяйственной метеорологии. Вып. 20. С.165-177.

Chapter 4. Potential Impact of Climate Change on Agriculture Sector

The cultivation of crops, their productivity and quality, are directly dependent on different climatic factors. Climate change is already having an impact on agriculture (Peltonen-Sainio et al., 2010; Olesen et al., 2011), and has been attributed as one of the factors contributing to stagnation in wheat yields in parts of Europe despite continued progress in crop breeding (Brisson et al., 2010). Climate change is expected to continue to affect agriculture in the future (Falloon, Betts, 2010; Olesen et al., 2011), and the effects will vary greatly in space across Europe (Trnka, Olesen et al., 2011; Donatelli et al., 2012), but they may also change over time (Trnka, Eitzinger et al., 2011). It is generally accepted that productivity will increase in northern Europe due to a lengthened growing season and an extension of the frost-free period (Olesen, Bindi, 2002). In southern Europe, climate change is likely to negatively affect the productivity of crops and their suitability in certain regions primarily due to extreme heat events and an overall expected reduction in precipitation and water availability (Iglesias et al., 2010). Year-to-year variability in yields is generally expected to increase throughout Europe, due to extreme climatic events and other factors, including pests and diseases (Ferrise et al., 2011; Kristensen et al., 2011).

There is a large variation across the European continent in climatic conditions, soils, land use, infrastructure, and political and economic conditions, which greatly influence the responsiveness to climatic change (Olesen et al., 2011; Trnka, Olesen et al., 2011). Intensive farming systems in western and central Europe generally have a low sensitivity to climate change, because a given change in temperature or rainfall has modest impact, and because farmers have resources to adapt by changing management (Reidsma et al., 2010). However, there may be considerable difference in adaptive capacity between cropping systems and farms depending on their specialization and other farm characteristics (Reidsma, Ewert, 2008).

In general, impact studies are made using two different approaches: the analysis of agro-meteorological indicators or simulations of biophysical models (and more precisely crop growth models). The two approaches differ in their specific targets, strengths, assumptions and limitations.

4.1. Agro-Meteorological Indicators

The first and relatively simple approach to assess the impact of climate change on agriculture is to calculate agro-meteorological or agro-climatic indicators. Examples of such indicators include the length of growing period, temperature conditions (such as frost or heat constraints) moisture conditions, or soil drainage conditions. Agro-meteorological indicators of that sort have been proposed as criterions to define intermediate Less Favored Areas (LFAs) in the European Union (Eliasson et al., 2010).

The impact of climate change on agriculture can therefore be assessed based on how LFAs may appear or disappear according to climate change predictions from GCM-RCMs simulations based on SRES. For the sake of simplification, indicators relating to the optimal temperature for crops need to be generalized. Length of growing period is therefore defined based on the growing degree days calculated based on the assumption that there is negligible growth below 5°C or above 35-40°C for most crops (Porter, Semenov, 2005). Such generalization at the European scale does not take into account that (i) crops and crop varieties have different responses to temperature and that (ii) farmers generally choose the crop variety best suited for the local conditions.

Trnka et al. (2011) have recently analyzed future agro-climatic conditions in Europe using such approach. Agricultural factors investigated include: potential biomass, time period suitable for crop growth, low temperature limitations, water deficiency, harvesting and sowing conditions. Indicators used in this study include (amongst others) sum of effective global radiation, number of days with water deficits in a given season, proportion of suitable days for sowing/harvesting in a given period, etc.

Taranu (2013) and Taranu et al. (2014) have evaluated how the temperature – based and humidity agroclimatic indices over the Republic of Moldova is likely to change in time (by the 2020s, 2050s, 2080s) and space (northern, central and southern AEZs) under an ensemble of 10 GCM for three SRES A2 (high), A1B (medium) and B1 (low) emission scenarios. 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 (IBEC) representing the heat and humidity conditions during the growing season. 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 AEZs. 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.

Composite indicators, i.e. a combination of individual indicators, can be of high value for policy makers since composite indicators can potentially resume different climatic information into a single number. The downside is that they might be too complex or not transparent enough, leading to a higher probability of misinterpretation. Few studies proposing composite indicators exist, not for agro-meteorological indicators nor for impact studies, but rather for climate change (i.e. based on precipitation and temperature changes only). An example includes the Regional Climatic Change Index (RCCI) proposed by Giorgi (2006) which has latter been linked worldwide to socio-economic indicators of poverty, wealth and population (Diffenbaugh et al., 2007). Baettig et al. (2007) have proposed a composite Climate Change Index (CCI), based on individual indices in temperature and precipitation, as a measure for how strongly future climate will change relative to today's natural variability (the CCI mostly differs from the RCCI on this last point: setting today's natural variability as a benchmark).

While assessments based on indicators can be implemented in a relatively simple way and can be robust or more sensitive to specific climatic events, they must still be regarded as what they are: indicators. They offer a more qualitative overview of the impact rather than a quantitative one.

4.2. Crop Modeling for Agriculture Climate Impacts Research

Assessment studies of the impacts of climate change on agriculture at farm to regional levels need to analyze complex interactions of climate, agro-ecosystem function, and human management. To this end, researchers typically link climate predictions to crop models and land management decision tools (Tubiello et al., 2002). For instance, Decision Support System for Agrotechnology Transfer (DSSAT) (Rosenzweig et al., 1995, Tsuji et al., 1995), Erosion Product Impact Calculator (EPIC) (Williams, 1995), Terrestrial Ecosystem Model (TEM) (Felzer et al., 2004), and the AEZ model (Tubiello, Fischer, 2007) have been used at the global scale. Simulation models often provide the only available tool to investigate complex interactions and feedbacks of many variables.

4.2.1. Process-Based Models

Most studies have made use of process-based crop and pasture models to evaluate the impacts of climate change scenarios either at a local or at the global scale (Rosenzweig, Parry, 1994; IFPRI, 2009) for crop and pasture species. This may be carried out using field-scale models, either directly (e.g., de Wit et al., 2005; Xiong et al., 2007) or in a manner that accounts for subgrid heterogeneity (e.g., Irmak et al., 2005; Jagtap, Jones, 2002). Alternatively, a "large area" process-based model—with a focus on the influence of weather and climate on crop growth and development—can be designed to capitalize on known large-scale relationships between climate and crop yield (e.g., Challinor et al., 2003, 2004). These assessments build confidence in the use of this method with climate change scenarios and permit the quantification of uncertainty in a manner that is substantially different from the common approach of random sampling of uncertainty using a range of crops, locations, models, or scenarios (e.g., Challinor, Wheeler, 2008 a,b). However, substantial time, data, and expertise are needed to calibrate these models for particular locations (Wallach et al., 2006) and the lack of process-based models for many minor crops, restricts the scope of this approach. Nevertheless, mechanistic models have recently been expanded in the context of climate change studies to cover an extended range of crop species, including potato (Wolf, Van Oijen, 2003), sugar beet (Launay et al., 2009), cassava, sorghum, millet (Liu et al., 2008), and quinoa (Lebonvallet et al., 2009).

4.2.2. Generic Models

An intermediate approach uses detailed agronomic-based knowledge to simulate availability and use of land resources, farm-level management options, and crop production potentials as a function of climate (AEZ, Fischer et al., 2005). It computes potentially attainable, rather than actual, crop yields. Thus, wherever the gap between actual and potential yields is large, such as in many developing countries, there is uncertainty in translating the calculated impacts of climate change into changes in actual crop productivity. In those regions with large yield gaps, this approach may predict larger positive impacts of climate change on crop production than is actually possible in real fields (Tubiello, Fischer, 2007). It should be noted that results from such approaches, as well as of some of the generic crop modelling (e.g. CROPSYST; Stöckle et al., 2001), can be used to compare the future suitability of land for a range of crops, which allows mapping of the likely future climatic envelopes of the main cropping systems. This method, which has been used by many authors (e.g., Izaurralde et al., 2003; Southworth et al., 2002), can capture the complex biophysical processes associated with climate change that are usually overlooked by studies of the first kind. However, these models may sometimes be over parameterized (Cox et al., 2006). The use of many parameters produces results that are location specific because the yields depend on the specific crop variety, soils, and management practices used. Although this can be useful for decision support, it presents a problem when estimates over large areas are required. While this problem can be overcome through the identification of representative farms, this choice can itself be problematic (Luo, Lin, 1999). Furthermore, unless any downscaling methods used are dynamic, there is a risk of nonstationarity in the downscaling relationships (Jenkins, Lowe, 2003), thus putting into question their use in future climates (Challinor et al., 2005b).

4.2.3. Statistical Models

Statistical models of crop responses to climate change, based on historical datasets of crop and climate variables have recently been used (Iglesias et al., 2000; Lobell et al., 2008; Paeth et al., 2008; Schlenker, Roberts, 2009) to address climatic change impacts on food security in developing countries. This method has the advantage of being applicable on large spatial scales, thus facilitating the quantification of impacts in human terms such as levels of risk of hunger (e.g., Parry et al., 2004, 2005). One disadvantage of this method is the potential to introduce significant errors through the linearization of the equations for crop yield (Challinor et al., 2006) and/or the use of monthly data (e.g., Fischer et al., 2005), which may not be able to account sufficiently for sub seasonal variability in weather. Interestingly, at least one study of this first kind reports that the skill of the parameterization of crop yield was lowest in the tropics (Parry et al., 2004). The validity of empirical methods may be compromised when used with data outside the range for which they were fitted (e.g., climate change).

This approach can be used for all crops and all regions, but has several deficiencies (as acknowledged by the authors): (i) errors in statistical data of production and in gridded climate data, and (ii) in some instances, low weight of climatic factors for the between year variation in crop yields. Moreover, statistical models cannot be extrapolated without further assumptions to predict production impacts for future conditions (e.g. higher temperature than any historical year, elevated CO_2 concentration (Soussana et al., 2010).

4.3. Projecting Climate Change Impacts on Major Annual Crops Yields

It is now universally accepted that increased atmospheric concentrations of 'greenhouse gases' are the main cause of the ongoing climate change (Forster et al., 2007) and that these changes are expected to have important effects on different economic sectors e.g. agriculture, forestry, energy consumptions, tourism, etc. (Hanson et al., 2007). Since agricultural practices are climate-dependent and yields vary from year to year depending on climate variability, the agricultural sector is particularly exposed to changes in climate. In Europe, the present climatic trend indicates that in the northern areas, climate change may primarily have positive effects through increases in productivity and in the range of species grown (Alcamo et al., 2007), while in southern areas the disadvantages will predominate with lower harvestable yields, higher yield variability and a reduction in suitable areas for traditional crops (Olesen, Bindi, 2007; Constantinova, 2009; Moriondo et al., 2010; Taranu, 2013).

For climate change impact assessment, crop growth models have been widely used to evaluate crop responses (development, growth and yield) by combining future climate conditions, obtained from General or Regional Circulation Models (GCMs and RCMs, respectively), with the simulation of CO_2 physiological effects, derived from crop experiments (Ainsworth, Long, 2005). Many of these impact studies were aimed at assessing crop development shifts and yield variations under changes in mean climate conditions. These analyses showed that increasing temperatures generally shortened the growing period of commercial crops (Giannakopoulos et al., 2009), resulting in a shorter time for biomass accumulation. On the other hand, changes in yields were not homogeneous and dependent on crop phenology (e.g. summer and winter crops), crop type (e.g. C3 and C4 plants) or environmental conditions (water and nutrient availability) (Ainsworth, Long, 2005; Thomson et al., 2005; Brassard, Singh, 2008; Giannakopoulos et al., 2009; Moriondo et al., 2010).

Other studies stressed that changes in climate variability, as can be expected in a warmer climate, may have a more profound effect on yield than changes in mean climate (Porter, Semenov, 2005). Furthermore, the changes in the frequency of extreme climatic events during the more sensitive growth stages have been recognized as a major yield-determining factor for some regions in the future (Easterling, Apps, 2005; Schneider et al., 2007). Temperatures outside the range of those typically expected during the growing season may have severe consequences on crops, and when occurring during key development stages they may have a dramatic impact on final production, even in case of generally favorable weather conditions for the rest of the growing season.

Many studies highlighted the potential of heat stresses during the anthesis stage as a yield reducing factor (Wheeler et al., 2000; Morrison, Stewart, 2002; Challinor et al., 2005), while others pointed out that the joint probability of heat stress-anthesis is likely to increase in future scenarios (Moriondo, Bindi, 2006; Semenov, 2007; Schneider et al., 2007; Alcamo et al., 2007).

Statistical models of crop responses to climate change are the second method for climate change impact assessment in agriculture, based on historical datasets of crop and climate variables have recently been used (Iglesias et al., 2000; Iglesias, Quiroga, 2007; Lobell, Field, 2007; Schlenker, Roberts, 2009; Constantinova et al., 2009; Quiroga, Iglesias, 2009, 2010) to address climatic change impacts on agriculture. This method has the advantage of being applicable on large spatial scales, thus facilitating the quantification of impacts in human terms such as levels of risk of hunger (Parry et al., 2004, 2005).

One disadvantage of this method is the potential to introduce significant errors through the linearization of the equations for crop yield (Challinor et al., 2006) and/or the use of monthly data (Fischer et al., 2005), which may not be able to account sufficiently for sub seasonal variability in weather. The validity of empirical methods may be compromised when used with data outside the range for which they were fitted (e.g., climate change). This approach can be used for all crops and all regions, but has several deficiencies (as acknowledged by the authors): (i) errors in statistical data of production and in gridded climate data, and (ii) in some instances, low weight of climatic factors for the between year variation in crop yields. Moreover, statistical models cannot be extrapolated without further assumptions to predict production impacts for future conditions (e.g. higher temperature than any historical year, elevated CO_2 concentration (Soussana et al., 2010).

Lobell et al. (2010) emphasize three important points that users of crop models should consider in future work. First, statistical models represent a very useful if imperfect tool for projecting climate responses, with all three statistical approaches able to reproduce some of the key aspects of the simulated responses to temperature and precipitation changes. Second, the relative performance of statistical models will depend on the response in question. Time-series models appear particularly good at estimating precipitation responses, while panel or cross-section methods appear more reliable for temperature responses. Finally, the accuracy of statistical approaches depends on the spatial scale of the training data and the scale at which output projections are required. In general, statistical models appear to become more appropriate as the scale of interest becomes broader. It is also at these broader scales that climate projections are most available and reliable, and therefore statistical models are likely to continue to play an important role in anticipating future impacts of climate change.

Projecting the qualitative consequences for the Republic of Moldovan agriculture as a result of global climate change is very difficult, because of the uncertainty of variety natural changes and the lack of reliable modeling tools as crop growth models, which need many input data and calibration. First assessment of the impact of climate change on crop production in Moldova was conducted by the authors as part of the First National Communication of the Republic of Moldova under the UNFCCC (2000). Continuation of the research in this area has been allowed to project the effect of direct exposure to elevated CO_2 concentrations in the atmosphere on a yield of winter wheat and maize for different time slices and models within the Second National Communication of the Republic of Moldova under the UNFCCC (2009).

The purpose of our study, realized in the frame of Third National Communication of the Republic of Moldova under the UNFCCC (2013), was to (i) examine the statistic-empirical relationships between observed mean temperature and precipitation during growing season and average crop yield, based on yield data at the Republic of Moldova's agricultural enterprises of various categories, and (ii) use these relationships to postulate possible projections of future changes in yield of these crops by 2020s, 2050s and 2080s, based on the projected changes from an ensemble of 10 GCM for three SRES A2 (high), A1B (medium) and B1(low) emission scenarios of greenhouse gases and aerosols. The typical winter (*Triticum aestivum* L.) and summer (*Zea Mays, Helianthus annuus* L., *Beta vulgaris* L. and *Nicotiana* L.) crops were considered in this study in order to analyze the specific interactions between the changing climate and crops having different seasonal growth cycles. The interactions phenology-environment in a changing climate were highlighted in order to explain the possible impact on final yield the most vulnerable cereal crops (winter wheat and maize).

4.3.1. Data and Methods

The assessment of the climate change impact on agricultural sector was made based on projections of changes in temperature and precipitation received by regionalization of global experiments the most reliable in the Republic of Moldova 10 GCMs for the three SRES A2, A1B and B1 emission scenarios of greenhouse gases and aerosols see more in Taranu et al. (2012). To assess the vulnerability of main agricultural crops to climate change was used empirical-statistical approach linking fluctuations of crops production yields to climate conditions during the growing season conform to Constantinov et al. (2009). Statistical analysis of the possible impact of climate change on yield of cereal (winter wheat and grain corn), oil (sunflower) and technical (sugar beet and tobacco) crops was carried out in several steps:

Firstly, according to the statistical data on productivity at agricultural enterprises of various categories were constructed linear and polynomial trends for crop yields in the Republic of Moldova over the two distinct time periods: 1961-1990 (baseline period) and 1981-2010 (recent period).

Secondly, multiple regression equations linking yield variability with average monthly temperature and precipitation during the agricultural crops growing season, with the highest level of statistical significance were calculated (using the statistical application package STATGRAPHICS Centurion and Microsoft Office Excel). The temperature and precipitation predictor variables were selected in conformity with the step by step regression analysis taking into account their contribution to the crops productivity and consecutive analysis of all possible combinations to find the most reliable model. The regression coefficients of the remaining months show, in what direction and how much may be modified the crops productivity in response to changes in the temperature and precipitation of the respective month.

Finally, the analysis of the impact of future climate changes, determined by temperature and precipitation conditions on the yield of major cereal, oil and technical crops without undertaken any adaptation measures was carried out according to methodological approach (Constantinov et al., 2009). Using the regression equations relationship in the yield variability of major agricultural crops with temperature and precipitation of the growing season, there were calculated projections of future yield changes in the Republic of Moldova, (%/30 years) according to an ensemble from 10 Global Climate Models (GCMs) for three SRES A2, A1B and B1 emission scenarios relative to 1981-2010 recent period.

4.3.2. Observed Linear Trends for the Major Annual Crops Yield

The yield of most crops has increased over the past several decades. However, in the most recent decade, yields have stagnated for many crops in several regions, whereas temperatures have generally increased. The reasons for this stagnation are debated, and could include agricultural policy (Finger, 2010), fundamental genetic limits (Calderini, Slafer, 1998), climate (Lobell, Asner, 2003; Brisson et al., 2010), agronomic practice and crop management (Brisson et al., 2010).

A global analysis of yields of cereal crops (wheat, maize and barley) has shown yield decreases due to increasing mean temperatures (Lobell, Field, 2007). Similar effects have been observed for various countries in Europe (Kristensen et al., 2011). Increasing temperatures have also been attributed as one of the main causes for the lack of yield increase of winter wheat in France despite improvements in crop breeding (Brisson et al., 2010). Grain yields in corn have been steadily increasing in northern Europe, whereas yields in southern Europe seem to have been stagnating. There is also a tendency for increasing variability of grain yields in France and Italy, linked to occurrence of heat waves and droughts (Olesen et al., 2011).

During the 2003 and 2010 summer heat waves, grain-harvest losses reached 20 and 30% in affected regions of Europe and Russia, respectively (Barriopedro et al., 2011; Ciais et al., 2005). Cereals production fell on average by

40% in the Iberian Peninsula during the intense 2004/2005 drought (EEA, 2010a). Climate-induced variability in wheat production has increased in recent decades in southern and central Europe (Brisson et al., 2010; Ladanyi, 2008; Hawkins et al., 2013), but no consistent reduction has been recorded in the northernmost areas of Europe (Peltonen-Sainio et al., 2010). Country-scale rainfed cereals yields are below agro-climatic potentials (Supit et al., 2010) and wheat yield increases have levelled off in several countries over 1961-2009 (Olesen et al., 2011). High temperatures and droughts during grain filling has contributed to the lack of yield increase of winter wheat in France despite improvements in crop breeding (Brisson et al., 2010; Kristensen et al., 2011).

In contrast, in eastern Scotland, warming has favored an increase in potato yields since 1960 (Gregory, Marshall, 2012). Potato and sugar beet seem to have responded positively to the increasing temperatures by increasing yields, most likely due to longer growing seasons (Peltonen-Sainio et al., 2010).

According to Daradur (2001), agricultural crop productivity could be determined by the level of farming culture, by soil, climatic and weather conditions. Following the generally accepted methodology, we have viewed crop productivity (*Yi*) as a sum of two elements:

$$Y_i = Y_i^{(T)} + \Delta Y_i^{(T)} \quad (4.1)$$

Where $Y_i^{(T)}$ is presented via dynamic average value, determined by the rate of farming intensification and climatic conditions close to average for many years, and the deviation from it $\Delta Y_i^{(T)}$ is explained by the anomaly of weather conditions of the latter. In other words, the tendencies of crop productivity depend on the implementation of scientific and technical achievements into practice, increased investment into technical means, compliance with the agro technical measures and crop rotation, improved labor organization, better use of fertilizers, modification of varieties used, irrigation, etc. These tendencies are a consequence of gradual improvement in the culture of farming in average soil and climatic conditions.

The linear trends of major agricultural crops productivity variability on the territory of the Republic of Moldova (RM) for years 1961-1990 have been characterized by a sustainable increase of crop yield, by 7.3 q/ha per decade for winter wheat, 3.5 q/ha per decade for grain maize, 0.9 q/ha per decade for sunflower and 25.6 q/ha per decade for sugar beet (**Table 4-1; Figure 4-1**). Crop productivity increased significantly due to the implementation of intensive technologies and use of irrigation in the 1981-1990 and has reached the maximum level for winter wheat – 35.0 q/ha; maize for grain – 39.0 q/ha; sunflower – 18.0 q/ha; and sugar beet – 272.5 q/ha.

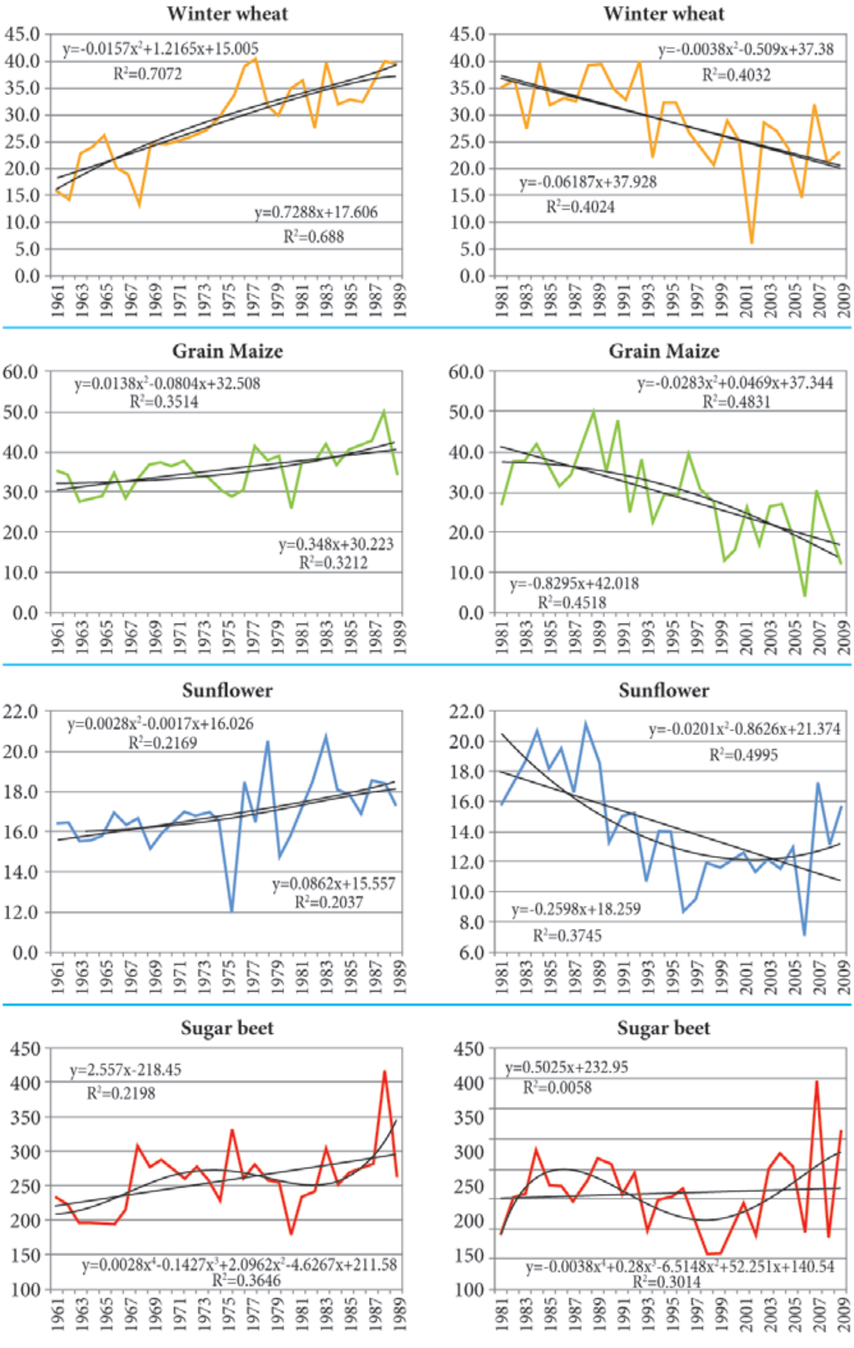


Figure 4-1: Yield Variability Trends for the Main Crops and Their Coefficients of Determination (R^2) for Two Observation Periods (left - 1961-1990, right - 1981-2010) in the Republic of Moldova

Then, in the forthcoming three decades (1981-2010) there was a tendency for sharp decrease in crop productivity by 6.2 q/ha per decade for winter wheat, 8.3 q/ha per decade for grain maize, 2.5 q/ha per decade for sunflower. The greatest decrease in crop productivity was observed in the 1991 – 2010 years, for winter wheat reaching the level of 23.0 q/ha; for grain maize – 19.8 q/ha, while for sunflower – 12.6 q/ha.

Table 4-1: Yield linear trends (quintal/year) of major crops and their statistical significance *(p-value)* for the three observation periods in the Republic of Moldova

Crop	*Yield*					
	1961-1990		1981-2010		1991-2010	
	Trend	*p-value*	*Trend*	*p-value*	*Trend*	*p-value*
Winter wheat	0.7288	**0.0000**	-0.6187	**0.0003**	-0.6958	**0.0297**
Grain maize	0.3480	**0.0011**	-0.8295	**0.0000**	-1.0674	**0.0042**
Sunflower	0.0862	**0.0123**	-0.2598	**0.0004**	-0.0038	0.9697
Sugar beet	2.5578	**0.0090**	0.5025	0.6956	0.5025	0.3392
Tobacco	-	-	-0.0687	0.2486	0.0030	0.9774

Note: Bold is used to mark statistically significant values.

4.3.3. The Relationship of Major Agricultural Crops Yield Variability with Temperature and Precipitation during the Vegetation Period (1981 - 2010)

The analysis of the data presented in the **Table 4-2** shows that the influence of climatic conditions during growing season on winter wheat yield in the 1981-2010 years was statistically significant at 99.9% highest level of significance ($p \leq 0.001$). Coefficient of determination R^2 shows that the combined effect of precipitation and temperature defined about 65.3% of the variability of average annual productivity of winter wheat during this period. The regression equation characterizing the interrelation of agricultural crops (corn, sunflower, sugar beet and tobacco) yield variability with the temperature and precipitations during the vegetation period, revealed as well a high level of significance at 99% ($p \leq 0.01$).

The combined effect of temperature and precipitation during the vegetation period determined the yield variability at the level of 66.4 per cent for sunflower, 64.1 per cent for corn, 53.2 per cent for tobacco and 49.9 per cent for sugar beet.

Table 4-2: The relationship of Major Agricultural Crops Yield Variability with Temperature and Precipitation during the Vegetation Period (1981 - 2010)

Crop	Regression equation	*p* – value	R^2, %
Winter wheat	$Y = 130.473 - 2.27358*T_V - 2.60312*T_{VII} - 0.815868*T_X + 0.0181492*P_{VI} + 0.0335445*P_{IX}$	**0.0003**	65.26
Grain maize	$Y = 177.365 - 2.20195*T_{VI} - 1.62369*T_{VII} - 3.21222*T_{VIII} + 0.0169456*P_{IV} + 0.0113687*P_{VII}$	**0.0002**	61.79
Sunflower	$Y = 41.6803 - 0.817938*T_{VIII} - 0.671806*T_X + 0.0242598*P_{VI} - 0.0415422*P_{VIII} - 0.0454977*P_X$	**0.0011**	66.36
Sugar beet	$Y = 431.527 - 16.9561*T_{VI} + 1.09464*P_{IV} + 0.338911*P_V + 0.241995*P_{VII} + 0.314864*P_{VIII}$	**0.0048**	49.92
Tobacco	$Y = 26.6589 - 1.05*T_X + 0.0488325*P_V - 0.0176172*P_{VIII} - 0.0229145*P_{IX} - 0.031975*P_X$	**0.0024**	53.20

Note: Y - yield, quintal/ha; T - average monthly air temperature, ^{0}C; P - average monthly precipitations, mm; with Roman numerals are noted the corresponding months of vegetation period: since April (IV) to October (X). Bold is used to mark statistically significant values.

4.3.4. Projections of Future Changes in Productivity of Major Agricultural Crops

The regional distribution of climate change impacts on agricultural production is likely to vary widely (Iglesias et al., 2012), (Donatelli et al., 2012). Southern Europe would experience the largest yield losses (-25% by 2080 under a 5.4°C warming (Ciscar et al., 2011) with increased risks of rain fed summer crop failure (Bindi, Olesen, 2011; Ferrara et al., 2010; Ruiz-Ramos et al., 2011). Warmer and drier conditions by 2050 (Trnka et al., 2010; 2011) would cause moderate declines in crop yields in Central Europe regions (Ciscar et al., 2011). In Western Europe, increased heat stress around flowering could cause considerable yield losses in wheat (Semenov, 2009). For Northern Europe, there is diverging evidence concerning future impacts. Positive yield changes combined with the expansion of climatically suitable areas could lead to crop production increases (between 2.5 and 5.4°C regional warming) (Bindi, Olesen, 2011).

However, increased climatic variability would limit winter crops expansion (Peltonen-Sainio et al., 2010) and cause at high latitudes high risk of marked cereal yield loss (Rötter et al., 2011). Cereal yield reduction from ozone (Fuhrer, 2009) could reach 6 and 10% in 2030 for the European Union with the B1 and A2 scenarios, respectively (Avnery et al., 2011a,b). Because of limited land availability and soil fertility outside of chernozem (black earth) areas, the shift of agriculture to the boreal forest zone would not compensate for crop losses due to increasing aridity in South European regions of Russia with the best soils (Dronin, Kirilenko, 2011; IPCC, 2014).

For the Republic of Moldova according to Taranu (2013, 2014) without undertaken any adaptation measures it can be expected by 2080s significant drop in the productivity for grain maize from 49% (SRES B1) to 74% (SRES A1B) and winter wheat from 38% (SRES B1) to 71% (SRES A2); a medium drop in the productivity for sunflower from 11% (SRES B1) to 33% (SRES B2), respectively for sugar beet from 10% (SRES B1) to 20% (SRES B2); and for tobacco from 9% (SRES B1) to 19% (SRES B2), in comparison with the average productivity of the Republic of Moldova's major agricultural crops in the most recent period of 1981-2010.

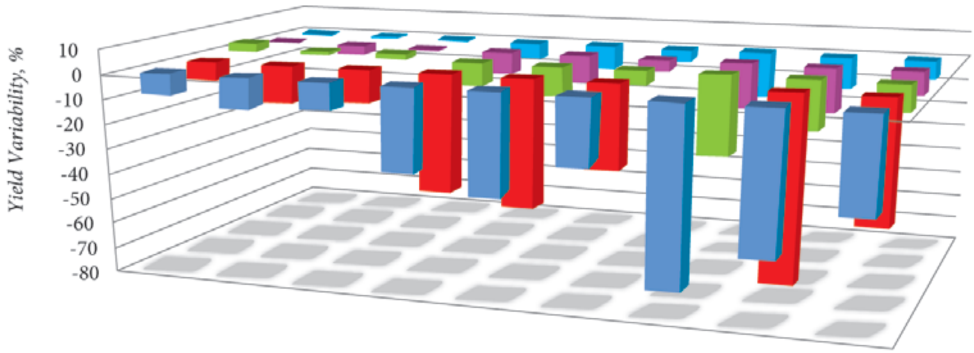
Crops are known to be sensitive to various aspects of climate. Persistently elevated temperatures have long been known to accelerate progress towards maturity, and more recently have been shown to have a significant impact on leaf ageing (Asseng et al., 2011; Lobell et al., 2012). Crop responses to shorter periods of high temperature, particularly when coincident with flowering, show yield falling dramatically beyond a threshold temperature (Luo, 2011). Maize is particularly sensitive to hot daytime temperatures, with rapid losses when temperature exceeds 30°C (Schlenker, Roberts, 2009; Lobell et al., 2011a).

Crop yields are also sensitive to precipitation. Quantifying the relative effect of temperature and precipitation variability is important for understanding impacts and developing adaptation options for future climatic changes. As temperatures are projected to significantly increase over the next few decades due to continuing anthropogenic emissions of greenhouse gases, whereas precipitation changes are far less certain (Meehl et al., 2007; Hawkins, Sutton, 2011), this suggests predictability in future crop yields. In addition, it is likely that temperature will have the largest impact as the projected changes are far further outside the range of natural variability than for precipitation changes (Lobell, Burke, 2008), and because of the seasonal timing of changes in climate (Semenov, Shewry, 2011).

To effectively guide adaptation to future changes, perhaps with different crop growing strategies (Rosenzweig, Tubiello, 2007) or selective crop breeding (Cattivelli et al., 2008), there should several key questions to consider (Hawkins et al, 2013). Firstly, can the relative effects of improved technology, precipitation variability and increasing temperatures be quantified?

If so, what is the relative size of the effects of rainfall and hot temperatures on yields? And, what level of technology development may be required to overcome any impact of future climatic changes on yield?

The possible changes in the yield of major agricultural crops (winter wheat, grain maize, sunflower, sugar beet and tobacco), due to future climate changes in the Republic of Moldova, without undertaken any adaptation measures, is revealed in **Figure 4-2**.



	2020s			2050s			2080s		
	A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Winter wheat	-9	-13	-12	-34	-41	-27	-71	-56	-38
Grain maize	-9	-16	-14	-48	-52	-35		-74	-49
Sunflower	4	2	3	-10	-13	-7	-33	-21	-11
Sugar beet	0	-5	-1	-10	-12	-5	-20	-19	-10
Tobacco	-1	-1	0	-8	-10	-6	-19	-14	-9

Figure 4-2: Projections of Future Changes in Productivity of Major Agricultural Crops in the Republic of Moldova, (%/30 years) Relative to 1981-2010 Current Period, According to an Ensemble from 10 GCMs for SRES A2, A1B and B1 Emission scenarios in the XXI century

4.3.4.1. Winter Wheat

As one of the most essential resources to world food supply, wheat yield is very sensitive to temperature change (Schmidhuber, Tubiello, 2007; Lobell et al., 2011). Lobell and Field (2007) reported about 5.4% decrease in global mean wheat yield per 1°C increase in temperature, but Asseng et al. (2011) suggested from model simulations that an average growing-season temperature increase by 2°C could cause 50% grain yield reduction in Australia because temperatures more than 34°C stimulate leaf senescence.

The analysis of the obtained results revealed that due to the impact of the main climate indicators (temperature and precipitation) in the Republic of Moldova, productivity of the winter wheat by 2020s could decrease from 9% (SRES A2) to 12% (SRES B1) (**Figure 4-2**). In comparison with the 1981-2010 time periods, by 2050s the crop productivity may decrease in dependence of the assessed emission scenario from 27% (SRES B1) to 34% (SRES A2). The maximum values of productivity decrease may be reached by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of winter wheat may decrease from 38% (SRES B1) to 71% (SRES A2).

Until now in the Republic of Moldova vulnerability assessment of agricultural crops production was carried out only at the national level, while the development of adaptation programs require at least district or local level. Proceeding from this, additionally to the national level, we have assessed the impact of temperature and precipitation during the growing season on winter wheat yield for the Republic of Moldova's territorial administrative units (district level) in order to distinguish the most and least vulnerable to climate change winter wheat production districts in the 1981-2010 years.

The analysis of the data presented in the **Table 4-3** reveals that the influence of climatic conditions during growing season on winter wheat yield in the 1981-2010 years was statistically significant at 99.9% highest level of significance ($p \leq 0.001$) in the majority of districts of the Republic of Moldova. Coefficient of determination R^2 shows that the combined effect of precipitation and temperature defined from 57.6 to 93.2% of the variability of average annual yield of winter wheat during this period in northern AEZ; from 51.3 to 71.1% of the variability of yield in central AEZ; and from 53.6 to 72.7% of the variability of yield in southern AEZ. The greatest impact of climatic conditions during growing season in the 1981-2010 time series on productivity of winter wheat is determined in districts: Briceni, Donduseni, Drochia, Edinet, Floresti, Falesti, Ocnita, Singerei, Soroca, Anenii Noi, Criuleni, Dubasari, Hincesti, Ialoveni, Orhei, Straseni, Telenesti, Basarabeasca, Cahul, Causeni, Taraclia and Stefan Voda, coefficient of determination R^2 is from 62.0 to 93.2% and the lowest one in the districts: Calarasi, Nisporeni, Soldanesti, Ungeni, Cantemir, Leova and Cimislia, coefficient of determination R^2 is from 51.3 to 59.4% (**Table 4-3**).

Table 4-3: The relationship of Winter Wheat Yield Variability with Temperature and Precipitation during the Vegetation Period (1981 - 2010)

District	Regression equation	p – value	R^2, %
Northern AEZ			
Briceni	$Y = 95.00 - 1.29*T_{II} - 2.16*T_{IV} - 1.70*T_{VII} - 0.42*P_{I} + 0.11*P_{IV} + 0.05*P_{VI} - 0.07*P_{VII}$	**0.0000**	86.52
Donduseni	$Y = 119.74 + 0.63*T_{III} - 1.21*T_{IV} - 1.32*T_{V} - 2.93*T_{VII} - 0.38*T_{X} + 0.05*P_{VI} - 0.05*P_{VII}$	**0.0005**	69.36
Drochia	$Y = 121.16 - 0.88*T_{II} - 1.59*T_{IV} - 4.97*T_{V} - 2.55*T_{VI} - 3.47*T_{VII} + 3.61*T_{VIII} + 2.64*T_{IX} - 0.243*P_{I} - 0.12*P_{II} - 0.11*P_{III} + 0.11*P_{VI} + 0.07*P_{IX} + 0.19*P_{X}$	**0.0000**	93.23
Edinet	$Y = 97.47 - 1.06*T_{II} - 3.41*T_{VI} - 1.11*T_{X} - 0.21*P_{I} - 0.11*P_{II} + 0.11*P_{IV} + 0.03*P_{VI} - 0.03*P_{VII}$	**0.0018**	68.01
Falesti	$Y = 156.58 - 2.49*T_{V} - 2.59935*T_{VI} - 1.9819*T_{VII}$	**0.0000**	63.81
Floresti	$Y = 152.62 - 2.42*T_{V} - 2.43*T_{VI} - 2.38*T_{VII} + 0.11*P_{IV}$	**0.0000**	75.41
Glodeni	$Y = 153.42 - 2.65*T_{V} - 2.28*T_{VI} - 1.93*T_{VII}$	**0.0001**	57.62
Ocnita	$Y = 93.34 - 1.38*T_{II} - 3.12*T_{VI} - 1.15*T_{X} - 0.26*P_{I} - 0.15*P_{II} + 0.12*P_{IV}$	**0.0001**	70.22
Riscani	$Y = 93.52 - 0.17*P_{I} - 0.10*P_{II} + 0.12*P_{IV} + 0.01*P_{VI} - 0.02*P_{VII} - 0.69*T_{II} - 3.20*T_{VI} - 0.78*T_{X}$	**0.0153**	58.25
Singerei	$Y = 111.70 + 0.41*T_{II} - 1.60*T_{IV} - 3.74*T_{VI} - 1.32*T_{X} + 0.12*P_{IV} - 0.02*P_{VI} - 0.03*P_{VII} + 0.15*P_{XII}$	**0.0003**	74.20
Soroca	$Y = 96.87 - 0.14*T_{II} - 0.84*T_{IV} - 3.36*T_{VI} - 0.96*T_{X} + 0.10*P_{IV} - 0.01*P_{VI} - 0.03*P_{VII} + 0.07*P_{XII}$	**0.0055**	63.34
Central AEZ			
Anenii Noi	$Y = 164.35 - 3.10*T_{V} - 3.24*T_{VII} - 1.61*T_{X} + 0.01*P_{VI} + 0.07*P_{IX}$	**0.0003**	64.38
Calarasi	$Y = 95.450 - 1.256*T_{V} - 1.57*T_{VII} - 1.72*T_{X} + 0.04*P_{VI} + 0.02*P_{IX}$	**0.0066**	51.31
Criuleni	$Y = 158.74 - 3.57*T_{V} - 2.61*T_{VII} - 1.68*T_{X} + 0.05*P_{VI} + 0.07*P_{IX}$	**0.0003**	64.94
Dubăsari	$Y = 161.03 - 3.14*T_{V} - 2.34*T_{VII} - 3.217*T_{X} + 0.05*P_{VI} + 0.08*P_{IX}$	**0.0000**	71.15
Hincesti	$Y = 146.53 - 2.77*T_{V} - 2.54*T_{VII} - 1.98*T_{X} + 0.02*P_{VI} + 0.06*P_{IX}$	**0.0003**	65.31
Ialoveni	$Y = 146.31 - 2.84*T_{V} - 2.59*T_{VII} - 1.73*T_{X} + 0.02*P_{VI} + 0.05*P_{IX}$	**0.0003**	64.79
Nisporeni	$Y = 136.34 - 1.85*T_{V} - 2.10*T_{VII} - 3.44*T_{X} + 0.04*P_{VI} + 0.06*P_{IX}$	**0.0023**	56.39
Orhei	$Y = 145.35 - 2.84*T_{V} - 2.69*T_{VII} - 1.48*T_{X} + 0.05*P_{VI} + 0.05*P_{IX}$	**0.0006**	62.07
Rezina	$Y = 119.65 - 2.09*T_{V} - 2.72*T_{VII} - 0.32*T_{X} + 0.04*P_{VI} + 0.03*P_{IX}$	**0.0005**	62.82
Straseni	$Y = 130.28 - 2.63*T_{V} - 2.50*T_{VII} - 0.60*T_{X} + 0.02*P_{VI} + 0.01*P_{IX}$	**0.0006**	62.27
Soldanesti	$Y = 113.24 - 2.19*T_{V} - 2.44*T_{VII} + 0.02*T_{X} + 0.02*P_{VI} + 0.03*P_{IX}$	**0.0054**	52.35
Teleneşti	$Y = 140.64 - 2.98*T_{V} - 3.16*T_{VII} - 0.03*T_{X} + 0.02*P_{VI} + 0.06*P_{IX}$	**0.0004**	64.01
Ungheni	$Y = 112.76 - 1.98*T_{V} - 2.20*T_{VII} - 0.26*T_{X} + 0.02*P_{VI} + 0.04*P_{IX}$	**0.0026**	55.94
Southern AEZ			
Basarabeasca	$Y = 155.03 - 1.87*T_{V} - 2.13*T_{VI} - 1.71*T_{VII} - 1.71*T_{X} - 0.03*P_{VI} + 0.01*P_{VIII} + 0.05*P_{IX}$	**0.0039**	62.75
Cahul	$Y = 148.24 - 1.94*T_{V} + 0.04*T_{VI} - 3.05*T_{VII} - 1.80*T_{X} - 0.03*P_{VI} - 0.033*P_{VIII} + 0.03*P_{IX}$	**0.0004**	71.42
Cantemir	$Y = 112.30 - 2.06*T_{V} - 0.13*T_{VI} - 2.06*T_{VII} - 0.45*T_{X} - 0.01*P_{VI} + 0.02*P_{VIII} + 0.03*P_{IX}$	**0.0077**	59.43
Causeni	$Y = 148.98 - 1.73*T_{V} - 1.24*T_{VI} - 2.55*T_{VII} - 1.15*T_{X} - 0.04*P_{VI} + 0.01*P_{VIII} + 0.07*P_{IX}$	**0.0032**	63.57
Cimislia	$Y = 143.66 - 2.19*T_{V} - 1.46*T_{VI} - 1.83*T_{VII} - 1.15*T_{X} - 0.01*P_{VI} + 0.01*P_{VIII} + 0.03*P_{IX}$	**0.0187**	54.65
Leova	$Y = 112.93 - 1.85*T_{V} - 0.35*T_{VI} - 1.91*T_{VII} - 0.72*T_{X} - 0.01*P_{VI} + 0.02*P_{VIII} + 0.02*P_{IX}$	**0.0225**	53.55
Stefan Voda	$Y = 165.27 - 2.40*T_{V} - 0.94*T_{VI} - 2.68*T_{VII} - 1.43*T_{X} - 0.05*P_{VI} - 0.02*P_{VIII} + 0.06*P_{IX}$	**0.0003**	72.67
Taraclia	$Y = 157.53 - 2.71*T_{V} - 0.53*T_{VI} - 2.15*T_{VII} - 2.37*T_{X} - 0.04*P_{VI} + 0.01*P_{VIII} + 0.07*P_{IX}$	**0.0009**	68.55

Note: Bold is used to mark statistically significant values.

Using these regression equations relationship in the yield variability of winter wheat with the temperature and precipitation of the growing season in three AEZs, there were calculated projections of future winter wheat yield changes in the Republic of Moldova's districts, (%/30 years) according to an ensemble from 10 Global Climate Models (GCMs) for three SRES A2, A1B and B1 emission scenarios relative to 1981-2010 current periods. Without application of adaptation measures the most vulnerable to climate change in the Republic of Moldova in territorial aspect would be the southern and central AEZs and in less extent the northern AEZ (**Table 4-4**).

According to projections the most vulnerable districts for winter wheat cultivation will be Basarabeasca, Taraclia, Cimislia, Cahul, Stefan Voda and Causeni in southern; and Dubasari, Anenii Noi, Hincesti, Ialoveni, Orhei, Telenesti and Nisporeni in central AEZs in which productivity of the winter wheat by 2020s could decrease from 11 to 15% (SRES A2) and/or from 12 to 19% (SRES B1). In comparison with the 1981-2010 time series, by 2050s the crop productivity may decrease, in dependence of the assessed emission scenario, from 40 to 52% under SRES A2 and/or from 32 to 42% under SRES B1. The maximum values of productivity decrease may be reached by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of winter wheat may decrease from 46-58% under SRES B1 to 97 % under SRES A2.

The least vulnerable districts for winter wheat cultivation will be Riscani, Soroca, Donduseni, Drochia, Briceni and Singerei in the northern AEZ; Ungheni, Calaras and Soldanesti in the central AEZ, in which the productivity of the winter wheat by 2020s could decrease from 0 to 4% under SRES A2 and/or from 2 to 7% under SRES B1. In comparison with the 1981-2010 time series, by 2050s the crop productivity may decrease in dependence of the assessed emission scenario from 19 to 28% under SRES A2 and/or from 13 to 22% under SRES B1. The maximum values of productivity decrease may be reached by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of winter wheat in these districts may decrease from 21-34% under SRES B1 and/or from 48 to 64% under SRES A2 (**Table 4-4**).

Table 4-4: Projected Winter Wheat Yield Changes Relative to the Current situation (%/30 Year) under the Ensemble of 10 GCMs for SRES A2, A1B and B1 scenarios

AEZs/district	1981-2010, q/ha	2020s			2050s			2080s		
		A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Northern AEZ										
Briceni	33.5	-12	-10	-10	-31	-34	-24	-54	-49	-32
Donduseni	29.0	-3	-6	-6	-24	-32	-17	-52	-48	-28
Drochia	32.1	-8	-11	-13	-30	-38	-25	-52	-58	-36
Edinet	30.0	-12	-15	-12	-36	-38	-27	-63	-57	-37
Falesti	32.4	-6	-13	-11	-31	-40	-26	-63	-61	-37
Floresti	29.3	-4	-11	-9	-33	-41	-26	-68	-65	-38
Glodeni	33.6	-5	-11	-10	-29	-36	-24	-58	-56	-34
Ocnita	30.4	-17	-19	-16	-41	-42	-33	-69	-62	-41
Riscani	31.4	-10	-13	-10	-28	-30	-22	-49	-45	-29
Singerei	30.6	-10	-13	-11	-32	-34	-24	-54	-52	-34
Soroca	29.5	-7	-11	-9	-28	-30	-21	-50	-47	-30
Central AEZ										
Anenii Noi	28.1	-13	-18	-16	-48	-58	-39		-81	-54
Călăraşi	24.9	-4	-7	-6	-28	-34	-21	-64	-48	-31
Criuleni	30.4	-9	-15	-13	-42	-51	-34	-91	-72	-48
Dubăsari	29.6	-13	-17	-17	-49	-59	-40		-82	-55
Hincesti	27.1	-11	-16	-15	-45	-54	-36	-96	-75	-51
Ialoveni	26.6	-10	-15	-14	-43	-53	-35	-94	-74	-49
Nisporeni	27.3	-12	-15	-14	-46	-54	-36	-98	-75	-51
Orhei	28.3	-10	-14	-13	-41	-50	-33	-90	-70	-46
Rezina	25.0	-5	-9	-7	-32	-40	-24	-74	-56	-36
Străşeni	26.5	-5	-10	-8	-32	-41	-26	-73	-58	-37
Şoldăneşti	25.5	-4	-8	-7	-28	-35	-22	-64	-50	-32
Teleneşti	25.1	-8	-14	-12	-40	-50	-32	-89	-70	-46
Ungheni	30.9	0	-2	-2	-19	-24	-13	-48	-36	-21
Southern AEZ										
Basarabeasca	25.5	-15	-20	-19	-52	-60	-42		-89	-58
Cahul	26.4	-11	-16	-14	-43	-52	-35	-92	-76	-49
Cantemir	26.4	-6	-10	-9	-30	-35	-23	-63	-53	-34
Causeni	26.6	-11	-16	-14	-44	-52	-35	-92	-77	-49
Cimislia	26.1	-13	-18	-17	-46	-53	-37	-92	-78	-51
Leova	26.1	-8	-12	-11	-33	-38	-26	-67	-56	-36
Stefan Voda	30.2	-12	-17	-16	-43	-51	-36	-89	-75	-49
Taraclia	28.7	-15	-19	-18	-48	-56	-40	-97	-81	-54

4.3.4.2. Grain Corn

Lobell & Asner (2003) evaluated grain corn and soybean production relative to climatic variation in the United States, reporting a 17 percent reduction in yield for every 1°C rise in temperature, but this response is unlikely because the confounding effect of rainfall was not considered. In a recent evaluation of global grain corn production response to both temperature and rainfall over the period 1961-2002 (Lobell, Field, 2007) reported an 8.3 percent yield reduction per 1°C rise in temperature.

The analysis of obtained results (**Figure 4-2**) revealed, that due to changes in heat and water regime during the growing season, yield of grain corn in RM by 2020s may decrease from 9-14% (SRES A2 and B1) and to 16% (SRES A1B). In comparison with the 1981-2010 years, by 2050s the crop productivity may decrease in dependence of the assessed emission scenario from 35% (SRES B1) to 48-52% (SRES A2 and A1B). The maximum values of productivity decrease may be reached by 2080s. So, due to changes in values of main climate predictor variables – precipitation and temperature – the productivity of grain corn may decrease from 49% (SRES B1) to 74% (SRES A1B).

Until now in the RM vulnerability assessment of agricultural crops production was carried out only at the national level, while the development of adaptation programs require at least district or local level. Proceeding from this, additionally to the national level, we have assessed the impact of temperature and precipitation during the growing season on grain corn productivity in the Republic of Moldova's territorial administrative units (district level) in order to distinguish the most and least vulnerable to climate change grain corn production districts in the 1981-2010 years.

The analysis of the data presented in the **Table 4-5** shows that the influence of climatic conditions during growing season on grain corn yield in the 1981-2010 years was statistically significant at 99.99 % highest and 99.95 high level of significance (*$p \leq 0.001$, $p \leq 0.01$ and $p \leq 0.05$)* in the majority of districts of the Republic of Moldova's AEZs. Coefficient of determination R^2 shows that the combined effect of precipitation and temperature defined from 57.4 to 76.2% of the variability of average annual yield of grain corn during this period in the northern AEZ; from 41.4 to 79.0% of the variability of yield in the central AEZ; and from 57.1 to 83.6% of the variability of yield in the southern AEZ.

Table 4-5: The relationship of Grain Corn Yield Variability with Temperature and Precipitation during the Vegetation Period (1981 - 2010)

District	Regression equation	p – value	R^2, %
Northern AEZ			
Briceni	$Y = 245.87 - 3.32*T_{VII} - 4.21*T_{VIII} - 7.37*T_{X} + 0.12*P_{IV} - 0.05*P_{VIII}$	**0.0161**	57.36
Donduseni	$Y = 90.96 - 4.98*T_{VII} + 4.67*T_{IX} - 3.14*T_{X} - 0.06*P_{VII} + 0.11*P_{IX}$	**0.0007**	70.93
Drochia	$Y = 93.61 - 2.30*T_{VII} - 3.31*T_{VIII} + 2.50*T_{IX} + 0.19*P_{IV} - 0.05*P_{VIII}$	**0.0081**	59.34
Edinet	$Y = 164.35 - 4.06*T_{VII} - 4.09*T_{VIII} + 1.46*T_{IX} + 0.13*P_{IV} - 0.03*P_{VIII}$	**0.0019**	66.58
Falesti	$Y = 83.57 - 3.37*T_{V} - 1.78*T_{X} + 0.16*P_{IV} + 0.04*P_{VII} - 0.10*P_{IX}$	**0.0092**	58.56
Floresti	$Y = 206.72 + 1.84*T_{IV} - 3.65*T_{VI} - 5.21*T_{VIII} - 4.45*T_{X} + 0.24*P_{IV}$	**0.0015**	67.85
Glodeni	$Y = 151.114 + 1.15*T_{IV} - 3.02*T_{VII} - 3.94*T_{VIII} + 0.21*P_{IV} - 0.08*P_{V}$	**0.0003**	74.19
Ocnita	$Y = 156.55 - 2.94*T_{VII} - 3.05*T_{VIII} + 0.16*P_{IV} - 0.08*P_{VII}$	**0.0009**	64.73
Riscani	$Y = 179.89 + 2.26*T_{IV} - 7.79*T_{VIII} - 3.03*T_{X} + 0.25*P_{IV} - 0.06*P_{VIII}$	**0.0002**	76.16
Singerei	$Y = 178.97 - 2.24*T_{VII} - 4.67*T_{VIII} - 2.52*T_{X} + 0.22*P_{IV} - 0.08*P_{VIII}$	**0.0002**	75.05
Soroca	$Y = 161.44 - 3.08*T_{VII} - 3.13*T_{VIII} - 2.39*T_{X} + 0.27*P_{IV} + 0.01*P_{VIII}$	**0.0075**	59.74
Central AEZ			
Anenii Noi	$Y = 175.20 - 3.12*T_{V} - 2.35*T_{VII} - 5.78*T_{X} + 0.23*P_{IV} + 0.07*P_{VII}$	**0.0001**	79.02
Călăraşi	$Y = 142.99 - 2.78*T_{V} - 1.61*T_{VII} - 4.16*T_{X} + 0.10*P_{IV} + 0.05*P_{VI}$	**0.0002**	76.99
Criuleni	$Y = 190.01 + 2.22*T_{IV} - 7.21*T_{VIII} - 4.05*T_{X} + 0.20*P_{IV} + 0.08*P_{VI}$	**0.0001**	76.74
Dubăsari	$Y = 178.58 + 1.14*T_{IV} - 6.05*T_{VIII} - 3.80*T_{X} + 0.19*P_{IV} + 0.01*P_{VI}$	**0.0009**	70.03
Hincesti	$Y = 140.29 - 2.76*T_{V} - 2.58*T_{VII} - 2.24*T_{X} + 0.16*P_{IV} + 0.06*P_{VII}$	**0.0115**	57.27
Ialoveni	$Y = 170.55 - 2.74*T_{V} - 2.79*T_{VII} - 4.59*T_{X} + 0.16*P_{IV} + 0.06*P_{VII}$	**0.0006**	71.53
Nisporeni	$Y = 190.12 - 2.86*T_{V} - 3.90*T_{VII} - 3.39*T_{X} + 0.11*P_{IV} + 0.02*P_{VII}$	**0.0006**	71.23
Orhei	$Y = 181.56 - 3.32*T_{V} - 3.11*T_{VII} - 4.29*T_{X} + 0.16*P_{IV} + 0.06*P_{VII}$	**0.0060**	60.95
Rezina	$Y = 114.93 - 3.53*T_{V} - 1.87*T_{VII} + 0.09*P_{IV} + 0.08*P_{VII}$	**0.0480**	41.42
Străşeni	$Y = 172.082 - 2.73*T_{V} - 3.42*T_{VII} - 3.19*T_{X} + 0.07*P_{IV} + 0.05*P_{VII}$	**0.0069**	60.19
Soldanesti	$Y = 97.5726 - 2.52*T_{V} - 2.00*T_{VII} + 0.15*P_{IV} + 0.091*P_{VII}$	0.0567	40.08
Teleneşti	$Y = 108.485 - 1.53*T_{V} - 2.73*T_{VII} - 1.38*T_{X} + 0.18*P_{IV} + 0.06*P_{VII}$	**0.0020**	66.51
Ungheni	$Y = 180.564 - 3.34*T_{V} - 3.64*T_{VII} - 1.49*T_{X} + 0.04*P_{IV} + 0.06*P_{VII}$	**0.0511**	46.95
Southern AEZ			
Basarabeasca	$Y = 120.23 - 1.29*T_{IV} - 2.84*T_{VIII} - 2.54*T_{X} + 0.13*P_{IV} - 0.01*P_{VII} + 0.05*P_{VIII}$	**0.0002**	80.70
Cahul	$Y = 201.14 - 3.018*T_{V} - 4.87*T_{VII} - 1.79*T_{X} + 0.05*P_{IV} + 0.02*P_{VII}$	**0.0001**	77.91
Cantemir	$Y = 115.96 - 0.44*T_{V} - 3.57*T_{VII} - 0.92*T_{X} + 0.15*P_{IV} - 0.01*P_{VII}$	**0.0119**	57.08
Causeni	$Y = 133.61 - 0.97*T_{V} - 3.92*T_{VII} - 1.11*T_{X} + 0.13*P_{IV} + 0.03*P_{VII}$	**0.0002**	75.70
Cimislia	$Y = 112.39 + 0.35*T_{IV} - 3.34*T_{VIII} - 2.82*T_{X} + 0.26*P_{IV} - 0.02*P_{VIII}$	**0.0019**	66.57
Leova	$Y = 104.63 - 1.33*T_{V} - 2.54*T_{VII} - 1.00*T_{X} + 0.190*P_{IV} + 0.04*P_{VII}$	**0.0086**	58.98
Stefan Voda	$Y = 145.56 - 1.77*T_{V} - 4.11*T_{VII} - 0.27*T_{X} + 0.07*P_{IV} + 0.03*P_{VII}$	**0.0000**	83.56
Taraclia	$Y = 151.93 - 1.35*T_{V} - 3.88*T_{VII} - 2.23*T_{X} + 0.17*P_{IV} + 0.03*P_{VII}$	**0.0005**	72.37
UTA Gagauzia	$Y = 154.20 - 1.58*T_{V} - 3.83*T_{VII} - 2.25*T_{X} + 0.19*P_{IV} + 0.01*P_{VII}$	**0.0005**	72.02

Note: Bold is used to mark statistically significant values.

The greatest impact of climatic conditions during growing season in the years 1981-2010 on productivity of grain corn is determined in districts: Donduseni, Edinet, Floresti, Glodeni, Ocnita, Riscani, Singerei, Anenii Noi, Criuleni, Calarasi, Dubasari, Ialoveni, Nisporeni, Telenesti, Basarabeasca, Cahul, Causeni, Cimislia, Taraclia Stefan Voda and UTA Gagauzia, coefficient of determination R^2 is from 64.7 to 83.6%, and the lowest one in the districts: Briceni, Drochia, Falesti, Soroca, Hincesti, Rezina, Ungeni, Cantemir and Leova, coefficient of determination R^2 is from 41.4 to 59.7 %.

Using these regression equations relationship in the yield variability of grain corn with the temperature and precipitation of the growing season in three AEZs, there were calculated projections of future grain corn yield changes in the Republic of Moldova's districts, (%/30 years) according to an ensemble from 10 Global Climate Models (GCMs) for three SRES A2, A1B and B1 emission scenarios relative to 1981-2010 recent period.

Without application of adaptation measures the most vulnerable to climate change in the Republic of Moldova in territorial aspect would be the central AEZ and in less extent the northern and southern AEZs. According to projections, the most vulnerable districts for grain corn cultivation will be Anenii Noi, Orhei, Ialoveni, Straseni, Nisporeni, Calarasi, Criuleni and Dubasari; Briceni and Floresti in the northern AEZ; respectively, Basarabeasca, Cahul, Cimislia, Causeni, Taraclia and UTA in the southern AEZ, in which productivity of the grain corn by 2020s could decrease from 8 to 28% (SRES A2) and/or from 11 to 31% (SRES B1) (**Table 4-6**).

In comparison with the 1981-2010 time series, by 2050s the crop productivity may decrease in dependence of the assessed emission scenario from 57 to 81% (SRES A2) and/or from 44 to 67% (SRES B1). The maximum values of productivity decrease may be reached by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of grain corn may decrease from 47 to 90% (SRES B1).

The least vulnerable districts for grain corn cultivation will be Donduseni, Drochia, Ocnita and Glodeni in the northern AEZ, in which productivity of grain corn by 2020s could increase from 5 to 19% (SRES A2) and/or from 4 to 10% (SRES B1). In comparison with the 1981-2010 time series, by 2080s the grain corn productivity may decrease in dependence of the assessed emission scenario from 4 to 31% (SRES B1) and/or from 17 to 70% (SRES A2).

Table 4-6: Projected Grain Corn Yield Changes Relative to the Current situation (%/30 Year) under the Ensemble of 10 GCMs for SRES A2, A1B and B1 scenarios

AEZs/district	1981-2010, q/ha	2020s			2050s			2080s		
		A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Northern AEZ										
Briceni	36.0	-24	-24	-23	-76	-85	-58			-78
Donduseni	28.9	13	11	7	3	-7	0	-17	-13	-4
Drochia	25.1	19	9	10	0	-10	0	-23	-20	-4
Edinet	28.6	-4	-17	-15	-38	-58	-38	-89	-74	-44
Falesti	24.2	-10	-11	-9	-33	-34	-23	-55	-50	-32
Floresti	28.6	-14	-23	-19	-68	-76	-51			-72
Glodeni	29.1	5	-4	-2	-25	-35	-20	-70	-57	-31
Ocnita	36.7	9	5	4	-13	-21	-9	-44	-37	-17
Riscani	31.1	-2	-9	-7	-44	-51	-32		-79	-45
Singerei	26.2	-5	-11	-9	-55	-65	-40		-98	-56
Soroca	30.7	-4	-8	-6	-42	-51	-29	-96	-76	-44
Central AEZ										
Anenii Noi	25.3	-28	-34	-31	-81	-92	-67			-90
Călăraşi	24.8	-19	-24	-22	-60	-70	-49		-96	-67
Criuleni	28.5	-11	-14	-14	-65	-65	-44		-90	-61
Dubăsari	28.6	-14	-17	-18	-62	-64	-45		-88	-62
Hincesti	24.9	-16	-21	-18	-54	-63	-44		-87	-60
Ialoveni	26.5	-24	-30	-27	-71	-82	-59			-79
Nisporeni	27.5	-21	-26	-23	-66	-78	-54			-74
Orhei	24.0	-27	-34	-30	-81	-94	-67			-90
Rezina	24.3	-6	-13	-10	-35	-42	-28	-76	-61	-40
Străşeni	23.8	-22	-29	-25	-71	-84	-58			-79
Şoldăneşti	23.6	-5	-11	-7	-31	-37	-24	-69	-54	-34
Teleneşti	19.7	-14	-19	-15	-52	-60	-41		-84	-56
Ungheni	34.3	-11	-17	-13	-43	-51	-34	-90	-71	-48
Southern AEZ										
Basarabeasca	24.8	-17	-22	-22	-57	-62	-45		-88	-61
Cahul	27.0	-11	-17	-18	-57	-63	-44		-91	-58
Cantemir	23.8	-7	-13	-10	-39	-45	-29	-85	-69	-42
Causeni	25.1	-8	-10	-11	-48	-51	-35		-76	-47
Cimislia	20.6	-16	-19	-17	-58	-63	-44		-92	-61
Leova	24.7	-4	-4	-5	-31	-32	-22	-67	-49	-29
Stefan Voda	26.5	-6	-10	-11	-37	-43	-29	-79	-63	-39
Taraclia	27.6	-13	-16	-17	-52	-56	-40		-81	-54
UTA Gagauzia	26.0	-11	-13	-14	-51	-55	-39		-81	-51

Without adaptation measures (if maintaining the current cultivation technologies and used varieties), due to changes in climatic conditions in all districts of the Republic of Moldova, by the end of the XXI century, the cultivation of grain corn will be either impossible according to the SRES A2 high emission scenario or economically not cost effective according to the SRES A1B medium and SRES B1 lower emission scenarios.

4.3.4.3. Sunflower

For oil crops, such as sunflower, which is relatively drought-resistant, there are projected more favorable climate conditions during the growing season than for cereal crops: winter wheat and grain corn. Slight increase in productivity by 2-4% it is possible for sunflower in the 2020s, which will be replaced in the future with consecutive decline in yield. By 2050s, the most severe decrease in productivity by 10-13% is projected under the SRES A2 high and SRES A1B medium emission scenario. While under the SRES B1 low emission scenario the projection is more favorable, it is expected a decrease of productivity only by 7%. In 2080s, the most severe yield reduction for sunflower in the Republic of Moldova will be observed according to SRES A2 high emission scenario - by 33%, while for SRES B1 low emission scenario the forecast is more favorable – a decrease by 11% (**Figure 4-2**).

Until now in the Republic of Moldova vulnerability assessment of agricultural crops production was carried out only at the national level, while the development of adaptation programs require at least district or local level. Proceeding from this, additionally to the national level, we have assessed the impact of temperature and precipitation during the growing season on sunflower productivity in the Republic of Moldova's territorial administrative units (district level) in order to distinguish the most and least vulnerable to climate change sunflower production districts in the 1981-2010 years.

The analysis of the data presented in the **Table 4-7** shows that the influence of climatic conditions during growing season on sunflower yield in the 1981-2010 years was statistically significant at 99.9%, 99.0% and 95.0% the highest and high level of significance (*$p \leq 0.001$, $p \leq 0.01$ and $p \leq 0.05$*) in the majority of districts of the Republic of Moldova's AEZs, except Riscani district. Coefficient of determination R^2 shows that the combined effect of precipitation and temperature during growing season defined from 18.3 to 60.0% of the variability of average annual yield of sunflower during this period in the northern AEZ; from 38.1 to 75.0% of the variability of yield in the central AEZ; and from 38.3 to 77.3% of the variability of yield in the southern AEZ.

Table 4-7: The Relationship of Sunflower Yield Variability with Temperature and Precipitation during the Vegetation Period (1981 - 2010)

District	Regression equation	p – value	R^2, %
Northern AEZ			
Briceni	$Y = 72.824 - 1.110*T_{VII} - 1.630*T_{VIII} + 0.029*P_{VI} - 0.026*P_{VII} - 0.031*P_{VIII}$	**0.0041**	53.76
Donduseni	$Y = 62.295 - 1.361*T_{VII} - 1.063*T_{VIII} + 0.038*P_{VI} - 0.013*P_{VII} - 0.006*P_{VIII}$	**0.0425**	40.13
Drochia	$Y = 73.02 - 1.66*T_{VII} - 1.11757*T_{VIII} + 0.0345085*P_{VI} - 0.00944228*P_{VII} - 0.0169344*P_{VIII}$	**0.0190**	45.33
Edinet	$Y = 65.897 - 1.35577*T_{VII} - 1.19662*T_{VIII} + 0.0437071*P_{VI} - 0.0289116*P_{IX}$	**0.0214**	39.44
Falesti	$Y = 48.716 - 1.04296*T_{VI} - 0.64527*T_{VII}$	**0.0441**	22.91
Floresti	$Y = 39.326 - 1.28046*T_{VII} + 0.0310918*P_{IV} + 0.0293818*P_{VI} - 0.012833*P_{VII}$	**0.0191**	40.17
Glodeni	$Y = 74.346 - 0.966043*T_{V} - 1.97064*T_{VII} - 0.0411566*P_{V} + 0.0370904*P_{VI}$	**0.0429**	34.92
Ocnita	$Y = 58.278 - 1.09167*T_{VII} - 1.0803*T_{VIII} + 0.0390917*P_{VI} - 0.0324273*P_{IX}$	**0.0146**	41.78
Riscani	$Y = 34.938 - 0.997047*T_{VII} + 0.0261227*P_{VI}$	0.0885	18.29
Singerei	$Y = 58.442 - 1.1348*T_{VI} - 1.10725*T_{VII} + 0.0470479*P_{IV} + 0.0150347*P_{VI} - 0.0190463*P_{VIII}$	**0.0010**	60.02
Soroca	$Y = 42.899 - 1.36734*T_{VII} + 0.0257575*P_{VI} - 0.0161456*P_{VII}$	**0.0110**	37.79
Central AEZ			
Anenii Noi	$Y = 65.672 - 0.892331*T_{VII} - 1.20032*T_{VIII} - 0.681574*T_{X} + 0.0272668*P_{VI} - 0.0419288*P_{VIII}$	**0.0000**	75.02
Călăraşi	$Y = 57.636 - 1.28701*T_{VI} - 0.774853*T_{VIII} - 0.0185867*P_{VII} - 0.0188614*P_{VIII} - 0.0280318*P_{X}$	**0.0026**	52.80
Criuleni	$Y = 70.096 - 1.88257*T_{VIII} - 1.04742*T_{X} + 0.0310442*P_{VI} - 0.0534452*P_{VIII} - 0.0543642*P_{X}$	**0.0000**	72.39
Dubăsari	$Y = 68.246 - 0.835005*T_{V} - 1.22375*T_{VII} - 1.13669*T_{X} - 0.0153051*P_{VIII} - 0.0334063*P_{X}$	**0.0129**	44.74
Hincesti	$Y = 76.051 - 1.25374*T_{V} - 1.22216*T_{VII} - 1.17491*T_{X} - 0.0195369*P_{VIII} - 0.0272483*P_{X}$	**0.0000**	72.54
Ialoveni	$Y = 85.646 - 1.16619*T_{V} - 1.5658*T_{VII} - 1.62883*T_{X} - 0.0159455*P_{VIII} - 0.00623931*P_{X}$	**0.0001**	66.25
Nisporeni	$Y = 59.298 - 1.94748*T_{VI} + 1.36637*T_{IX} - 2.61626*T_{X} - 0.0536727*P_{VIII} + 0.049282*P_{IX}$	**0.0004**	60.45
Orhei	$Y = 76.755 - 0.84434*T_{V} - 1.32278*T_{VII} - 1.41355*T_{X} - 0.0308042*P_{VII} - 0.0519284*P_{X}$	**0.0004**	60.26
Rezina	$Y = 45.743 - 0.849108*T_{VIII} - 1.08229*T_{X} + 0.0253391*P_{VI} - 0.0386815*P_{VIII} - 0.068319*P_{X}$	**0.0011**	56.49
Străşeni	$Y = 63.612 - 1.01284*T_{V} - 1.64643*T_{VII} + 1.24428*T_{IX} - 1.9432*T_{X} + 0.0442227*P_{IX}$	**0.0000**	65.52
Teleneşti	$Y = 74.031 - 0.899153*T_{VI} - 1.41992*T_{VII} - 0.902098*T_{X} - 0.040912*P_{VII} + 0.0287032*P_{IX}$	**0.0001**	65.08
Ungheni	$Y = 52.233 - 1.12389*T_{VI} - 0.867384*T_{X} - 0.0401728*P_{VIII} - 0.0498753*P_{X}$	**0.0175**	38.13
Southern AEZ			
Basarabeasca	$Y = 53.936 - 1.97571*T_{VII} + 0.0318082*P_{V} + 0.01083*P_{VII} - 0.00735462*P_{VIII} + 0.0121677*P_{IX}$	**0.0000**	77.34
Cahul	$Y = 26.011 - 0.369613*T_{V} + 0.87794*T_{VI} - 1.32078*T_{VII} + 0.0207176*P_{V} + 0.0286453*P_{VI}$	**0.0005**	60.04
Cantemir	$Y = 31.652 - 0.531535*T_{VI} - 1.13309*T_{VII} + 0.692449*T_{VIII} + 0.0295651*P_{IV} + 0.0314665*P_{V}$	**0.0000**	69.18
Causeni	$Y = 58.885 - 1.14165*T_{VII} - 0.690653*T_{VIII} - 0.448687*T_{X} + 0.0267304*P_{V} - 0.0385722*P_{VIII}$	**0.0000**	71.38
Cimislia	$Y = 51.313 - 1.77068*T_{VII} + 0.0536262*P_{V} - 0.0239447*P_{VIII}$	**0.0000**	62.81
Leova	$Y = 44.249 - 0.525382*T_{V} - 1.54453*T_{VII} + 0.899538*T_{VIII} - 0.910406*T_{X} + 0.0341232*P_{V}$	**0.0003**	61.29
Stefan Voda	$Y = 53.683 - 0.593185*T_{V} - 0.980578*T_{VII} - 0.826324*T_{X} + 0.0495747*P_{IV} - 0.0305294*P_{VIII}$	**0.0000**	70.61
Taraclia	$Y = 21.241 - 0.714112*T_{V} + 1.28982*T_{VI} - 1.25222*T_{VII} + 0.0295117*P_{VI} + 0.017178*P_{IX}$	**0.0347**	38.26
UTA Gagauzia	$Y = 29.564 - 0.544881*T_{V} - 0.648799*T_{VII} + 0.0336109*P_{IV} + 0.0231656*P_{IX} + 0.052354*P_{X}$	**0.0341**	38.97

Note: Bold is used to mark statistically significant values.

The highest impact of climatic conditions during growing season in the years 1981-2010 on productivity of sunflower is observed in the districts: Singerei, Anenii Noi, Criuleni, Hincesti, Ialoveni, Nisporeni, Orhei, Straseni, Telenesti, Basarabeasca, Cahul, Cantemir, Causeni, Cimislia, Leova and Stefan Voda, coefficient of determination R^2 is from 60.0 to 77.3% and the lowest one in districts: Donduseni, Edinet, Falesti, Floresti, Glodeni, Soroca Ungeni, Taraclia and UTA Gagauzia, coefficient of determination R^2 is from 22.9 to 40.2% (**Table 4-7).**

Using these regression equations relationship in the yield variability of sunflower with the temperature and precipitation of the growing season in three AEZs, there were calculated projections of future sunflower yield changes in the Republic of Moldova's districts, (%/30 years) according to an ensemble from 10 Global Climate Models (GCMs) for three SRES A2, A1B and B1 emission scenarios relative to 1981-2010 recent periods.

Without application of adaptation measures the most vulnerable to climate change in the Republic of Moldova would be in territorial aspect the central AEZ and in less extent the northern and southern AEZs. According to projections the most vulnerable districts will be Anenii Noi,Telenesti, Ialoveni, Dubasari, Hincesti, Orhei, Straseni and Nisporeni in central AEZ, in which productivity of sunflower by 2020s could decrease from 3 to 17% (SRES A2) and/or from 6 to 20% (SRES B1). In comparison with the 1981-2010 time periods, by 2050s the crop productivity may decrease in dependence of the assessed emission scenario from 35 to 56% (SRES A2) and/or from 27 to 47% (SRES B1). The maximum values of productivity decrease may be reached by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of sunflower may decrease from 39 to 63% (SRES B1) and/or from 69 to 92% (SRES A2) (**Table 4-8**).

Table 4-8: Projected Sunflower Yield Changes Relative to the Current situation (%/30 Year) under the Ensemble of 10 GCMs for SRES A2, A1B and B1 scenarios

AEZs/district	1981-2010, q/ha	2020s			2050s			2080s		
		A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Northern AEZ										
Briceni	16.3	8	2	2	-16	-26	-12	-51	-43	-20
Donduseni	15.4	7	1	3	-16	-26	-11	-51	-42	-20
Drochia	18.3	7	1	3	-15	-25	-11	-48	-40	-19
Edinet	17.0	8	1	5	-14	-24	-10	-47	-39	-18
Falesti	16.2	2	-2	-1	-11	-16	-9	-28	-26	-14
Floresti	15.7	7	5	6	-4	-10	-1	-21	-16	-6
Glodeni	19.7	3	-1	0	-15	-23	-12	-42	-37	-20
Ocnita	16.5	7	1	4	-12	-21	-8	-41	-34	-16
Riscani	16.4	6	3	5	-3	-7	-1	-17	-13	-4
Singerei	17.2	5	-1	1	-12	-18	-9	-34	-30	-15
Soroca	15.4	7	5	5	-4	-11	-2	-23	-19	-7
Central AEZ										
Anenii Noi	12.2	-3	-8	-6	-37	-44	-27	-90	-61	-39
Călăraşi	11.7	-3	-9	-9	-28	-32	-22	-60	-48	-30
Criuleni	15.2	3	-2	-1	-26	-30	-18	-69	-45	-28
Dubăsari	13.3	-9	-13	-11	-38	-46	-31	-83	-64	-44
Hincesti	13.8	-11	-15	-13	-41	-51	-35	-89	-71	-48
Ialoveni	13.5	-17	-22	-20	-56	-67	-47		-91	-63
Nisporeni	14.9	-10	-14	-16	-35	-41	-31	-69	-57	-39
Orhei	14.5	-11	-13	-13	-39	-47	-32	-82	-65	-45
Rezina	12.7	4	2	3	-16	-19	-11	-48	-31	-18
Straseni	12.7	-12	-16	-16	-44	-54	-37	-92	-73	-50
Şoldanesti	14.0	-4	-8	-7	-18	-21	-15	-36	-31	-19
Telenesti	13.8	-16	-18	-18	-46	-53	-37	-92	-72	-49
Ungheni	16.5	-2	-5	-4	-16	-19	-13	-36	-29	-18
Southern AEZ										
Basarabeasca	12.4	-1	-5	-3	-30	-34	-18	-71	-51	-29
Cahul	11.3	7	6	7	-10	-10	0	-32	-18	-7
Cantemir	13.6	5	4	6	-6	-7	0	-24	-16	-5
Causeni	12.9	7	3	5	-23	-30	-13	-69	-50	-25
Cimislia	13.4	6	3	5	-17	-24	-8	-57	-40	-17
Leova	12.7	-1	-3	0	-23	-28	-14	-58	-43	-25
Stefan Voda	13.5	-1	-3	-2	-24	-30	-18	-62	-49	-29
Taraclia	10.5	7	6	6	-8	-10	-1	-29	-16	-7
UTA Gagauzia	10.4	-8	-9	-10	-25	-28	-20	-50	-41	-26

The least vulnerable districts for sunflower cultivation will be Briceni, Donduseni, Drochia, Edinet, Falesti, Floresti, Glodeni, Ocnita, Singerei, Riscani and Soroca in the northern AEZ; respectively, Cahul, Cantemir, Cimislia and Taraclia in the southern AEZs in which productivity of sunflower by 2020s could increase by 5-8% (SRES A2) and/or from 2 to 7% (SRES B1). In comparison with the 1981-2010 time periods, by 2050s the crop productivity may decrease in dependence of the assessed emission scenario from 3 to 16% (SRES A2) and/or from 0 to 12% (SRES B1). The maximum values of productivity decrease may be reached by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of sunflower in these districts may decrease from 4 to 20% (SRES B1) and/or from 17 to 57% (SRES A2).

4.3.4.4. Sugar Beet

For sugar beet by 2020s, when assessing the combined effect of temperature and precipitation during the growing season, it is expected a decrease in productivity by 1-5% under SRES B1 and A1B emission scenarios. By 2050s, there will persisting the decreasing trend in productivity due to climate changes. The most severe decrease in productivity, by 10-12% is predicted under the SRES A1B and A2 emission scenario. While under the SRES B1 emission scenario the projection is more favorable, it is predicted a decrease of productivity only by 5%. In 2080s, the most severe yield reduction for sugar beet in the RM will be observed according to SRES A2 emission scenario – by 20%, while for SRES B1 emission scenario the forecast is more favorable – a decrease by 10% (**Figure 4-2**).

Until now in the RM vulnerability assessment of agricultural crops production was carried out only at the national level, while the development of adaptation programs require at least district or local level. Proceeding from this, additionally to the national level we have assessed the impact of temperature and precipitation during the growing season on sugar beet productivity in the Republic of Moldova's territorial administrative units (district level) in order to distinguish the most and least vulnerable to climate change sugar beet production districts in the 1981-2010 years.

The analysis of the data presented in the **Table 4-9** shows that the influence of climatic conditions during growing season on sugar beet yield in the 1981-2010 years was statistically significant in the majority of investigated districts of northern and central AEZs, that have been traditionally engaged in the cultivation of sugar beet. Coefficient of determination R^2 shows that the combined effect of precipitation and temperature defined from 32.0 to 70.8% of the variability of average annual yield of sugar beet during this period in the northern AEZ; from 42.6 to 65.2% of the variability of yield in the central AEZ.

Table 4-9: The Relationship of Sugar Beet Yield Variability with Temperature and Precipitation during the Vegetation Period (1981 - 2010)

District	Regression equation	p – value	R^2, %
	Northern AEZ		
Briceni	$Y = 182.01 + 11.57*T_{VIII} - 11.66*T_{IX} + 0.71*P_{VIII} - 0.94*P_{X}$	**0.0471**	32.02
Donduseni	$Y = -172.91 + 15.41*T_{VIII} + 0.66*P_{IV} + 0.42*P_{VII} + 0.83*P_{VIII} - 0.59*P_{X}$	**0.0388**	38.14
Drochia	$Y = 921.97 - 28.44*T_{VI} - 22.06*T_{X} + 1.10*P_{IV} + 0.55*P_{V} - 0.47*P_{VI}$	**0.0026**	52.76
Edinet	$Y = -41.11 + 12.51*T_{V} + 1.24*P_{IV} + 0.38*P_{V} - 0.31*P_{IX}$	0.0990	26.86
Falesti	$Y = 872.38 - 24.23*T_{VI} - 16.54*T_{VIII} + 1.29*P_{IV} + 0.56*P_{VII} + 0.86*P_{VIII}$	**0.0006**	59.16
Floresti	$Y = 604.92 - 8.75*T_{V} - 21.35*T_{VI} + 1.45*P_{IV} + 0.41*P_{VII} + 0.55*P_{VIII}$	**0.0028**	52.43
Glodeni	$Y = 751.35 - 15.62*T_{VI} - 13.59*T_{IX} - 8.92*T_{X} + 0.89*P_{IV} + 0.78*P_{X}$	**0.0089**	46.77
Ocnita	$Y = -122.49 + 11.53*T_{VIII} + 9.66*T_{X} + 0.64*P_{IV} + 0.59*P_{VIII} - 0.44*P_{IX}$	0.0665	34.49
Riscani	$Y = 313.23 - 5.86*T_{IX} - 5.88*T_{X} + 1.14*P_{IV} + 0.35*P_{VIII}$	**0.0354**	33.87
Singerei	$Y = 987.15 - 19.72*T_{VI} - 17.13*T_{VII} - 16.91*T_{X} + 1.35*P_{IV} + 0.75*P_{V}$	**0.0000**	70.84
Soroca	$Y = 301.55 - 15.19*T_{VI} + 1.62*P_{IV} + 0.37*P_{V} + 0.44*P_{VII} + 0.62*P_{VIII}$	**0.0004**	60.73
	Central AEZ		
Orhei	$Y = 568.10 - 11.56*T_{V} - 11.68*T_{VII} + 0.903875*P_{IV} + 0.57*P_{VI} + 0.27*P_{VII}$	**0.0011**	59.66
Rezina	$Y = 394.49 - 8.83*T_{VI} - 6.07*T_{VII} + 0.83*P_{IV} + 0.23*P_{VII} + 0.28*P_{VIII}$	**0.0003**	65.19
Şoldanesti	$Y = 49.75 + 5.50177*T_{V} + 0.57*P_{IV} + 0.63*P_{V} - 0.48*P_{X}$	**0.0128**	42.56
Telenesti	$Y = 531.73 - 13.60*T_{V} - 13.46*T_{IX} + 1.23*P_{IV} + 0.35*P_{VI} + 0.33*P_{VII}$	**0.0058**	51.92
Ungheni	$Y = 348.42 - 20.58*T_{VII} + 14.28*T_{VIII} + 1.24*P_{V} + 0.25*P_{VI}$	**0.0005**	55.18

Note: Bold is used to mark statistically significant values.

The greatest impact of climatic conditions during growing season in the years 1981-2010 on productivity of sugar beet is revealed in districts: Falesti, Singerei, Soroca, Orhei and Rezina, coefficient of determination R^2 is from 59.2 to 70.8%, and the lowest one in districts: Edinet, Briceni, Donduseni, Drochia, Floresti, Glodeni, Riscani, Soldanesti, Telenesti and Ungeni, coefficient of determination R^2 is from 26.9 to 55.2%.

Using these regression equations relationship in the yield variability of sugar beet with the temperature and precipitation of the growing season in three AEZs, there were calculated projections of future sugar beet yield changes in the Republic of Moldova's districts, (%/30 years) according to an ensemble from 10 Global Climate Models for three SRES A2, A1B and B1 emission scenarios, relative to 1981-2010 recent period.

According to projections without application of adaptation measures (**Table 4-10**) the most vulnerable districts for sugar beet cultivation will be Glodeni, Drochia and Singerei in the northern AEZ; Telenesti and Rezina in the central AEZ, in which productivity of the sugar beet by 2020s could decrease from 6 to 15% (SRES A2) and/or from 7 to 14 % (SRES B1). In comparison with the 1981-2010 time periods, by 2050s the crop productivity may decrease in dependence of the assessed emission scenario from 23 to 34% (SRES A2) and/or from 24 to 38% (SRES B1). The maximum values of productivity decrease may be reached by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of sugar beet may decrease in these districts from 41-67% (SRES A2) and/or from 23 to 33% (SRES B1).

Table 4-10: Projected Sugar Beet Yield Changes Relative to the Current situation (%/30 Year) under the Ensemble of 10 GCMs for SRES A2, A1B and B1 scenarios

AEZs/district	1981-2010, q/ha	2020s			2050s			2080s		
		A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Northern AEZ										
Briceni	250.3	-4	-2	0	-3	-1	0	-4	-3	-3
Donduseni	228.7	2	2	5	11	14	12	22	20	12
Drochia	258.9	-11	-13	-11	-34	-35	-24	-60	-52	-33
Edinet	213.9	8	8	10	13	15	14	23	23	17
Falesti	284.1	-5	-13	-8	-25	-30	-18	-54	-48	-29
Floresti	225.7	-4	-10	-6	-20	-23	-14	-39	-37	-23
Glodeni	262.9	-15	-16	-14	-33	-34	-25	-58	-49	-33
Ocnita	227.6	3	4	5	10	12	10	21	17	11
Riscani	251.0	-4	-3	-2	-10	-9	-5	-18	-13	-9
Singerei	250.5	-6	-9	-7	-33	-38	-22	-67	-56	-32
Soroca	207.1	0	-5	0	-11	-13	-4	-23	-20	-10
Central AEZ										
Orhei	213.1	-1	-4	-2	-16	-20	-11	-41	-30	-17
Rezina	150.1	-7	-10	-8	-23	-24	-17	-44	-35	-23
Şoldanesti	176.0	7	8	8	10	11	11	13	14	13
Telenesti	183.4	-10	-13	-11	-29	-33	-23	-60	-46	-31
Ungheni	281.1	0	1	2	-2	-6	1	-10	-6	-1

The least vulnerable districts for sugar beet cultivation will be Donduseni in the northern AEZ; and Soldanesti in the central AEZ, in which productivity of the sugar beet by 2020s could increase from 2 to 7% (SRES A2) and/or from 5 to 8% (SRES B1). In comparison with the 1981-2010 time periods, by 2050s the crop productivity in these districts may increase in dependence of the assessed emission scenario by 10-11% (SRES A2) and/or by 11 to 12 % (SRES B1). The maximum value of productivity increase is projected by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of sugar beet in these districts may increase from 13 to 22% (SRES A2) and/or by 12-13% (SRES B1). Increase in the productivity of sugar beet is also projected for Drochia and Ocnita districts in the northern AEZ, however, the yield trends in reference period (1981-2010) are statistically significant on the lowest significant level ($p \leq 0.1$), so it can be noted just a tendency to increase in the yield in these districts.

4.3.4.5. Tobacco

For other high value technical crop – tobacco, similar changes are expected: a slight decrease in the yield by 1%, according to the SRES A2 and A1B scenarios in the 2020s. By 2050s, there will persisting the decreasing trend in productivity due to climate changes. The most severe decrease in productivity, by 8-10% is predicted under the SRES A1B medium and SRES A2 high emission scenarios. While under the SRES B1 low emission scenario the projection is more favorable, it is predicted a decrease of productivity only by 6%. In 2080s, the most severe yield reduction for tobacco in the Republic of Moldova will be observed according to SRES A2 high emission scenario – by 19%, while for SRES B1 low emission scenario the forecast is more favorable – a decrease by 9% (**Figure 4-2**).

Until now in the RM vulnerability assessment of agricultural crops production was carried out only at the national level, while the development of adaptation programs require at least district or local level. Proceeding from this, additionally to the national level we have assessed the impact of temperature and precipitation during the growing season on tobacco productivity in the Republic of Moldova's territorial administrative units (district level) in order to distinguish the most and least vulnerable to climate change tobacco production districts in the 1981-2010 years.

The analysis of the data presented in the **Table 4-11** shows that the influence of climatic conditions during growing season on tobacco yield in the 1981-2010 years was statistically significant at in the majority of districts of the Republic of Moldova's AEZs that have been traditionally engaged in the cultivation of tobacco, except Ialoveni, Soldanesti and Stefan Voda districts. Coefficient of determination R^2 shows that the combined effect of precipitation and temperature defined from 35.1 to 64.7% the variability of average annual yield of tobacco during this period in the northern AEZ; from 35.4

to 61.0% the variability of yield in the central AEZ; and from 33.9 to 61.6% the variability of yield in the southern AEZ.

Table 4-11: The relationship of Tobacco Yield Variability with Temperature and Precipitation during the Vegetation Period (1981 - 2010)

District	Regression equation	p – value	R^2, %
	Northern AEZ		
Briceni	$Y = 89.64 - 2.36*T_{VI} - 0.89*T_{IX} - 1.81*T_{X} - 0.04*P_{VI} - 0.02*P_{VII}$	**0.0050**	56.09
Donduseni	$Y = 89.40 - 1.95*T_{VI} - 1.09*T_{IX} - 2.12*T_{X} - 0.04*P_{VI} - 0.04*P_{VII}$	**0.0045**	64.68
Drochia	$Y = 52.58 - 0.58*T_{VI} - 0.68*T_{IX} - 1.52*T_{X} + 0.01*P_{VI} - 0.02*P_{VII}$	**0.0145**	44.09
Edinet	$Y = 51.21 - 1.15*T_{VI} - 1.60*T_{X} - 0.03*P_{VI} - 0.03*P_{X}$	**0.0293**	35.07
Falesti	$Y = 57.69 - 1.53*T_{VI} - 0.10*T_{IX} - 0.73*T_{X} - 0.05*P_{VI} - 0.02*P_{VII}$	**0.0171**	43.16
Floresti	$Y = 71.87 - 0.45*T_{V} - 1.94*T_{VI} - 1.19*T_{X} - 0.04*P_{VI} - 0.03*P_{VIII}$	**0.0203**	46.45
Glodeni	$Y = 79.69 + 0.52*T_{IV} - 1.36*T_{V} - 0.77*T_{VI} - 0.80*T_{VII} - 2.21*T_{X}$	**0.0027**	52.64
Ocnita	$Y = 45.01 - 0.88*T_{VI} - 1.62*T_{X} - 0.04*P_{IX} - 0.03*P_{X}$	**0.0214**	45.56
Riscani	$Y = 63.75 - 1.22*T_{VI} - 0.80*T_{IX} - 1.00*T_{X} - 0.09*P_{IV} - 0.03*P_{VII}$	**0.0106**	48.69
Singerei	$Y = 36.38 - 0.57*T_{V} - 0.66*T_{VII} + 0.02*P_{V} + 0.02*P_{VI} - 0.02*P_{IX}$	**0.0427**	37.52
Soroca	$Y = 79.91 - 0.69*T_{V} - 1.71*T_{VI} - 2.10*T_{X} - 0.05*P_{VI} – 0.4*P_{VIII}$	**0.0034**	51.48
	Central AEZ		
Criuleni	$Y = 16.29 + 1.09*T_{IX} - 1.73*T_{X} + 0.05*P_{V} - 0.04*P_{VIII} - 0.02*P_{IX}$	**0.0023**	53.28
Dubăsari	$Y = 37.47 - 0.53*T_{VIII} - 1.01*T_{X} - 0.05*P_{IV} + 0.04*P_{V} - 0.02*P_{X}$	**0.0256**	40.77
Hincesti	$Y = 49.95 - 0.93*T_{VI} - 1.04*T_{IV} + 0.04*P_{V} - 0.03*P_{IX}$	**0.0403**	35.35
Ialoveni	$Y = 11.50 + 0.56*T_{V} - 1.12*T_{VII} + 1.18*T_{VIII} - 0.90*T_{X} + 0.05*P_{V}$	0.0789	38.37
Nisporeni	$Y = 71.93 - 0.66*T_{V} - 1.13*T_{VI} - 0.70*T_{VIII} - 0.93*T_{X} - 0.02*P_{IX}$	**0.0009**	57.54
Orhei	$Y = 15.72 + 0.27*T_{VII} - 0.67*T_{X} + 0.05*P_{V} - 0.03*P_{IX} - 0.03*P_{X}$	**0.0003**	61.02
Rezina	$Y = 27.76 + 0.11*T_{VII} - 1.67*T_{X} + 0.03*P_{V} - 0.01*P_{IX} - 0.03*P_{X}$	**0.0137**	44.40
Şoldăneşti	$Y = 40.01 - 0.85*T_{VIII} - 0.63*T_{X} - 0.02*P_{VIII} - 0.02*P_{IX} - 0.03*P_{X}$	0.0883	32.44
Teleneşti	$Y = 30.70 - 0.49*T_{VII} - 0.74*T_{X} + 0.04*P_{V} - 0.02*P_{IX} + 0.02*P_{X}$	**0.0214**	41.85
Ungheni	$Y = 64.59 - 0.35*T_{V} - 0.91*T_{VI} - 0.55*T_{VIII} - 1.26*T_{X} + 0.01*P_{V} - 0.00554214*P_{IX}$	**0.0275**	44.86
	Southern AEZ		
Cantemir	$Y = -4.26 + 0.55*T_{IV} + 0.52*T_{IX} + 0.06*P_{V}$	**0.0144**	33.91
Causeni	$Y = 24.43 + 0.96*T_{VI} - 1.86*T_{IX} + 0.05*P_{VI} - 0.06*P_{VIII} - 0.06*P_{IX}$	**0.0475**	42.28
Cimislia	$Y = 65.10 - 0.57*T_{V} - 1.58*T_{VI} - 1.10*T_{X} - 0.03*P_{IX} + 0.02*P_{V}$	**0.0036**	61.57
Leova	$Y = 7.62 - 0.80*T_{IV} + 0.87*T_{IX} - 0.116*P_{IV} + 0.08*P_{V}$	**0.0014**	50.95
Stefan Voda	$Y = 30.42 - 0.64*T_{IX} + 0.02*P_{VI} - 0.02*P_{VII} - 0.03*P_{VIII} - 0.06*P_{IX}$	0.0881	32.45
Taraclia	$Y = -4.62 + 0.50*T_{V} + 0.52*T_{IX} + 0.05*P_{V} - 0.02*P_{VI} + 0.04*P_{VIII}$	**0.0163**	47.78
UTA Gagauzia	$Y = -8.44 + 0.74*T_{V} + 0.98*T_{IX} - 0.67*T_{X} + 0.07*P_{V} - 0.02*P_{VIII}$	**0.0004**	60.45

Note: Bold is used to mark statistically significant values.

The greatest impact of climatic conditions during growing season in the years 1981-2010 on productivity of tobacco is revealed in districts: Briceni, Donduseni, Glodeni, Soroca, Criuleni, Nisporeni, Orhei, Cimislia, Leova and UTA Ggauzia, coefficient of determination R^2 is from 50.9 to 64.7% and the lowest one in the districts: Drochia, Edinet, Falesti, Floresti, Ocnita, Riscani, Singerei, Dubasari, Hincesti, Rezina, Telenesti, Ungeni, Cantemir, Causeni and Taraclia, coefficient of determination R^2 is from 33.9 to 48.7 % (**Table 4-11**).

Using these regression equations relationship in the yield variability of tobacco with the temperature and precipitation of the growing season in three AEZs, there were calculated projections of future tobacco yield changes in the Republic of Moldova's districts, (%/30 years) according to an ensemble from 10 Global Climate Models for three SRES A2, A1B and B1 emission scenarios relative to 1981-2010 recent period.

Without application of adaptation measures the most vulnerable to climate change in the Republic of Moldova would be in territorial aspect the northern and central AEZ and in less extent the southern AEZ. According to projections the most vulnerable districts for tobacco cultivation will be Donduseni, Briceni, Floresti, Glodeni, Ocnita, Riscani and Soroca in the northern AEZ, Nisporeni district in the central AEZ and Cimislia district in the southern AEZs, in which productivity of tobacco by 2020s could decrease from 20 to 44% (SRES A2) and/or from 20 to 42% (SRES B1) (**Table 4-12**).

In comparison with the 1981-2010 time periods, by 2050s the crop productivity in these districts may decrease in dependence of the assessed emission scenario from 48 to 86% (SRES A2) and/or from 41 to 70% (SRES B1). The maximum values of productivity decrease may be reached by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of tobacco may decrease from 51 to 88% (SRES B1) and/or from 76 to 98% (SRES A2).

Without adaptation measures (if maintaining the current cultivation technologies and used varieties), due to changes in climatic conditions, by the end of the XXI century the cultivation of tobacco in Donduseni, Briceni, Soroca, Glodeni, Nisporeni and Cimislia districts will be either impossible according to the SRES A2 high emission scenario, or economically not cost effective according to SRES B1 low emission scenarios.

The least vulnerable districts for tobacco cultivation will be Cantimir, Leova, Taraclia and UTA Gagauzia in the southern AEZ, in which productivity of tobacco by 2020s could increase from 7 to 14% (SRES A2) and/or from 4 to

17% (SRES B1). In comparison with the 1981-2010 time periods, by 2050s the crop productivity may increase in dependence of the assessed emission scenario from 8 to 23% (SRES A2) and/or from 9 to 25% (SRES B1). The maximum value of productivity decrease is projected by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of tobacco in these districts may increase from 13 to 37% (SRES A2) and/or from 8 to 30% (SRES B1).

Table 4-12: Projected Tobacco Yield Changes Relative to the Current Situation (%/30 Year) under the Ensemble of 10 GCMs for SRES A2, A1B and B1 scenarios

AEZs/district	1981-2010, q/ha	2020s			2050s			2080s		
		A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Northern AEZ										
Briceni	13.0	-40	-41	-40	-84	-87	-69			-88
Donduseni	13.9	-44	-42	-42	-86	-87	-70			-88
Drochia	17.0	-16	-12	-12	-34	-34	-23	-59	-47	-32
Edinet	12.9	-17	-17	-16	-41	-41	-32	-72	-61	-42
Falesti	15.6	-10	-11	-12	-25	-26	-22	-44	-41	-28
Floresti	15.8	-24	-26	-26	-49	-51	-43	-78	-72	-51
Glodeni	14.6	-20	-21	-20	-56	-61	-43		-89	-58
Ocnita	12.1	-36	-37	-34	-54	-55	-47	-76	-68	-55
Riscani	15.9	-27	-27	-26	-48	-51	-41	-81	-72	-52
Singerei	16.1	2	-1	0	-8	-12	-5	-20	-18	-9
Soroca	13.0	-27	-27	-28	-65	-65	-53			-66
Central AEZ										
Criuleni	15.3	3	3	3	1	-1	0	-2	-1	0
Dubăsari	14.6	-6	-7	-7	-20	-23	-15	-41	-30	-21
Hincesti	14.7	-10	-12	-10	-27	-31	-20	-53	-42	-28
Ialoveni	14.5	-6	-3	-2	-5	-8	-4	-12	-8	-5
Nisporeni	12.6	-15	-23	-21	-51	-57	-41	-97	-80	-56
Orhei	14.1	1	1	2	0	-1	1	-2	-2	0
Rezina	12.7	-9	-9	-9	-22	-25	-18	-42	-33	-24
Şoldăneşti	11.6	1	-2	-1	-17	-19	-13	-41	-29	-19
Teleneşti	14.3	-7	-8	-7	-18	-21	-14	-35	-26	-18
Ungheni	15.3	-13	-17	-17	-39	-44	-32	-75	-60	-42
Southern AEZ										
Cantemir	12.7	14	18	17	23	27	25	37	37	30
Causeni	10.2	-20	-19	-16	-31	-31	-25	-54	-42	-31
Cimislia	12.6	-26	-31	-28	-56	-62	-47	-98	-85	-60
Leova	13.7	7	5	4	8	5	9	13	10	8
Stefan Voda	15.6	-8	-9	-7	-11	-12	-10	-17	-16	-12
Taraclia	14.9	9	11	10	15	19	17	29	27	20
UTA Gagauzia	15.1	11	14	12	20	21	20	31	32	24

4.3.5. Projections of Future Changes in Cereal Crops Phenology Duration

Changes in crop phenology provide important evidence of responses to recent regional climate change (Menzel et al., 2003). Although phenological changes are often influenced by management practices, in particular sowing date and choice of cultivar, recent warming in Europe has clearly advanced a significant part of the agricultural calendar. Specific stages of growth (e.g. flowering, grain filling) are particularly sensitive to weather conditions and critical for final yield. The timing of the crop cycle (agro-phenology) determines the productive success of the crop. In general, a longer crop cycle is strongly correlated with higher yields, since a longer cycle permits better use of the available thermal energy, solar radiation and water resources (EEA, 2012).

Sowing or planting dates of several agricultural crops have been advanced, for example by 5 days for potatoes in Finland (1965–1999), 10 days for grain corn and sugar beet in Germany (1961–2000) and 20 days for grain corn in France (1974–2003) (IPCC, 2007; Lavalle et al, 2009). An analysis of the modelled flowering date for winter wheat in Europe between 1975 and 2010 shows a general and clear increasing trend, which is most pronounced in north-western Europe (EEA, 2012). In parts of Europe the modelled flowering date has advanced by 0.3–0.5 days per year and over the Republic of Moldova by 0.20-0.49 days per year. This modelled advance in flowering date probably exceeds what is observed in reality, as day length responses in plants and farmers' choices of cultivars with longer growth duration will reduce this response.

4.3.5.1. Winter Wheat

With the projected warming of the climate in Europe, further reductions in the number of days required for flowering in cereals and maturity may be expected throughout Europe. Since many plants (including cereals) in Europe require long days to flower, the effect of warming on date of flowering is smaller than would otherwise be expected. The flowering date for winter wheat is projected to show the greatest advance in western parts of Europe, but with a large uncertainty due to uncertainty in the underlying climate change projections. The advance in maturity date is larger than the advance in flowering date, leading to a shortening of the grain filling period, which will negatively affect yields (Fels-Klerx et al., 2012). An independent study with a different phenology model and other climate change projections found similar advances in flowering date for winter wheat for England and

Wales (14–16 days by 2050) (Semenov, 2009). In the future scenario period, according to Van der Fels-Klerx et al. (2013) flowering of winter wheat was estimated to be 3 to 6 days earlier with ECHAM5/RACMO2 model data and 9 to 12 days earlier with HadCM3Q0/HadRM3Q0 data. Dates of full maturity were expected to be up to 2 weeks earlier with ECHAM5/RACMO2 data and up to 3 weeks earlier with HadCM3Q0/HadRM3Q0 data. The length of the grain filling period was projected to be significantly shorter in the future period as compared to the baseline period for both climate model combinations. The overall difference was a reduction of 5 and 7 days for ECHAM5/RACMO2 and HadCM3Q0/HadRM3Q0 model data, respectively.

The sharp decline in the productivity of winter wheat in the Republic of Moldova can be explained by a shift of critical phenological phases in a more unfavorable period due to temperature increase. The vegetation period of winter wheat (starting with temperatures higher than 5°C in spring), according to an ensemble of 10 GCMs will start in the RM by 2020s earlier by 1 - 4 days (under the SRES ▯2) and/or by 2 - 6 days (under the SRES ▯1).

By the 2080s, the vegetation period of winter wheat will start earlier by 7 - 9 days (under the SRES B1) and/or by 10 - 13 days (under the SRES A2), in dependence of the assessed emission scenario, with a maximum expected shift in central AEZ.

Change of phenology duration is an essential factor for wheat yield. Previous studies had found that warming will shorten wheat phenology duration and decrease wheat yield, mainly due to a shorter growing period, which decreases the duration of photosynthesis and wheat mass accumulation (Wheeler et al., 2000; Hatfield et al., 2011). The reduction would be 4–7% for each 1°C raised (Hatfield et al., 2011) and even more (see example above). Farooq et al. (2011) have been found that wheat yield would decrease with maximum temperatures higher than the optimum temperature in anthesis and grain-filling stages.

By use of the index 'sum of effective temperatures above 5°C' there were calculated for winter wheat, according to an ensemble from 10 GCMs for three SRES A2, A1B and B1 emission scenarios, the average initiating date of main development phases in the spring-summer period. Analysis of the data for the most vulnerable central AEZ revealed that by 2020s output in the tiller initiating phase at winter wheat may have shifted in average from 4 days (SRES A2) up to 6 days (SRES B1). By 2050s the shift in the respective phenological phases will account from 9 days (SRES A2) up to 11 days

(SRES A1B), while by 2080s according to the SRES A2 and A1B emission scenarios the tiller initiating phase will start by 14 days early the onset of respective phase in the reference period (1961-1990) (**Table 4-13**).

Table 4-13: Projections on Shifting the Period of Initiation of Phenological Phases in Winter Wheat Depending on the Sum of Effective Temperatures According to an Ensemble from 10 GCMs for SRES A2, A1B and B1 Emission Scenarios in Central AEZ of the Republic of Moldova

Scenario	Winter wheat			
	Sum of effective temperatures above 5°C necessary to initiate the phenological phase			
	Tiller initiating (125°C)	Jointing (455°C)	Kernel in milk (685°C)	Kernel in dough (945°C)
1961-1990	24/04	27/05	13/06	30/06
2020s				
A2	20/04	22/05	07/06	24/06
A1B	18/04	20/05	06/06	23/06
B1	18/04	20/05	06/06	23/06
2050s				
A2	15/04	17/05	02/06	18/06
A1B	13/04	16/05	31/05	17/6
B1	15/04	17/05	03/06	19/06
2080s				
A2	10/04	12/05	28/05	12/06
A1B	09/04	10/05	26/04	11/04
B1	14/04	15/05	31/04	18/06

According to the projections, by 2020s the phenological phase of jointing may come for winter wheat earlier from 4 days (SRES A2), up to 7 days (SRES B1). The humidity conditions in this period will be close to optimal (HTC = 1.0) (Taranu et al, 2014; see Chapter 3 for additional information). However, by 2080s this shift can already draw from 12 days (SRES B1) up to 15-17 days (SRES A2 and A1B). Humidity conditions for this period would be sufficient only in accordance with the SRES B1 low emission scenario (HTC = 1.0), while according the other two emission scenarios (SRES A2 and A1B) there will be recorded insufficient humidity conditions (HTC = 0.8-0.9), thus the critical period for jointing at winter wheat will take place in dryer conditions, which will impact a sharp decrease in the productivity.

4.3.5.2. Grain Corn

In the future scenario period, according to Van der Fels-Klerx et al. (2013) as with wheat, both flowering and full maturity dates of grain corn were projected to occur earlier in the season in the future as compared to the baseline period (both climate model combinations). Flowering was expected to advance by 4 to 9 days using ECHAM5/RACMO2 data and by 11 to 17 days for the HadCM3Q0/HadRM3Q0 model. Full maturity of grain corn advanced by 2 to 4 weeks with ECHAM5/RACMO2 model data and by 4 to over 6 weeks with HadCM3Q0/HadRM3Q0 model data. This resulted in a shortened grain filling period of between 8 and 20 days with ECHAM5/RACMO2 data (overall average 12 days) and between 15 and 31 days with HadCM3Q0/HadRM3Q0 data (overall average 22 days).

By use of the index 'sum of effective temperatures above 10°C' there were calculated for grain corn of different maturity groups, according to an ensemble from 10 GCMs for three SRES A2, A1B and B1 emission scenarios, the possible average initiating date of main development phases in the spring-summer period. Analysis of the data for the most vulnerable central AEZ revealed that by 2020s onset in the germination-tasseling phase at grain corn varieties may have shifted, in dependence from emission scenario and maturity group from 7 days (SRES A2) up to 9 days (SRES B1) for the early and intermediate; and from 8 days (SRES A2) up to 11 days (SRES B1) for late maturity groups. While by 2080s, according to SRES B1 and A2 emission scenarios, the germination - tasseling phase will start by 17-22 days (for the early and intermediate maturity groups); and by 20-26 days (for late maturity group) early the onset of respective phase in the reference period (1961-1990) (**Table 4-14**).

In this regard, it is interesting to note that the actual observed changes in the occurrence of phenological germination-tasseling phase of grain corn due to the temperature increase over the last two decades (1991-2010) were by 5 days, for early and intermediate maturity groups, and by 6 days for late maturing hybrids.

According to the projections, by 2020s onset in the sowing–milky grain phase at grain corn hybrids may have shifted, in dependence from emission scenario and maturity group from 9 days (SRES A2) up to 12 days (SRES B1) for the early maturity group and from 11 days (SRES A2) up to 14 days (SRES B1) for intermediate and late maturity groups. While by 2080s, according to the SRES B1and A2 emission scenarios, the sowing–milky grain phase will start early the onset of respective phase in the 1961-1990 periods by 21-30 days for the early maturity group and by 23-32 days for late maturity group.

Table 4-14: Projections on Shifting the Period of Initiation of Phenological Phases in Grain Corn Varieties of Different Maturity Groups Depending on the Sum of Effective Temperatures According to an Ensemble from 10 GCMs for SRES A2, A1B and B1 Emission Scenarios in Central AEZ of the Republic of Moldova

Scenario Maize varieties of different maturity groups (early, intermediate and late)	Maize varieties of different maturity groups (early, intermediate and late)		
	Sum of effective temperatures above 10°C necessary to initiate the phenological phase		
	Germination - tasseling		
	(320-410°C)	(400-510°C)	(520-660°C)
1960-1990	23/06	02/07	16/07
2020s			
A2	16/06	25/06	08/07
A1B	14/06	23/06	05/07
B1	14/06	23/06	05/07
2050s			
A2	09/06	18/06	29/06
A1B	06/06	15/06	27/06
B1	09/06	18/06	03/07
2080s			
A2	01/06	09/06	20/06
A1B	31/05	08/06	20/06
B1	06/06	15/06	27/06
Scenario	**Sowing – milky grain**		
	(720-770°C)	(820-870°C)	(880-930°C)
1961-1990	26/07	04/08	09/08
2020s			
A2	17/07	24/07	29/07
A1B	14/07	21/07	26/07
B1	14/07	22/07	27/07
2050s			
A2	08/07	15/7	19/07
A1B	05/07	12/07	16/07
B1	09/07	16/07	21/07
2080s			
A2	28/06	04/07	08/07
A1B	28/06	05/07	11/07
B1	05/07	12/07	17/07

Scenario	Sowing – milky dough grain		
	(770-820°C)	(870-920°C)	(970-1020°C)
1961-1990	31/07	08/08	17/08
2020s			
A2	20/07	28/07	05/08
A1B	18/07	26/07	02/08
B1	18/07	26/07	03/08
2050s			
A2	11/07	18/07	25/07
A1B	09/07	15/07	22/07
B1	13/07	20/07	27/07
2080s			
A2	01/07	08/07	14/07
A1B	01/07	08/07	15/07
B1	09/07	16/07	23/07

The actual observed changes in the occurrence of phenological sowing–milky grain phase at maize due to the temperature increase over past two decades (1991-2010) were by 7 days for early maturity group and by 9 days for intermediate and late maturing hybrids.

According to the projections, in the 2020s the humidity conditions will be close to optimal (HTC = 1.2) during the sowing–tasseling phenological phase across all three scenarios for early and intermediate hybrids, while for late maturity grain corn hybrids moisture conditions will be sufficient only under two scenarios SRES A2 and B1 (HTC = 1.0) (Taranu et al., 2014).

The next phenological stage, the flowering-milky ripening at grain corn will be ongoing in low humidity conditions (HTC = 0.9-1.0). By the 2080s, the humidity conditions would be close to optimal (HTC = 1.0) during the tasseling phenological stage under SRES A1B and B1 emission scenarios; and insufficient (HTC = 0.8) for the SRES A2 high emission scenario. The subsequent critical phenological phases as flowering and milk grain ripening at grain corn regardless of maturity group will take place in dryer conditions according to high emission SRES A2 (HTC = 0.6) and medium emission SRES A1B (HTC = 0.8) scenarios; or in insufficient humidity conditions (HTC = 0.9) under the low emission scenario SRES B1, which along with an increase of temperatures will reduce dramatically the crop yield.

Without adaptation measures (*if maintaining the current cultivation technologies and used varieties*), due to changes in climatic conditions in the Republic of Moldova, by the end of the XXI century, the cultivation of major cereal crops such as the winter wheat and grain corn will be either impossible according to the SRES A2 scenario, or economically not cost effective according to the SRES A1B and B1 scenarios.

According to the projections obtained, a warming climate was shown to threaten crop yield, and three major causes were identified: the change in relative duration of the pre- and post-flowering phases, increased drought and heat stress frequency. Accordingly, strategies for adapting to climate change should concentrate on the use of drought-tolerant cultivars, increasing water-use efficiency, and better matching phenology to the new environmental conditions to avoid extreme events. Both breeding techniques and change in management practices may be adopted for such purposes. In the Republic of Moldova winter crops with an earlier anthesis may be selected, as this will allow grain filling period to occur in the cooler, wetter parts of the year. Final yield is likely to be increased as a consequence of favorable climatic conditions and CO_2 fertilization. Management practices promoting advanced phenological stages, such as early sowing, may be also adopted, provided that a reduction in the duration of the frost period is occurring.

Enhanced drought tolerance should be the characteristic for rain-fed summer crop but other measures also should be considered to tackle the reduced time that they have for biomass accumulation. The selection or use of crops with a longer cycle may be suggested to compensate a shorter growing cycle. However, adopting or breeding slow maturing cultivars may be proposed only for those regions with adequate moisture conditions and low frequency of heat stress events. In the RM a prolonged time for biomass accumulation of summer crops, that is supposed positive for final yield, would shift anthesis period in summer time increasing crop exposure to heat stress with a consequent reduction of yields. In contrast, early sowing and choice of earlier anthesis varieties may partially reduce the growing season exposed to extreme events determining higher yield when compared to standard conditions.

In this chapter, relationships between observed mean temperature and precipitation during growing season and average crop yield based on statistical data at the Republic of Moldova's agricultural enterprises of various categories were explored and then used to estimate potential impacts of climate change scenarios on anticipated average yields for the 2020s, 2050s, and 2080s time periods.

Average yields of winter wheat, grain corn, sunflower, sugar beet and tobacco in the 1981-2010 years were highly correlated with precipitation and temperature during the growing period. Based on range of available temperature and precipitation climatic conditions during the vegetation period projected by an ensemble from 10 GCMs for SRES A2 (high), A1B (medium) and B1 (low) emissions scenarios average agricultural crop yields achievable in the Republic of Moldova could decrease by about 49 to 74% for grain corn; 38 to 71% for winter wheat; 11 to 33% for sunflower, 10 to 20% for sugar beet; and 9 to 19% for tobacco by 2080s, not including the direct effect of increased atmospheric CO_2 concentration, advances in plant breading and crop production practices or changes in the impacts of weeds, insects and diseases on yield. The sharp decline in the productivity of cereal crops can be explained by a shift of critical phenological phases in the more unfavorable humidity and temperature conditions due to climate change.

Autonomous adaptation by farmers, through the advancement of sowing and harvesting dates and the use of longer cycle varieties (Howden et al., 2007; Moriondo et al., 2011; Moriondo et al., 2010; Olesen et al., 2011) could result in a general improvement of European wheat yields in the 2030s compared to the 2000s (Donatelli et al., 2012). However, farmer sowing dates seem to advance slower than crop phenology (Menzel et al., 2006; Siebert, Ewert, 2012), possibly because earlier sowing is often prevented by lack of soil workability and frost-induced soil crumbling (Oort et al., 2012). Simulation studies which anticipate on earlier sowing in Europe may thus be overly optimistic. Further adaptation options include: changes in crop species, fertilization, irrigation, drainage, land allocation and farming system (Bindi, Olesen, 2011). At the high range of the projected temperature changes, only plant breeding aimed at increasing yield potential jointly with drought resistance and adjusted agronomic practices may reduce risks of yield shortfall (Olesen et al., 2011; Rötter et al., 2011; Ventrella et al., 2012). Crop breeding is however challenged by temperature and rainfall variability, since (i) breeding has not yet succeeded in altering crop plant development responses to short-term changes in temperature (Parent, Tardieu, 2012) and (ii) distinct crop drought tolerance traits are required for mild and severe water deficit scenarios (Tardieu, 2012).

Adaptation to increased climatic variability may require an increased use of between and within species genetic diversity in farming systems (Smith, Olesen, 2010) and the development of insurance products against weather-related yield variations (Musshoff et al., 2011). Adaptive capacity and long term economic viability of farming systems may vary given farm structural change induced by climate change (Mandryk et al., 2012; Moriondo et al., 2010b). In Southern Europe, the regional welfare loss caused by changes in the agriculture sector under a high warming scenario (+5.4°C) was estimated at 1% of GDP. Northern Europe was the single sub-region with welfare gains (+0.7%) from agriculture in this scenario (Ciscar et al., 2011; IPCC, 2014).

CONCLUSIONS

1. The impact assessment performed on national level allow conclude that the negative effect of global warming, according to an ensemble from 10 GCMs for SRES A2 (high), A1B (medium) and B1 (low) emission scenarios in the XXI century will not be offset by increase of precipitations. In these circumstances, without undertaken any adaptation measures, it can be expected by 2080s: a significant drop in the productivity for grain corn, from 49% (SRES B1) to 74% (SRES A1B) and winter wheat, from 38% (SRES B1) to 71% (SRES A2); a medium drop in the productivity for sunflower from 11% (SRES B1) to 33% (SRES B2), respectively for sugar beet, from 10% (SRES B1) to 20% (SRES B2); and for tobacco, from 9% (SRES B1) to 19% (SRES B2), in comparison with the average productivity of the Republic of Moldova's major agricultural crops in the most recent period of 1981-2010.

2. Until now in the Republic of Moldova vulnerability assessment of agricultural crops production was carried out only at the national level, while the development of adaptation programs require at least district or local level. Proceeding from this, additionally to the national level we have assessed the impact of temperature and precipitation during the growing season on agricultural crops productivity in the Republic of Moldova's territorial administrative units (district level), in order to distinguish the most and least vulnerable districts to climate change in 1981-2010 reference period and by 2020s, 2050s and 2080s, based on the projected changes, from an ensemble of 10 GCM for three SRES A2 (high), A1B (medium) and B1 (low) emission scenarios of greenhouse gases and aerosols.

3. According to projections the most vulnerable districts for cultivation of winter wheat will be Basarabeasca, Taraclia, Cimislia, Cahul and Causeni in the southern AEZ; and Dubasari, Anenii Noi, Hincesti, Ialoveni,

Orhei, Telenesti and Nisporeni in the central AEZ, in which productivity of the winter wheat may decrease from 46-58% (SRES B1) to 98% (SRES A2) by 2080s. The least vulnerable districts for cultivation of winter wheat production will be Riscani, Soroca, Briceni and Glodeni in the northern AEZ; and Ungheni, Calaras and Soldanesti in the central AEZ, in which productivity of the winter wheat by 2080s could decrease from 21-34% (SRES B1) and/or from 48 to 64% (SRES A2).

4. Without application of adaptation measures, the most vulnerable for grain corn cultivation would be the central AEZ and in less extent the northern and southern AEZs. The most vulnerable districts will be Anenii Noi, Orhei, Ialoveni, Straseni, Nisporeni, Calarasi, Criuleni and Dubasari in the central AEZ; Briceni and Floresti in the northern AEZ; Basarabeasca, Cahul, Cimislia, Causeni, Taraclia and UTA Gagauzia in the southern AEZ, in which productivity of the grain corn may decrease by 2080s from 47 to 90% (SRES B1). The least vulnerable districts to climate change will be Donduseni, Drochia, Ocnita and Glodeni in the northern AEZ, in which productivity of the grain corn may decrease by 2080s, in dependence of the assessed emission scenario, from 4 to 31% (SRES B1) and/or from 17 to 70% (SRES A2).

5. Without adaptation measures (if maintaining the current cultivation technologies and used varieties), due to changes in climatic conditions in all districts of the Republic of Moldova, by the end of the XXI century the cultivation of grain corn will be either impossible, according to the SRES A2 high emission scenario, or economically not cost effective, according to the SRES A1B medium and SRES B1 low emission scenarios.

6. Without application of adaptation measures, the most vulnerable for sunflower cultivation would be in the central AEZ and in less extent the northern and southern AEZs. According to projections the most vulnerable districts will be Anenii Noi, Telenesti, Ialoveni, Dubasari, Hincesti, Orhei, Straseni and Nisporeni in the central AEZ, in which productivity of sunflower by 2080s may decrease from 39 to 63% (SRES B1) and/or from 69 to 92% (SRES A2). The least vulnerable for sunflower cultivation districts will be Briceni, Donduseni, Drochia, Edinet, Falesti, Floresti, Glodeni, Ocnita, Singerei, Riscani and Soroca in the northern AEZ; respectively, Cahul, Cantemir, Cimislia and Taraclia in the southern AEZ, in which productivity of sunflower may decrease by 2080s, from 4 to 20% (SRES B1) and/or from 17 to 57% (SRES A2).

7. The most vulnerable districts for sugar beet cultivation will be Glodeni, Drochia and Singerei in the northern AEZ; respectively, Telenesti and Rezina in the central AEZ, in which productivity of the sugar beet by 2080s may decrease from 41-67% (SRES A2) and/or from 23 to 33% (SRES B1). The least vulnerable districts for sugar beet cultivation will be Donduseni district in the northern AEZ and Soldanesti district in the central AEZ, in which productivity of the sugar beet may increase by 2080s from 13 to 22% (SRES A2) and/or by 12-13% (SRES B1), in comparison with the 1981-2010 time periods. Increase in the productivity of sugar beet is also projected for Edinet and Ocnita districts in the northern AEZ, however the yield trends in reference period (1981-2010) are statistically significant on the lowest significant level ($p \leq 0.1$), so it can be noted just a tendency to yield increase in these districts.

8. Without application of adaptation measures, the most vulnerable for tobacco cultivation would be the northern and central AEZs and in less extent the southern AEZ. According to projections the most vulnerable districts will be Donduseni, Briceni, Floresti, Glodeni, Ocnita, Riscani and Soroca in the northern AEZ; Nisporeni district in the central AEZ and Cimislia district in the southern AEZ, in which productivity of tobacco could decrease by 2080s, from 51 to 88% (SRES B1) and/or from 76 to 98% (SRES A2). The least vulnerable districts for tobacco cultivation will be Cantimir, Leova, Taraclia and UTA Gagauzia in the southern AEZ, in which productivity of tobacco may increase by 2080s from 13 to 37% (SRES A2) and/or from 8 to 30% (SRES B1), in comparison with the 1981-2010 time periods.

9. Without adaptation measures (if maintaining the current cultivation technologies and used varieties), due to changes in climatic conditions, by the end of the XXI century, the cultivation of tobacco in Donduseni, Briceni, Soroca, Glodeni, Nisporeni and Cimislia districts will be either impossible, according to the SRES A2 high emission scenario, or economically not cost effective, according to SRES B1 low emission scenarios.

4.4. Projecting Climate Change Impacts on Livestock Production

Climate change is perceived as a major threat to the survival of many species and ecosystems and the financial sustainability of pastoral systems in various parts of the world, especially in developing countries (Gaughan et al., 2009). The possible effects of climate change on food production are not limited to crops and agricultural production. Animal production is affected by climate in four major ways: (1) changes in livestock feed-grain availability and price; (2) livestock pastures and forage crop production and quality; (3) distribution of livestock diseases, disease vectors and parasites; and (4) direct effect of weather and extreme events on animal health, growth and reproduction (Feenstra et al., 1998; Scholtz et al., 2010; Herrero et al., 2008; Scholtz et al., 2013). Recent economic studies have suggested that severe losses will occur if the current management systems are not modified in the face of climate change (Nardone et al., 2010).

Climate change will have tremendous consequences for dairy, meat and wool production, mainly arising from its impact on grassland and rangeland productivity. Heat distress suffered by animals will reduce the rate of animal feed intake and result in poor growth performance (Rowlinson, 2008). Some of the greatest impacts of global warming will be visible in grazing systems in arid and semi-arid areas (Hoffman, Vogel, 2008). Increasing temperatures and decreasing rainfall reduce yields of rangelands and contribute to their degradation. Higher temperatures tend to reduce animal feed intake and lower feed conversion rates (Rowlinson, 2008).

In the non-grazing systems, which are characterized by the confinement of animals (often in climate-controlled buildings), the direct impacts of climate change can be expected to be limited and mostly indirect resulting from reduction of yields and increased prices of the main feed used in animal production (OECD–FAO, 2008). Changes in the primary productivity of crops, forages and rangelands could be observed in areas affected by climate change. Increased temperatures coupled with water scarcity and irregular rainfall patterns would affect the optimal growth rates of many forage and range species. The substitution of some crops that used to be cropped for fodder production (e.g., grain corn) by others (e.g., sorghum and millet) more suited to drier environments should be emphasized. Probabilities of germination and establishment decreased with a decrease in precipitation and increased with an increase in precipitation. Peters et al. (2010) observed reductions in recruitment (73-80%) for all vegetation types with 50% less rainfall.

However, reductions in rainfall below 25% of current amounts would reduce recruitment to low levels (<0.03). As temperature and the level of CO_2 change the competition dynamics of plant species and the floristic composition of rangelands will be exacerbated. The increase of CO_2 level will result in increased growth grassland from livestock grazing. Reduced grazing intensity would result in increased soil carbon stocks (Peters et al., 2010). Heat stress is a major factor involved in reducing productivity and animal development. If animals experience thermal discomfort, they seek ways to lose heat and this involves a series of adaptations of the respiratory, circulatory, excretory, endocrine and nervous systems. These characteristics of adaptation can determine the tolerance of each breed to its environment (McManus et al., 2009). The coordination of all these systems to maintain the productive potential under thermal stress varies between species, breeds and individuals and within the same breed (Marai, 2010).

Despite all the expected negative impacts of global warming on livestock, some positive effects can be addressed. For example, higher winter temperature can reduce the cold stress experienced by livestock raised outside. Furthermore, warmer winter weather may reduce the maintenance energy requirements of animals and reduce the need for heating in animal housing (FAO, 2009a). Changes in weather conditions can result in the redistribution of animals within or between regions, changes in the criteria for choice of species used (cattle, sheep or goats), changes in genotype or breed (use of breeds that can maintain production in adverse conditions) and the environment (environmental protection or mitigation). Studies on animal production in many countries have shown that there will be a need to replace breeds and species in production systems over the next 30 years due to changes in the environment and the market demands (Seo et al., 2008; Wolfe et al., 2008; Yahdjian et al., 2008).

Therefore, there is great interest in understanding how livestock production may respond to climate change and future feed-grain availability. An empirical-statistical model can be used to explain system dynamics by empirically analyzing the relationships between some defined input and output variable such as a particular climate variable and forage yield on livestock production. This type of model is relatively simple to develop and can have a very high accuracy of prediction over the range of data for which it was developed. However, these models do have limitations. Statistical models are descriptive and not mechanistic in nature. Thus, they provide only limited insight into the mechanisms underlying the particular patterns of interest. They are also unsuited for predicting responses to novel situations for which no data are available (Feenstra et al., 1998).

The purpose of this study realized in the frame of Third National Communication of the Republic of Moldova under the UNFCCC (2013) was to: (i) examine the statistic-empirical relationships between livestock production by categories with observed mean temperature and main cereal crops (grain maize and winter wheat) yield during the most recent 30-yr (1981-2010) time period, based on livestock production and yield statistical data at the Republic of Moldova's agricultural enterprises of various categories; and (ii) use these relationships to calculate possible projections of future changes in livestock production by categories in the 2020s, 2050s and 2080s, based on the projected changes in average temperatures and main cereal crops yield received from an ensemble of 10 GCM for three SRES A2 (high), A1B (medium) and B1 (low) emission scenarios of greenhouse gases and aerosols. The milk, eggs, wool, beef, pork, mutton and poultry production was considered in this study in order to analyze the specific interactions between the changing climate and future feed-grain availability.

4.4.1. Data and Methods

The assessment of the climate change impact on livestock sector was made based on projections of changes in temperature received by regionalization of global experiments the most reliable in the Republic of Moldova 10 GCMs for the three SRES A2, A1B and B1 emission scenarios of greenhouse gases and aerosols (see more in Taranu et al., 2012) and projections of changes in productivity of main cereal crops (winter wheat and grain corn) in the Republic of Moldova (see more in Taranu, 2013). To assess the livestock production (by categories) vulnerability to climate change, it was used the empirical-statistical approach, linking fluctuations of livestock production to climate conditions during the most recent time period (1981-2010). Statistical analysis of the possible impact of the climate change on livestock production by categories (milk, eggs, wool, beef, pork, mutton and poultry) was carried out in several steps.

Initially, according to the statistical data on livestock production at agricultural enterprises of various categories were constructed linear and polynomial trends for livestock production by categories in the Republic of Moldova over the two distinct time periods: 1965-1990 (baseline period) and 1981-2010 (most recent period).

Secondly, the Pearson correlations between livestock production by categories and predictor variables have been used for selection statistical significant variables. After that, multiple regression equations linking livestock production by categories with average monthly temperature and crop productivity during the most recent time period (1981-2010)[1], with the highest level of statistical significance were calculated (using the statistical application package STATGRAPHICS Centurion and Microsoft Office Excel).

The regression model used was the following:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + e, \quad (4.2)$$

Where:

Y – Dependent variables (livestock production by categories);

X – Independent variables, inclusive:

- X_1 – June average monthly air temperature (T_{Jun});
- X_2 – July average monthly air temperature (T_{Jul});
- X_3 – August average monthly air temperature (T_{Aug});
- X_4 – cereal crop yield ($Y_{grain\ corn}$);
- X_5 – cereal crop yield ($Y_{winter\ wheat}$);

a – Constant;

b – Regression coefficient;

e – Error.

The temperature and crop predictor variables were selected in conformity with the step by step regression analysis, by taking into account their contribution to the livestock production by categories, and the consecutive analysis of all possible combinations, with the purpose to find the most reliable model. The regression coefficients of the remaining months show, in what direction and how much may be modified the livestock production in response to changes in the temperature of the respective month and cereal crop yield.

Finally, the analysis of the impact of future climate changes, determined by projections of changes in temperature and productivity of main cereal crops ($Y_{grain\ corn}$ and $Y_{winter\ wheat}$) on the livestock production without undertaken any adaptation measures was carried out according to methodologi-

[1] In analysis a shift in one year have been used to cereal crop yield because for livestock feed is used the crop yield of the previous year.

cal approach proposed by Constantinov et al. (2009). Using the regression equations relationship in the livestock production variability by categories with projections of changes in temperature and productivity of main cereal crops, there were calculated projections of future yield changes in the Republic of Moldova (%/30 years) for 2020s, 2050s and 2080s according to an ensemble from 10 Global Climate Models (GCMs) for the three SRES A2, A1B and B1 emission scenarios relative to the most recent time period (1981-2010).

4.4.2. Observed Linear Trends of Variability in Livestock Production

The linear trends of variability in production of main livestock products at all categories of producers in the RM for years 1965-1990 have been characterized by a sustainable increase of the livestock production: by 355.2 kt per decade for milk; by 311 million pieces per decade for eggs; by 33.2 kt per decade for pork; by 26.9 kt per decade for beef; and by 20.3 kt per decade for poultry. Negative trend was observed only for wool production, by 173.4 t per decade (**Table 4-15; Figure 4-3**).

Table 4-15: Linear trends of livestock production and their statistical significance *(p-value)* for two observation time periods (1965-1990 and 1981-2010) in the Republic of Moldova

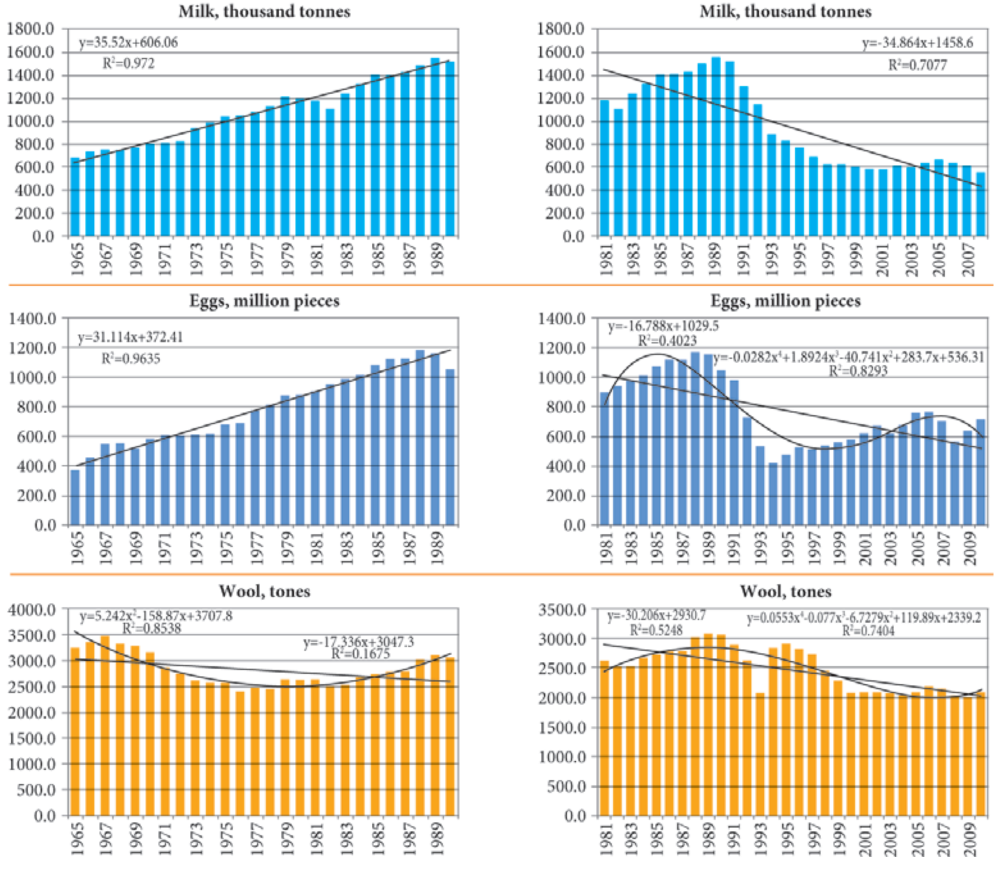
Livestock production	*Yield*			
	1965-1990		1981-2010	
	Trend	*p-value*	*Trend*	*p-value*
Milk, kt	35.52	**0.0000**	-34.86	**0.0000**
Eggs, million pieces	31.11	**0.0000**	-16.79	**0.0001**
Wool, t	-17.34	**0.0378**	-30.21	**0.0000**
Beef, kt	2.693	**0.0000**	-3.707	**0.0000**
Pork, kt	3.320	**0.0000**	-4.519	**0.0000**
Mutton, kt	0.009	0.5776	-0.090	**0.0000**
Poultry, kt	2.029	**0.0000**	-1.150	**0.0005**

Note: Bold is used to mark statistically significant values.

Livestock production increased significantly due to the implementation of intensive technologies of animal growing in the 1981-1990 time periods, achieving the maximum average annual level: for milk – 1359.22 kt; eggs – 1051.2 million pieces; wool – 2761.9 tons; pork – 147.4 kt; beef– 94.3 kt; and poultry – 55.4 kt.

Then, in the forthcoming three decades (1981-2010) there was a tendency for sharp decrease in livestock production: by 348.6 kt per decade for milk, by 167.9 million pieces per decade for eggs, by 302.1 tons per decade for wool, by 45.2 kt per decade for pork, by 37.1 kt per decade for beef, by 11.5 kt per decade for poultry, and by 0.9 kt per decade for mutton (**Table 4-15; Figure 4-3**).

The greatest decrease in the annual average livestock production was observed in the 2001 – 2010 years: for milk – 600.4 kt; wool – 2071.1 tons; pork – 45.4 kt; beef – 14.2 kt; mutton – 2.4 kt and in the 1991-2000 years for eggs – 583.9 million pieces; and poultry – 23.9 kt.



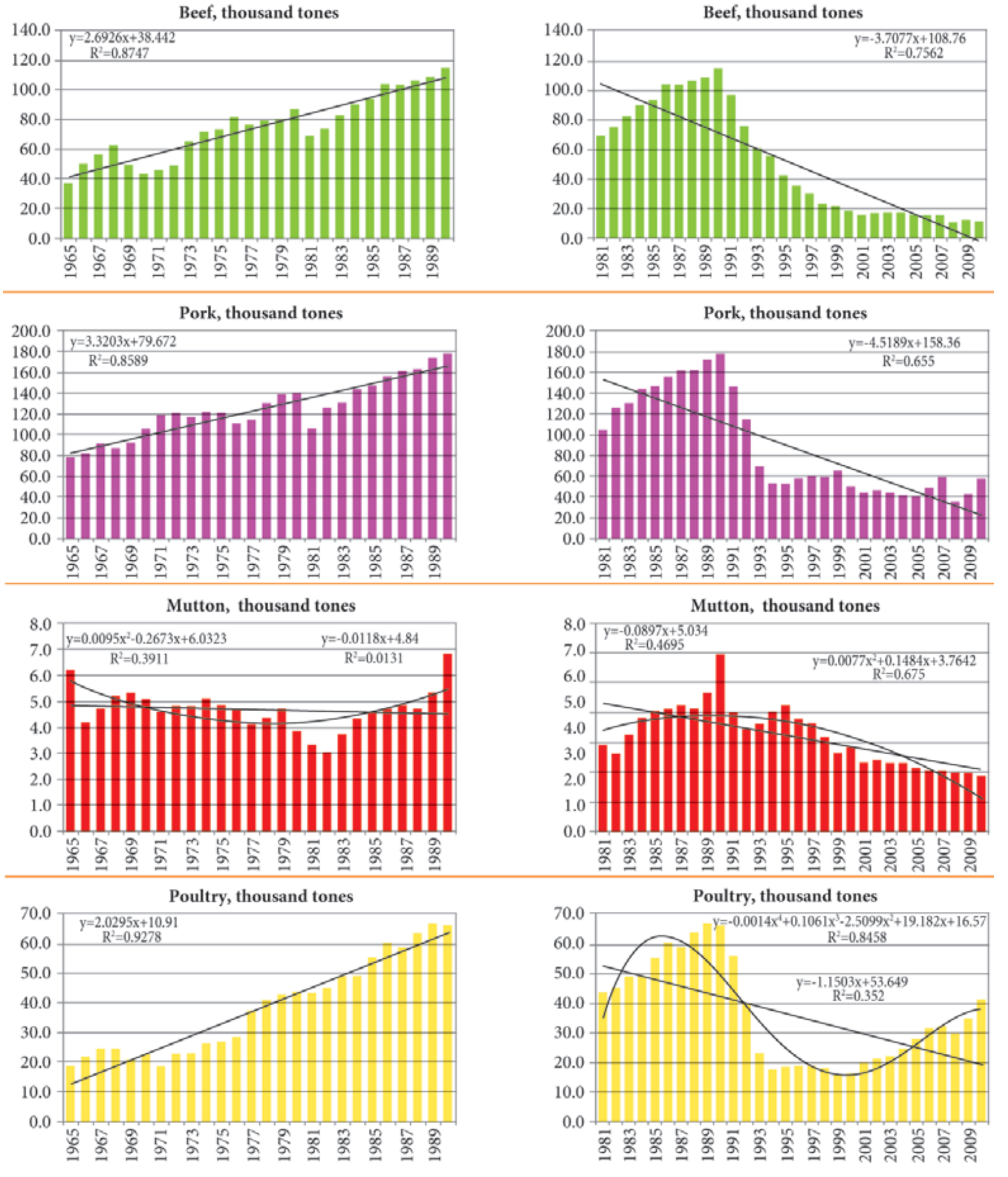


Figure 4-3: Livestock production variability trends and their coefficients of determination (R^2) for two observation periods (on the left: 1965-1990, on the right: 1981-2010) in the Republic of Moldova

4.4.3. Pearson Correlations between Livestock Production and Predictor Variables

The data presented in **Table 4-16** reveals the Pearson correlations between livestock production by categories and predictor variables during the most recent time period (1981–2010). The correlation coefficients (r) range between -1 and +1 and measure the strength of the linear relationship between the variables. The second number in each column of the table is a *p-value* which tests the statistical significance of the estimated correlations. Bold is used to mark statistically significant values: *p-value* ≤ *0.001* indicate statistically significant non-zero correlations at the 99.9% confidence level, *p-value* ≤0.01 indicate statistically significant non-zero correlations at the 99.0%, and *p-value* ≤0.05 indicate statistically significant non-zero correlations at the 95.0% confidence level. The correlation coefficient between livestock production and temperature varies from r = - 0.40 to r = - 0.54 which indicate that temperature and livestock production has an inverse relationship, this means that as temperature increase, livestock production by categories will reduce. The correlation coefficient between livestock production and cereal crop yield varies from r = +0.42 to r = +0.69 which indicate that cereal crop yield has a direct relationship with livestock production, this means that as cereal crop yield increase, livestock production by categories also will increase.

Table 4-16: The Pearson correlations between livestock production and predictor variables during the 1981 – 2010 time periods

Livestock production	Temperature						Yield			
	Jun		Jul		Aug		Corn		Winter wheat	
	r	*p-value*	r	*p-value*	r	*p-value*	r	*p-value*	r	*p-value*
Milk	-0.54	**0.0023**	-0.54	**0.0026**	-0.47	**0.0110**	0.69	**0.0000**	0.62	**0.0003**
Eggs	-0.48	**0.0089**	-0.46	**0.0112**	-0.40	**0.0325**	0.49	**0.0071**	0.42	**0.0227**
Wool	-0.32	0.0924	-0.27	0.1528	-0.40	**0.0309**	0.69	**0.0000**	0.63	**0.0003**
Beef	-0.53	**0.0030**	-0.53	**0.0030**	-0.48	**0.0082**	0.70	**0.0000**	0.66	**0.0001**
Pork	-0.48	**0.0089**	-0.50	**0.0053**	-0.43	**0.0202**	0.68	**0.0000**	0.61	**0.0004**
Mutton	-0.40	**0.0303**	-0.34	0.0682	-0.41	**0.0252**	0.69	**0.0000**	0.62	**0.0003**
Poultry	-0.42	**0.0228**	-0.42	**0.0229**	-0.29	0.1223	0.53	**0.0034**	0.47	**0.0098**

Note: Bold is used to mark statistically significant values: *p ≤ 0.001* indicate statistically significant non-zero correlations at the 99.9% confidence level; *p ≤ 0.01* indicate statistically significant non-zero correlations at the 99.0%, and p ≤ 0.05 indicate statistically significant non-zero correlations at the 95.0% confidence level.

4.4.4. The Relationship of Livestock Production Variability with Predictor Variables during the 1981 – 2010 time period in the Republic of Moldova

A multiple linear regression analysis was used with June, July and August average monthly air temperatures (T_{Jun}, T_{Jul} and T_{Aug}) and cereal crop yields ($Y_{grain\ corn}$ and $Y_{winter\ wheat}$) as independent variables, and livestock production by categories (milk, eggs, wool, beef, pork, mutton and poultry) at the country level, as the dependent variable to quantify the separate effects of those factors.

The influential climate predictor variables were not identical for each livestock production category. The analysis of data presented in the **Table 4-17** reveals that the influence of predictor variables on milk, wool, beef, pork, and mutton production in the 1981-2010 years was statistically significant at 99.9% highest level of significance ($p \le 0.001$) with exception for eggs and poultry production ($p \le 0.05$).

Table 4-17: The relationship of livestock production variability with predictor variables during the 1981–2010 time periods in the Republic of Moldova

Livestock production	Regression equation	*p* – value	R^2, %
Milk, thousand tons	$P_{milk} = 3350.47 - 69.37{*}T_{Jun} - 27.83{*}T_{Jul} - 46.73{*}T_{Aug} + 14.69{*}Y_{Corn} + 5.22{*}Y_{Wheat}$	**0.0001**	67.13
Eggs, million pieces	$P_{eggs} = 2475.81 - 43.97{*}T_{Jun} - 17.85{*}T_{Jul} - 29.11{*}T_{Aug} + 6.46{*}Y_{Corn} + 0.49{*}Y_{Wheat}$	**0.0222**	41.60
Wool, tons	$P_{wool} = 2839.79 - 52.26{*}T_{Aug} + 17.87{*}Y_{Corn} + 7.28281{*}Y_{Wheat}$	**0.0002**	54.33
Beef, thousand tons	$P_{beef} = 287.22 - 6.44{*}T_{Jun} - 3.02{*}T_{Jul} - 4.98{*}T_{Aug} + 1.31{*}Y_{Corn} + 0.99{*}Y_{Wheat}$	**0.0000**	69.20
Pork, thousand tons	$P_{pork} = 351.73 - 6.93{*}T_{Jun} - 4.03{*}T_{Jul} - 5.46{*}T_{Aug} + 2.00{*}Y_{Corn} + 0.82{*}Y_{Wheat}$	**0.0004**	60.78
Mutton, thousand tons	$P_{mutton} = 7.59 - 0.14{*}T_{Jun} - 0.15{*}T_{Aug} + 0.06{*}Y_{Corn} + 0.02{*}Y_{Wheat}$	**0.0003**	57.08
Poultry, thousand tons	$P_{poultry} = 101.31 - 2.49{*}T_{Jun} - 1.72{*}T_{Jul} + 0.46{*}Y_{Corn} + 0.31{*}Y_{Wheat}$	**0.0188**	37.74

Note: Bold is used to mark statistically significant values: $p \le 0.001$ indicate statistically significant non-zero correlations at the 99.9% confidence level; $p \le 0.01$ indicate statistically significant non-zero correlations at the 99.0%, and $p \le 0.05$ indicate statistically significant non-zero correlations at the 95.0% confidence level. *P* – livestock production by categories; Predictor Variables: *T* – June, July, and August average monthly air temperature, ^{0}C; *Y* – winter wheat and grain corn yield, q/ha.

Coefficient of determination R^2 shows that the combined effect of T_{Jun}, T_{Jul} and T_{Aug} and cereal crop yield defined about 69.2% of the variability of average annual production of beef, 67.1% of the variability of milk, and 60.8% of pork and 41.6% of eggs production during this period. Approximately 57.1% of mutton production could be explained by a combination of the T_{Jun}, T_{Aug} and cereal crop yield. The combined effect of T_{Aug} and cereal crop yield determined the wool production variability at the level of 54.3%, and about 37.7% of poultry production could be explained by a combination of the T_{Jun}, T_{Jul} and cereal crop yield in the 1981-2010 time period.

4.4.5. Projections of Future Changes in Livestock Production in the Republic of Moldova

The possible projections in the livestock production (milk, eggs, wool, beef, pork, mutton and poultry), due to future climate changes in the Republic of Moldova, have been considered for two alternative scenarios: (i) assuming increase in summer average temperature (Jun, Jul and Aug) and no decrease in the future cereal crops yield – optimistic scenario (**Figures 4-4A and 4-5A**); and (ii) considering increase in summer average temperature (Jun, Jul and Aug) and possible decrease in the yield of the main cereal crops (winter wheat and grain maize) (Taranu, 2013) – pessimistic scenario (**Figures 4-4B and 4-5B**).

4.4.5.1. Milk Production

In dairy cows, similarly to other species the various factors of the environment, such as the average temperature, humidity and air velocity play an important role in the fertility, reproductive performance and milk yield. The optimal ambient temperature for dairy cows is between 5 to 15°C.

Over 15°C the animals start to sweat, although they are still able to maintain the equilibrium between heat production and heat dissipation. Heat dissipation by sweating gradually increases and although it becomes quite intense above the upper critical temperature (25°C) the cow is no more able to maintain the heat balance at such high temperatures. Kadzere et al., 2002 found that on days of heat stress the amount of water lost through evaporation may be up to or even exceed the amount of water excreted in the milk.

The high rate of water loss stresses the importance of water supply for dairy cows at high temperatures. The efficiency of body cooling by evaporative water loss, however, decreases with the increase of humidity. The use of the Temperature-Humidity Index (THI) is suggested as an indicator of the thermal climatic conditions:

$$THI = 0.72\,(W + D) + 40.6, \quad (4.3)$$

Where:

W – wet bulb;

D – dry bulb temperature, in °C.

When the THI is in the range of 72-80, 80-90 or 90-98, the corresponding heat stress is mild, medium or severe. Both the increasing ambient temperature (from 25 to 32°C), and the increasing THI (from 73 to 82) have a negative impact on the dry matter intake and milk production of cows (West et al., 2003).

The relevant data show, that the shorter the animal is exposed to heat stress, the better they can tolerate it, although even a moderate heat stress will impair their production performance. The heat stress caused feed refusal predisposes the animal to certain metabolic disorders, first of all to ketosis.

The occurrence of ketosis at herd level not only leads to a temporary decline in milk production, but in consequence of the mortalities may also cause a drop in the number of dairy cows. The present day selection for production weakens heat tolerance, thus combined selection for heat tolerance and production is recommended when facing the challenge of climate change (Ravagnolo, Misztal, 2000).

Summarizing the relevant data it can be stated that sever heat stress results in an average production loss of 1.5-2 liters/cow/day (5-10% of the daily milk yield). Moreover, the altered rumen fermentation influences not only milk yield but also milk composition by reducing its protein and fat content (Babinszky et al., 2011).

The analysis of the obtained results revealed that due to the impact of the main climate and crop predictors variables in the Republic of Moldova, the milk production by 2020s could decrease from 7% (SRES A2) to 12% (SRES A1B), without changes in cereal crop yield (optimistic scenario), respectively from 12% (SRES A2) to 22% (SRES A1B), by considering projections of changes in the yield of winter wheat and grain maize (pessimistic scenario). In comparison with the 1981-2010 time periods, by 2050s the milk production may decrease in dependence of the assessed emission scenario, from 23% (SRES B1) to 34% (SRES A1B) under the optimistic scenario, respectively from 44% (SRES B1) to 66% (SRES A1B) under the pessimistic scenario. The maximum values of milk production decrease may be reached by 2080s. Due to changes in values of main climate predictors (T_{Jun}, T_{Jul} T_{Aug} and main cereal crop yield) the milk production will decrease from 32% (SRES B1) to 63% (SRES A2) under optimistic scenario (**Figure 4-4A**), respectively from 61% (SRES B1) to 93% (SRES A1B) according to the pessimistic scenario (**Figure 4-4B**).

4.4.5.2. Eggs Production

The optimal laying temperature is between 11°C and 26°C (Kekeocha, 1985). Relative humidity level above 75 per cent will cause a reduction in egg laying. When the temperature is rise above 28° C the production and quality of eggs decrease (**Table 4-18**). Seasonal temperature increases can reduce eggs production by about 10 per cent.

Table 4-18: Temperature and its effects on eggs production

Temperature (°C)	Effects/Impacts
11 - 26	Good production
26 - 28	Some reduction in feed intake
28 - 32	Feed consumption reduced and water intake increased; eggs of reduced size and thin shell
32 - 35	Slight panting.
35 - 40	Heat prostration sets in, measures to cool the house must be taken
40 and above	Mortality due to heat stress

Source: Kekeocha, 1985: Poultry production handbook. London, Macmillan Publishers Ltd., cited from <http://www.fao.org/docrep/005/y4628e/y4628e03.htm>.

In addition, several studies reported that high ambient temperatures decrease the digestibility of nutrients in poultry likely due to a reduced activity of trypsin, chymotrypsin, and amylase (Hai et al., 2000).

Consequently, the lower and by most probability insufficient nutrient supply limits eggs production and eggs mass in layers, and the growth rate in broilers. During heat stress poultry lose a large amount of carbon dioxide by panting; CO2 however, is essential for Ca-carbonate in eggshell formation. Therefore, in addition to an insufficient nutrient supply, the compromised eggs shell formation limits the eggs production further (eggs/day or eggs production/number of birds), which can be very substantial as the eggs production percentage might decline from 80-90% to 50-60%, with a 10 g lower egg weight on average (Mashaly et al., 2004). Furthermore, the lack of carbon dioxide results in decreasing eggshell thickness and an increasing number of broken eggs that further aggravates the profit losses in hens kept in a hot environment (Babinszky et al., 2011).

The analysis of the obtained results revealed that due to the impact of main climate and crop predictor's variables in the Republic of Moldova, the eggs production by 2020s could decrease from 2% (SRES A2) to 6% (SRES A1B), under the optimistic scenario, respectively from 4% (SRES

A2) to 10% (SRES A1B), according to the pessimistic scenario. In comparison with the 1981-2010 time periods, by 2050s the eggs production may decrease from 14% (SRES B1) to 20-22% (SRES A2 and A1B) under the optimistic scenario, respectively from 23% (SRES B1) to 32-36% (SRES A2 and A1B) according to pessimistic scenario. The maximum values of eggs production decrease could be reached by 2080s, from 21% (SRES B1) to 44% (SRES A2) under the optimistic scenario (**Figure 4-4A**), respectively from 34% (SRES B1) to 70% (SRES A2) according to the pessimistic scenario (**Figure 4-4B**).

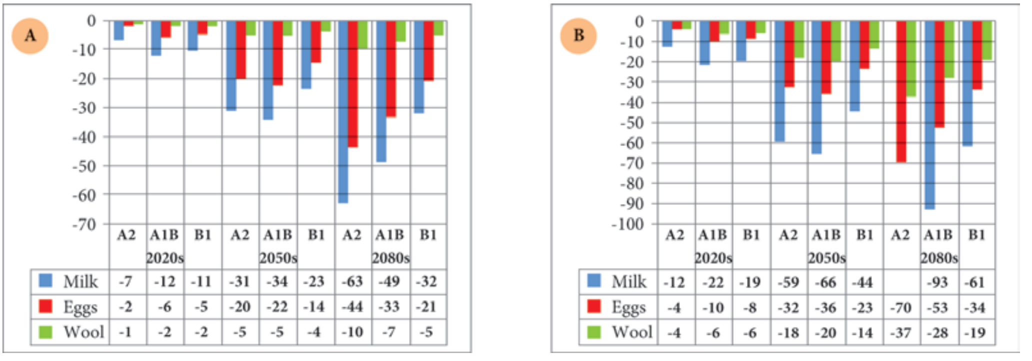


Figure 4-4: Projections of future changes in livestock production (milk, eggs and wool) in the Republic of Moldova (%/30 years) relative to 1981-2010 current period, according to an ensemble from 10 GCMs for SRES A2, A1B and B1 emission scenarios in the XXI century: (A) optimistic scenario – without changes in the yield of main cereal crops (winter wheat and grain maize); (B) pessimistic scenario – considering projections of changes in the yield of main cereal crops

4.4.5.3. Wool Production

A greater frequency of drought, pasture deterioration, higher summer temperatures and an increased incidence of pests and diseases under warmer climates are likely to put further physiological stress on sheep. This stress may be alleviated to some degree by higher winter temperatures and lengthening of warm seasons, both of which have the potential to improve wool quality.

For wool production in the Republic of Moldova, there is projected a slight decrease by 1-2% in the 2020s under the optimistic scenario, respectively a decrease by 4-6% under the pessimistic scenario. In comparison with the 1981-2010 time periods, by 2050s the wool production may decrease by 4-5% under the optimistic scenario, respectively from 14% (SRES B1) to 18-20% (SRES A2 and A1B) according to the pessimistic scenario. The maximum values of wool production reduction could be reached by the 2080s, from 5% (SRES B1) to 10% (SRES A2) under the optimistic scenario (**Figure 4-4A**), respectively from 19% (SRES B1) to 37% (SRES A2) according to the pessimistic scenario (**Figure 4-4B**).

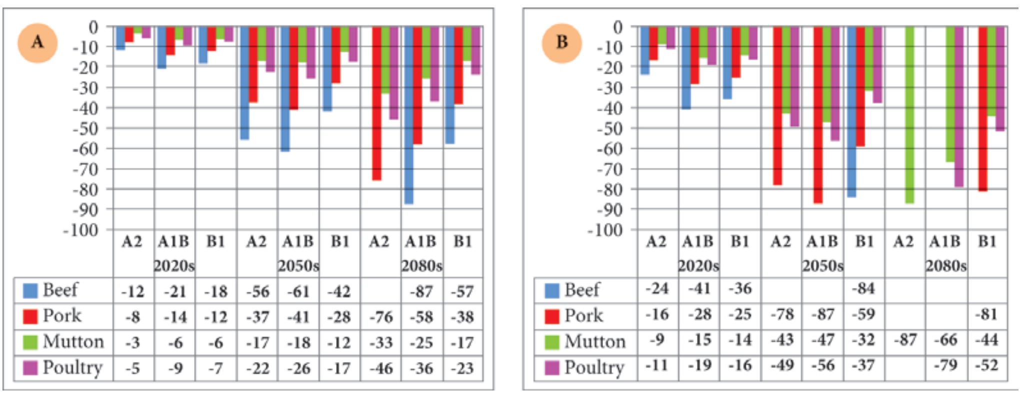
4.4.5.4. Beef Production

With reference to other cattle categories, the unfavorable meteorological conditions directly affect the animals and their physiology, as discussed in the above section on dairy cows. The extreme weather conditions diminish the growth performance (weight gain, feed intake and feed conversion potential) of beef calves, particularly of those kept outdoors. Slower growth and smaller slaughter weight however are reflected in the quality of meat as well, since animals of the same age but smaller body weight have less muscle fat and also the taste panel traits of juiciness and tenderness are poorer (Keane, Allen, 1998).

Increasing mean temperatures and declining precipitation reduce the dietary crude protein and digestible organic matter content of grass; it is unlikely, however, that any future increases in precipitation would compensate for the declines in forage quality following from the projected temperature increases (Craine et al., 2010). Aridity, water deficiency may lead to a drop in groundwater levels, alteration and thinning of pasture flora, and in consequence to a decline in feed supply, besides aggravating the problems of water supply (Babinszky et al., 2011). As a result, cattle are likely to experience greater nutritional stress in the future with the two options of either accepting the loss of performance or being prepared to provide supplemental nutrition to the extensive beef sector as well. Feeding concentrate to beef cattle increases the costs of beef production, and it may also affect the nutritive and health value of meat. In respect of fatty acid composition, numerous publications suggest that the meat of grass fed cattle contains more n-3 fatty acids and conjugated linoleic acid than meat from their concentrate fed peers (Nuernberg et al., 2005; Scollan et al., 2006). These fatty acids play an important role in maintaining health and preventing diseases (i.e. cardio vascular diseases, cancer) and consumers are increasingly aware of these functional components of foods. In addition to the above-mentioned problems, extreme weather may result in respiratory disease, immune suppression and thus higher mortality of the animals, which further reduces the profitability of beef production (Babinszky et al., 2011).

For beef production in the republic of Moldova by 2020s, when assessing the combined effect of T_{Jun}, T_{Jul}, T_{Aug} and cereal crop yield, it is expected a decrease in productivity by 12% (SRES A2) to 21% (SRES A1B) under the optimistic scenario, respectively by 24% (SRES A2) to 41% (SRES A1B) under the pessimistic scenario. By 2050s, there will persisting the decreasing trend in beef production due to climate changes increase in summer average temperature and decrease in cereal crop productivity. Severe decrease in beef production, by 42% (SRES B1) to 61% (SRES A1B), is expected under the optimistic scenario, while according to the pessimistic scenario, i.e. by considering the projected changes in the yield of the main cereal crops, under the SRES B1 low emission scenario, the animal breeding will be economically not cost-effective, while under the SRES A2 (high) and A1B (medium) emission scenarios, even impossible in the conditions of the Republic of Moldova. The maximum values of beef production decrease may be reached by 2080s, from 57% (SRES B1) to 87% (SRES A1B) under the optimistic scenario (**Figure 4-5A**), while according to the pessimistic scenario under all three SRES emission scenarios the cattle breeding will be impossible in the Republic of Moldova (**Figure 4-5B**).

In case the predicted climate change occurs, the current beef production potential can be maintained only if supplemental feed is offered; this factor would reduce significantly the economic efficiency of cattle production and may have an impact also on beef quality as well.



A

	A2 (2020s)	A1B (2020s)	B1 (2020s)	A2 (2050s)	A1B (2050s)	B1 (2050s)	A2 (2080s)	A1B (2080s)	B1 (2080s)
Beef	-12	-21	-18	-56	-61	-42		-87	-57
Pork	-8	-14	-12	-37	-41	-28	-76	-58	-38
Mutton	-3	-6	-6	-17	-18	-12	-33	-25	-17
Poultry	-5	-9	-7	-22	-26	-17	-46	-36	-23

B

	A2 (2020s)	A1B (2020s)	B1 (2020s)	A2 (2050s)	A1B (2050s)	B1 (2050s)	A2 (2080s)	A1B (2080s)	B1 (2080s)
Beef	-24	-41	-36			-84			
Pork	-16	-28	-25	-78	-87	-59			-81
Mutton	-9	-15	-14	-43	-47	-32	-87	-66	-44
Poultry	-11	-19	-16	-49	-56	-37		-79	-52

Figure 4-5: Projections of future changes in livestock production (beef, pork, mutton and poultry) in the RM (%/30 years) relative to 1981-2010 current period, according to an ensemble from 10 GCMs for SRES A2, A1B and B1 emission scenarios in the XXI century: (A) optimistic scenario – without changes in the yield of main cereal crops (winter wheat and grain maize); (B) pessimistic scenario – considering projections of changes in the yield of main cereal crops

4.4.5.5. Pork Production

The climate change with rising mean temperatures may cause a permanent stress load for pigs, especially in continental summer or warmer climate areas. The upper critical temperature for pigs from nursery to adult ages is 25-26°C; however, some research data suggest that the optimal temperature decreases with the increase in body weight. The heavier an animal, the less ability it has to lose heat due to the relative small surface area compared to its body weight. In consequence feed refusal increases with body weight at high ambient temperatures (Close, 1989; Quiniou et al., 2000). High temperatures cause loss of appetite in pigs; however, both the upper critical temperature and the rate of feed refusal are influenced by the relative humidity of the air (Collin et al., 2001; Huynh et al., 2005).

With the increase of humidity a 60–70 kg pig may lower its feed intake by up to 80-150 g/day (Huynh et al., 2005). The lower feed intake compromises the daily gain, however, after exposure to hot periods of 30-33°C pigs display compensatory growth, they overcome their heat stress and grow further, but they can't compensate for temperatures as high as 36°C (Babinszky et al., 2011).

There is a curvilinear relationship between the increase of temperature and the average daily gain and feed conversion rate of pigs fed ad libitum (reviewed by Noblet et al., 2001). The average daily gain reaches its maximum between temperatures of 15 to 25°C in young pigs (up to 30-34 kg) and between 10-20°C in growing and finishing pigs.

Recent publications highlight the fact that high temperatures not only impair growth but also change body composition and thus can impair the nutritive value and quality of pork. Prolonged heat stress (30-33°C) reduces the rate of protein deposition in growing and finishing pigs (Kerr et al., 2003; Le Bellego et al., 2002).

Due to warming and decrease in cereal crop productivity, pork production in the Republic of Moldova by 2020s may decrease from 8% (SRES A2) to 14% (SRES A1B) under the optimistic scenario, respectively by 16% (SRES A2) to 28% (SRES A1B) under the pessimistic scenario. In comparison with the 1981-2010 time periods, by 2050s the pork production may decrease, in dependence of the assessed emission scenario, from 28% (SRES B1) to 37-41% (SRES A2 and A1B) under the optimistic scenario, respectively from 59% (SRES B1) to 59-78% (SRES A2 and A1B) under the pessimistic scenario. The maximum values of pork production decrease may be reached by 2080s, from 38% (SRES B1) to 76% (SRES A2) under the optimistic scenario

(**Figure 4-5A**), while according to the pessimistic scenario, i.e. by considering the projected changes in the yield of the main cereal crops, under the SRES B1 low emission scenario the swine breeding will be economically not cost-effective, while under the SRES A2 (high) and A1B (medium) emission scenarios, even impossible in the conditions of the Republic of Moldova (**Figure 4-5B**).

4.4.5.6. Mutton Production

Temperatures ranging between 15°C and 29°C do not seem to have any effect on growth performance of lambs. The effects of high ambient temperature on growth performance are induced by the decrease of the anabolic activity and the increase in tissue catabolism (Marai et al., 2007). This decrease in anabolism is essentially caused by a decrease in voluntary feed intake of main nutrients. The increase in tissue catabolism occurs mainly in fat depots and/ or lean body mass. Lamb production is deleteriously affected by exposure to heat stress and this causes an economic loss (Salem et al., 2011).

For mutton production by 2020s, when assessing the combined effect of T_{Jun}, T_{Aug} and cereal crop yield, it is expected a slight decrease in the productivity, from 3% (SRES A2) to 6% (SRES B1 and A1B) under the optimistic scenario, respectively from 9% (SRES A2) to 14-15% (SRES B1 and A1B) under the pessimistic scenario. In comparison with the 1981-2010 time periods, by 2050s the mutton production may decrease, in dependence of the assessed emission scenario, from 12% (SRES B1) to 17-18% (SRES A2 and A1B) under the optimistic scenario, respectively from 32% (SRES B1) to 47% (SRES A1B) under the pessimistic scenario. The maximum values of mutton production decrease may be reached by 2080s. Due to changes in values of main climate predictors (T_{Jun}, T_{Aug} and reduced yield of the main cereal crops), the mutton production could decrease from 17% (SRES B1) to 33% (SRES A2) under the optimistic scenario (**Figure 4-5A**), respectively from 44% (SRES B1) to 87% (SRES A2) according to the pessimistic scenario (**Figure 4-5B**).

4.4.5.7. Poultry Production

There are a large number of reports on the effects of high ambient temperature and humidity on poultry production, since the poultry industry is concentrated in hot climate areas of the world, mainly in Asia and South America (Daghir, 2009). However, their higher production performance and feed conversion efficiency make today's chickens more susceptible to heat stress than ever before (Lin et al., 2006).

The thermoregulation characteristics of poultry differ to some extent from those of mammals due to their high rate of metabolism associated with more intensive heat production and low heat dissipation capacity caused by their feathers and lack of sweat glands. Evaporative cooling is achieved exclusively by panting. In the first days of their life poults need hot climate (32-38˚C), but the optimal temperature decreases rapidly with age by 2.5-3.0˚C per week (FASS, 2010).

After feathering birds prefer mean ambient temperatures between 18-22˚C for their growth performance and egg production although the optimal temperature for feed efficiency is higher. The crucial temperature for poultry is 30˚C, because up to this point birds, through a better feed conversion rate and lower basal metabolic rate, are able to compensate for the energy loss caused by the lower feed intake (Daghir, 2009). Above 30˚C the feed and energy intake declines to such an extent that birds are no more able to compensate for it, production declines rapidly and the rate of mortality increases.

The analysis of the obtained results revealed that due to the impact of the main climate (T_{Jun}, T_{Jul}) and crop yield predictors variables in the RM, the poultry production by 2020s could decrease from 5% (SRES A2) to 9% (SRES A1B) under the optimistic scenario, respectively from 11% (SRES A2) to 19% (SRES A1B) under the pessimistic scenario. In comparison with the 1981-2010 time periods, by 2050s the poultry production may decrease in dependence of the assessed emission scenario from 17% (SRES B1) to 22-26% (SRES A2 and A1B) under the optimistic scenario, respectively from 37% (SRES B1) to 49-56% (SRES A2 and A1B) under the pessimistic scenario. The maximum values of poultry production decrease could be reached by 2080s. Due to changes in values of main climate predictors (T_{Jun}, T_{Jul}, T_{Aug}) and reduced yield of the main cereal crops, the poultry production will decrease from 23% (SRES B1) to 46% (SRES A2) under the optimistic scenario (**Figure 4-5A**), respectively from 52% (SRES B1) to 79% (SRES A1B) under the pessimistic scenario (**Figure 4-5B**).

CONCLUSIONS

The impact assessment performed allow conclude that the negative effect of increased T_{Jun}, T_{Jul} and T_{Aug} average temperatures and the sharp decline in the crop productivity of main cereal crops, according to an ensemble from 10 GCMs for SRES A2 (high), A1B (medium) and B1(low) emission scenarios, without undertaken any adaptation measures, by 2080s will lead to a significant drop in the livestock production, from 57% (SRES B1) to 87% (SRES A1B) for beef, from 38% (SRES B1) to 76% (SRES A2) for pork, and from 32% (SRES B1) to 63% (SRES A2) for milk; to a medium drop in the livestock production, from 23% (SRES B1) to 46% (SRES A2) for poultry, from 21% (SRES B1) to 44% (SRES A2) for eggs, and from 17% (SRES B1) to 33% for mutton; respectively to a slight decrease in the livestock production, from 5% (SRES B1) to 10% (SRES A2) for wool, as per the optimistic scenario considered; respectively to a significant drop in the livestock production, from 61% (SRES B1) to 93% (SRES A1B) for milk, from 52% (SRES B1) to 79% (SRES A1B) for poultry; from 34% (SRES B1) to 70% (SRES A2) for eggs; from 44% (SRES B1) to 87% for mutton (SRES A2); to a medium drop in the livestock production, from 19% (SRES B1) to 37% (SRES A2) for wool, as per the pessimistic scenario considered (i.e., by considering the projections of future changes in the yield of main cereal crops: winter wheat and grain maize, with respect to the average Republic of Moldova's livestock production by categories in the most recent period of 1981-2010). Furthermore, according to the pessimistic scenario the production of milk, beef, pork and poultry in the Republic of Moldova will be impossible under the SRES A2 high emission scenario, if no adaptation measures will be undertaken in the country in the second half of 21^{st} century.

4.5. Projecting Climate Change Impacts on Grape Production

Perennial crops are the most valuable of the Republic Moldova's diverse agricultural products. They are also potentially the most influenced by information on future climate, since individual plants are commonly grown for more than 30 years. This study evaluated the impacts of future climate changes on the wine grape in the Republic of Moldova on the national and district level, using a combination of statistical crop models and downscaled climate model projections. National and districts data on wine grape yields and observed climate from 1983-2010 were used to evaluate the influence of climate on wine grape yields and the majority of statistical models on district level have had a clear climate response based on historical data.

We have focused on effects of future changes in average monthly temperature and precipitation, and therefore our results do not incorporate the potentially important additional effects of changes at sub-monthly time scales, such as increased frequency of extreme events. While perennial crops provide a unique opportunity to incorporate climate projections into decisions made today, they also present some unique challenges compared to projecting impacts and adaptation options in annual crops.

First, the multiannual growth of perennials makes experimental warming trials difficult. *Second*, far fewer models exist to describe perennial crop growth compared to annual crops, in part reflecting the lack of experimental data. While annual crop studies can rely on process-based models such as APES, CROPSYST, DAISY, DSSAT, FASSET, HERMES, STICS, WOFOST etc., modeling of perennial crops is limited primarily to statistical models developed from historical variations in weather and crop harvests. *Third*, perennials can be affected by climate at all times of the year, while annual crops are mainly influenced by weather during the summer growing season. Identifying the particular weather variables most relevant to perennial crop growth can therefore be more difficult than with annuals.

Additional to this we examined the structure and trends in temperature – based indices important to wine production in 4 agro-climatic zones dedicated to grape growing in Republic of Moldova in 1960-2010 years.

4.5.1. Structure and Trends in Temperature-Based Indices Describing Republic of Moldova's Wine Grape Growing Conditions

Traditionally the main grape growing and wine producing areas have been situated between 30° to 50°N and 30° to 40°S (Amerine et al., 1980), although grapes have been grown outside these limits in the tropics for a long time. These latitudes approximate the 10°C and 20°C annual isotherms, which due to the incorporation of winter temperatures do not accurately reflect the real geographical distribution. The current extension of viticulture is best represented by the 12–13°C (lower threshold) and 22–24°C (upper threshold) isotherm limits of the average growing season temperature (April–October in Northern Hemisphere; October–April in Southern Hemisphere) (Jones et al., 2005a, 2010; Schultz, Jones, 2008).

The 12°C lower limit would be situated just south of London, England (1961–1990 average), whereas the 24°C upper limit would include some tropical areas. For many viticultural regions a warming trend has been observed over the past 50–60 years and has been particularly strong over the past 20 years. An analysis of 27 wine regions worldwide showed that the average winter and summer temperatures have increased by 1.3 and 1.4°C, respectively (Jones et al., 2005a; 2005b) between 1950 and 2000 with a greater increase for regions in the northern hemisphere. Of these regions, 18 showed an increase in temperature variability, which confirms the projections of increased variability by the IPCC (2007). There is evidence that in many regions night temperatures have increased stronger than day temperature (Jones et al, 2005 a,b). The current observations in the trends corroborate the projections of the first UN climate report of 1990 (Rahmstorf et al., 2007). One of the early analyses of the impacts climate change on viticulture, shortly after the release of the first UN state of the climate report in 1990, were conducted by Kenny and Harrison (1992). The work indicated potential shifts and/or expansions in the geography of viticulture regions with parts of Southern Europe predicted to become too hot to produce high quality wines and northern regions becoming viable once again. These results have largely been proven correct. Other recent research by Jones et al. (2005a) examining growing season climates in 27 of the world's top wine producing regions reveals significant changes in each wine region with trends ranging from 0.2°C to 0.6°C per decade for 2000–2049. Overall trends by 2049 average 2°C across all regions. Depending on the underlying scenario, climate models predict an increase in global temperature of 1.5°C to 5.0°C by the end of this century (IPCC, 2007). An increase in temperature of this magnitude would substantially alter the geography of wine regions with the potential for relatively large latitudinal shifts in viable viticulture zones.

Some increases in suitable area might be seen on the poleward fringe in the Northern Hemisphere (NH), but decreases in area are likely in the Southern Hemisphere (SH) due to the lack of land mass. Within wine regions, spatial shifts are projected to be toward the coast, up in elevation, and to the north (NH) or south (SH). Furthermore, climate variability analyses have shown evidence of increased frequency of extreme events (Easterling et al., 2000 a,b; Klein Tank, Können, 2003; Ramos, Martínez-Casasnovas, 2006a) in many regions, while climate models predict a continued increase in variability globally (Schultz et al., 2010).

Analyses of the impact of climate change on viticulture and wine production in Europe have suggested short-term benefits in terms of more consistent and higher quality production, with lower year-to-year variability (Jones et al., 2005a). However, despite these short-term benefits for growers, winemakers, and connoisseurs, the rise in global temperatures projected for the next half century may ultimately bode problems for the wine industry. Small changes in growing season temperatures could induce shifts in varietal suitability in many regions (Jones et al., 2005a) or necessitate costly adaptation measures both in the vineyard and in the winery. Furthermore, in regions such as Europe, where vines are not irrigated, either due to legal constraints or supply issues, changes in total rainfall or in its distribution throughout the year may have significant effects on water availability for plants, particularly during the warmer periods of the year (Ramos et al., 2008).

In 2012, the Republic of Moldova was globally ranked 21st largest wine producer with nearly 34.318 thousand ha area planted to wine grapes and total harvest by 1,159.053 thousand quintals, with the wine industry being one of the largest in the country. Considering the economic and cultural importance of the wine industry in the Republic of Moldova and the country already warm to hot and dry climate for wine production, this research aims to examine the structure and trends in temperature – based indices important to wine production in 4 agro-climatic zones dedicated to grape growing in Republic of Moldova.

4.5.1.1. Data and Methods

Climatic resources as the sum of active temperature ($\sum T > 10°C$) and absolute minimum temperature (°C) in the Republic of Moldova allow the cultivation of early maturing grapes in every agro-climatic zone, even in Northern one (**Table 4-19**).

The height diapason, total and minimum temperature is presented for these zones according to the bent orientation. Conclusions for each sub-region describe the suitability of grape varieties. According to the territorial division, the Republic of Moldova is divided into four agro-climatic zones dedicated to grape growing:

(1) Northern zone (Balti) – bordering on Sculeni – Balti – Floresti – Soroca. This zone does not have the large vineyards necessary for industrial production. The grapes grown here are mainly used in the production of local "cognac" and fortified wines. A very small number of table wines are also produced here. White grapes (**Aligoté, Pinot, Feteasca**, **Traminer**) are dominant.

Table 4-19: Agro-climatic zones and sub-zones for grape growing in the Republic of Moldova

Agro-climatic zones and sub-zones	Regions	Bent			Absolute minimum, °C	Conclusions
		Position	Height	ΣT>10°C		
Northern Zone						
Platoul Moldovenesc de Nord	Briceni, Ocnița, Edineț, Dondușeni	S	280	2780-2870	-23…-24	Very early and early maturing varieties; consuming in fresh condition
Ridicătura prenistreană	Soroca, Camenca, Șoldanesti, Rezina, Orhei	N S V, E	300	2650-2530 2870-2980 2870	-23…-24	Very early and early maturing varieties; consuming in fresh condition
Cîmpia văluroasă Bălțeană	Râşcani, Făleşti, Glodeni, Donduşeni, Floreşti	N S V, E	190	2750-2620 2980-3100 2870	-23…-24	Very early and early maturing varieties; consuming in fresh condition
Câmpia de Nord a Prutului	Edineţ, Râşcani, Glodeni, Făleşti	N S V, E	80	2080-2940 3360-3460 3210	-20…-19	Very early and early maturing varieties; consuming in fresh condition
Central Zone						
Codrii centrali (raion de pădure)	Ungheni, Străşeni, Călăraşi, Nisporeni, Hânceşti	N S V, E	330	274-2610 2960-3080 2850	-23…-22	From very early till semi late maturing varieties
Codrii centrali (raion de silvostepă)	Ungheni, Străşeni, Călăraşi, Nisporeni, Ialoveni, Teleneşti	N S V, E	225	2900-2770 3150-3270 3020	-22…-21	Very early – semi late maturing varieties
Codrii centrali (raion de silvostepă Gârneţ)	Codrii centrali (raion de silvostepă Gârneţ)	N S V, E	170	3060-2910 3300-3410 3180	-22…-21	Very early, early and medium maturing varieties

Agro-climatic zones and sub-zones	Regions	Bent			Absolute minimum, °C	Conclusions
		Position	Height	ΣT>10°C		
Southern Zone						
Înălţimea Tigheciului (raionul de silvostepă Gârneţ)	Cantemir, Leova, Cahul, Comrat	N S V, E	260	2950-2820 3190-3310 3070	-23…-22	All periods maturing varieties
Câmpia Basarabiei de Sud (câmpia Bugeacului; depresiunea Dunării, subzona Prenistreană de sud-vest	Cahul, Vulcăneşti, Taraclia, CeadârLunga, Basarabeasca	N S V, E	60	3270-3190 3550-3610 3420	-20…-19	All periods maturing varieties (the most favorable sub-zone)
Eastern Zone						
Platoul Podoliei	Camenca, Râbniţa	N S V, E	200	2850-2710 3100-3230 2970	-23…-22	Very early, early and medium maturing varieties
Câmpia ridicată (raionul de silvostepă)	Râbniţa, Dubăsari, Grigoriopol	N S V, E	100	3000-2940 3250-3310 3130	-22…-21	Presence of limitative factors (absence of aerial drainage, etc.); it is necessary micro zone choice (underline Malovata micro-zone – 1000 ha sounds
Câmpia prenistreană	Grigoriopol, Cuciurgan, limanul Nistrului	N S V, E	60	3080 3340 3220		Presence of limitative factors (chillness and fog during maturity), it is necessary to choose micro-zones)

Source: National Institute of Wine and Vineyards (Report CNFA, PDBA, MEPO: Opportunities for Developing a Competitive Table Grape Production Sector in Moldova. Chisinau May, 2005. 31p.)

(2) Central zone (Codru) – bordering on Leova – Cimislia – Tighina is the most well developed wine zone in Moldova. Around 60% of the country's vineyards and the majority of "vinicoles" (large estates with visitor facilities) are located here, including the famous "Romanesti" S.A. The forested hills of the central zone protect the vines from winter frosts and summer drought, which are characteristic of a continental climate. White grape varieties still dominate, but they produce fresh and light wines. It is the best area for **Feteasca**, **Sauvignon**, **Riesling**, **Traminer rose** and **Cabernet** production. There is also a famous microclimate zone in this region – the Romanesti – the former wine-making Imperial colony of Romanov dynasty. This is the place to sample the best white and sparkling wines, as well as the so-called "divines" (fortified wines) and Sherries. Mixed grape variety wines have also been developed recently. Amongst the red grapes are **Cabernet-Sauvignon** and **Merlot**, which have been used to produce wine in this region for over 100 years.

(3) South-Eastern zone (Nistreana** or **Purcari) – include the southeastern Purcari zone stretches along the Western Dniester coast. The climatic conditions are favorable to the cultivation of red grape varieties: **Chardonnay**, **Sauvignon blanc**, **Cabernet Sauvignon**, **Merlot, Pinot noir**, **Malbec**, **Rara Neagră** and **Saperavi**, which serve as the basis for the production of ages wines. At the end of the 19th century the Purcari wines were supplied to the English royal court.

(4) Southern zone (Cahul) – including the whole country territory between Prut – Danube and Dniester. The climate in this region is characterized by frequent droughts, favoring the cultivation of grapes for red and syrupy wines. The climatic conditions are favorable to the cultivation of red grape varieties: **Merlot**, **Cabernet Sauvignon** and **Rara Neagră.**

This study was carried out using the longest available daily temperature (mean, maximum and minimum) data series 1960-2010 recorded at from 5 stations (Briceni, Balti, Chisinau, Tiraspol and Cahul) in the Republic of Moldova. Data from each station were organized into annual, growing season, or important grapevine growth periods and used to derive bioclimatic and extreme climate indices important for wine grape production (**Table 4-20**).

For temperature the average, maximum, and minimum values from each station were summarized for the growing season for wine grapes (April to October) since simple growing season averages explain much of the phenological development of grapevines, wine production, and quality (Jones et al., 2005a). For example, average growing season temperatures typically define the climate-maturity ripening potential for premium quality wine varieties grown in cool, intermediate, warm, and hot climates (Jones, 2006). For example, **Cabernet Sauvignon** is grown in regions that span from intermediate to hot climates with growing seasons that range from roughly 16.5–19.5°C (e.g., Bordeaux or Napa). For cooler climate varieties such as **Pinot Noir**, they are typically grown in regions that span from cool to lower intermediate climates with growing seasons that range from roughly 14.0–16.0°C (e.g., Northern Oregon or Burgundy). It is clear that the impacts of climate change are not likely to be uniform across all varieties and regions, but are more likely to be related to climatic thresholds whereby any continued warming would push a region outside the ability to produce quality wine with existing varieties. For example, if a region has an average growing season temperature of 15°C and the climate warms by 1°C, then that region is climatically more conducive to ripening some varieties, while potentially less for others. If the magnitude of the warming is 2°C or larger, then a region may potentially shift into another climate maturity type (e.g., from intermediate to warm). In addition, temperature extremes were assessed as proposed by the Working Group on Climate Change Detection (Peterson et al., 2001) and include the annual number of days with minimum or maximum temperatures >90th and <10th percentiles.

Table 4-20: Temperature-based indices analyzed for the five meteorological stations

Variable	Description
GST_{avg}	Average growing season temperature (April to October)
GST_{max}	Average growing season maximum temperature (April to October)
GST_{min}	Average growing season minimum temperature (April to October)
NDT_{max90p}	Annual number of days with maximum temperature >90th percentile
NDT_{min90p}	Annual number of days with minimum temperature >90th percentile
NDT_{max10p}	Annual number of days with maximum temperature <10th percentile
NDT_{min10p}	Annual number of days with minimum temperature <10th percentile
FD	Frost occurrence; number of days with minimum temperature <0°C
FFL	Frost-free period length; number of days between dates with temperature <0°C
ND_{25}	Number of days with T_{max} > 25°C
ND_{30}	Number of days with T_{max} > 30°C, critical temperature for optimum growth
HI	Huglin Index (Huglin, 1978)
GDD	Growing degree days (Winkler et al., 1974)
DTR	Daily temperature range during ripening

Frost occurrence was assessed by examining the number of days with temperatures $<0°C$ and the length of the frost-free period. To assess temperature stress during the growth period, the number of days with temperatures >25 and $>30°C$ were determined (Jones, Davis, 2000). While temperatures about 25°C are considered optimum for grapevine photosynthesis and growth (Coombe, 1987), prolonged periods at temperatures $>30°C$ can induce heat stress, premature véraison, berry abscission, enzyme activation and cause less flavor development (Mullins et al., 1992).

Other temperature-based variables derived for further analysis include:

(1) Huglin Index (HI) (Huglin, 1978) for April to October gives more weight to maximum temperatures; calculated as:

$$HI = \sum((T_{avg} - 10°C) + (T_{max} - 10°C)/2) \cdot K, \quad (4.4)$$

where T_{avg} is the average daily temperature; T_{max} is the maximum daily temperature; and K, is the length of day coefficient, varying from 1.02 to 1.06 at 40 to 50°N.

(2) Growing degree days (GDD) (Winkler et al., 1974) for April to October calculated by:

$$GDD = \sum((T_{max} + T_{min})/2 - 10°C), \quad (4.5)$$

where T_{max} is the maximum daily temperature; and T_{min} is the minimum daily temperature. These bioclimatic indices, which are based on variations in growing degree days, are the most widely utilized measures of spatial suitability for viticulture and provide general guidelines on wine style or potential quality (Jones et al., 2005b; Blanco-Ward et al., 2007).

Finally, the diurnal temperature range (DTR) during the ripening months of August, September and October was calculated to examine trends that influence important quality factors such as composition, flavor and aroma (Mullins et al., 1992), as:

$$DTR = T_{max} - T_{min}, \quad (4.6)$$

4.5.1.2. Descriptive Statistics and Trend Parameters for the Temperature Climate Variables

Temperature change over the near-term decades could create adaptation pressure by causing a given location to move from one Winkler and HI category to another. In addition, temperature change could alter the frequency with which the other temperature screening thresholds are exceeded in a given location. Because warming would be expected to increase the pressure from hot limits and decrease the pressure from cold limits, we test the potential for increased tolerance of hot conditions to reduce the loss of suitable area. For the growing season temperature the upper limit is 20°C (White et al., 2006). In addition, Jones et al. (2010) identified a hot limit of 21°C for premium wines in the region, and established that the range of 21–24°C is currently associated with bulk wine, table grapes and raisins. Daytime maximum temperatures of 25–30°C are critical for optimum grapevine development. While a few days with temperatures >30°C may be beneficial during the ripening period (Jones, Davis, 2000; White et al., 2006), too many days with temperatures >30°C can induce plant stress, premature véraison, and reduction in photosynthesis (Mullins et al., 1992).

For wine grape maturity potential, the locations are considered cool for Briceni (14.7°C) and intermediate for Balti, Chisinau, Tiraspol and Cahul (15 - 17°C), based on growing season average temperatures (Jones, 2006) (**Table 4-21**). While variability in GST_{avg} is similar across the 3 locations, GST_{max} (growing season maximum temperature), GST_{min} (growing season minimum temperature) and temperature extremes (10th and 90th percentiles) are more pronounced for South-Eastern (Tiraspol), than for the Central (Chisinau) or Southern (Cahul) areas of Republic of Moldova (**Figure 4-6**).

The Frost occurrence (FD), total annual number of days with temperatures <0°C was highest in Briceni (117 days) and the lowest in Cahul (95 days). The frost-free period (FFL) was the longest for Cahul averaging 270 days, followed by Chisinau with 269 days, Balti with 252 days and the shortest for Briceni with 249 days (**Table 4-21**).

The number of days during the growing season with temperatures >25°C and 30°C also follows the North with station Briceni experiencing fewer overall days (53 and 9, respectively), while Tiraspol experienced 91 days with temperatures >25°C and 29 days with temperatures >30°C per vintage.

Table 4-21: Descriptive statistics and trend parameters calculated for the temperature climate variables for the five meteorological stations Briceni, Balti, Chisinau, Tiraspol and Cahul (1960 – 2010)

Station	Variable	Descriptive Statistics				Trend Parameters		
		Mean	Std. Dev.	Max	Min	R^2	*P*-value	Trend yr^{-1}
Briceni	GST_{avg} (⁰C)	14.7	0.88	16.3	12.9	0.21	**0.0008**	**0.03**
	GST_{max} (⁰C)	20.3	0.96	22.2	18.2	0.08	**0.0474**	**0.02**
	GST_{min} (⁰C)	9.7	0.82	11.2	8.1	0.36	**0.0000**	**0.03**
	NDT_{max90p} (26.0⁰C) (d)	41.3	13.42	73.0	12.0	0.09	**0.0310**	**0.27**
	NDT_{min90p} (14.1⁰C) (d)	44.2	14.71	77.0	13.0	0.38	**0.0000**	**0.61**
	NDT_{max10p} (-1.8⁰C) (d)	34.5	14.86	70.0	8.0	0.03	0.2123	-0.18
	NDT_{min10p} (-8.4⁰C) (d)	32.7	15.07	67.0	6.0	0.09	**0.0367**	**-0.30**
	FD (d)	117	15.78	151	82	0.17	**0.0024**	**-0.44**
	FFL (d)	249	15.76	284	214	0.17	**0.0025**	**0.44**
	ND_{25} (d)	53	15.4	91	19	0.06	0.0756	0. 26
	ND_{30} (d)	9	6.98	26	0	0.15	**0.0043**	**0. 19**
	HI	1700.7	203.98	2072.4	1260.8	0.13	**0.0091**	**4. 97**
	GDD	1068.7	180.5	1411.7	703.1	0.22	**0.0005**	**5. 69**
	DTR	10.3	1.09	12.6	7.4	0.19	**0.0014**	**-0.03**
Balti	GST_{avg}	15.9	0.77	17.8	14.3	0.23	**0.0004**	**0.03**
	GST_{max}	22.2	1.05	24.5	20.1	0.25	**0.0002**	**0.04**
	GST_{min}	10.2	0.66	11.7	8.9	0.30	**0.0000**	**0.03**
	NDT_{max90p} (27.6⁰C) (d)	44.4	15.36	78.0	10.0	0.29	**0.0001**	**0. 55**
	NDT_{min90p} (14.9⁰C) (d)	43.9	12.92	75.0	19.0	0.38	**0.0000**	**0.54**
	NDT_{max10p} (-0.5⁰C) (d)	33.8	14.60	71.0	6.0	0.05	0.1320	-0.21
	NDT_{min10p} (-7.5⁰C) (d)	32.4	13.71	67.0	9.0	0.05	0.1108	-0.21
	FD (d)	112	13.35	146	75	0.10	**0.0260**	**-0.28**
	FFL (d)	254	13.36	290	219	0.10	**0.0256**	**0.28**
	ND_{25} (d)	78	17.33	114	39	0.22	**0.0005**	**0. 55**
	ND_{30} (d)	21	12.71	51	0	0.39	**0.0000**	**0. 53**
	HI	2032.1	206.29	2498.6	1613.6	0.25	**0.0002**	**6. 96**
	GDD	1326.2	176.0	1691.0	957.9	0.31	**0.0000**	**6. 60**
	DTR	11.8	1.04	14.1	8.9	0.1	0.6149	-0.01
Chisinau	GST_{avg}	16.6	0.84	18.7	14.8	0.16	**0.0041**	**0.02**
	GST_{max}	22.0	1.05	24.2	19.6	0.01	0.4608	0.01
	GST_{min}	11.8	0.81	13.8	10.3	0.49	**0.0000**	**0.04**
	NDT_{max90p} (27.7⁰C) (d)	41.1	14.62	76	7	0.05	0.1263	0.21
	NDT_{min90p} (16.3⁰C) (d)	45.9	15.22	85	18	0.47	**0.0000**	**0.70**
	NDT_{max10p} (-0.3⁰C) (d)	34.9	13.81	71	10	0.01	0.6133	-0.07

Station	Variable	Descriptive Statistics				Trend Parameters		
		Mean	Std. Dev.	Max	Min	R^2	*P*-value	Trend yr^{-1}
Chisinau	**NDT_{min10p} (-5.9°C) (d)**	33.4	13.99	67	8	0.02	0.3403	-0.13
	FD (d)	96	14.78	125	67	0.09	**0.0306**	**-0.30**
	FFL (d)	269	14.73	298	241	0.09	**0.0308**	**0. 30**
	ND_{25} (d)	75	16.68	110	34	0.01	0.4448	0. 12
	ND_{30} (d)	19	11.35	50	1	0.11	**0.0172**	**0. 25**
	HI	2085.0	207.83	2573.4	1627.1	0.06	0.0921	3. 33
	GDD	1461.4	257.7	1930.6	1116.1	0.16	**0.0035**	**4. 85**
	DTR	9.9	1.09	12.3	7.7	0.40	**0.0000**	**-0.05**
Tiraspol	**GST_{avg}**	16.7	0.77	18.8	15.2	0.12	**0.0129**	**0.02**
	GST_{max}	23.1	1.02	25.7	21.1	0.17	**0.0029**	**0.03**
	GST_{min}	10.8	0.55	12.1	9.5	0.01	0.6837	0.00
	NDT_{max90p} (28.6°C) (d)	43.5	15.78	91	12	0.23	**0.0003**	**0.51**
	NDT_{min90p} (15.7°C) (d)	40.8	11.02	73	21	0.12	**0.0111**	**0.26**
	NDT_{max10p} (0.5°C) (d)	34.76	13.93	71	11	0.02	0.2914	-0.14
	NDT_{min10p} (-6°C) (d)	35.0	13.53	66	9	0.001	0.8311	0.03
	FD (d)	104	14.68	130	69	0.01	0.4484	0. 12
	FFL (d)	252	14.74	296	235	0.01	0.5511	-0.08
	ND_{25} (d)	91	15.81	124	55	0.14	**0.0061**	**0. 40**
	ND_{30} (d)	29	14.85	71	2	0.27	**0.0001**	**0. 52**
	HI	2221.0	202.95	2754.7	1824.4	0.15	**0.0046**	**5. 34**
	GDD	1486.4	157.9	1889.9	1178.6	0.10	**0.0259**	**3. 31**
	DTR	12.1	0.89	13.5	9.5	0.04	0.1467	0. 12
Cahul	**GST_{avg}**	16.7	0.81	18.7	15.2	0.14	**0.0076**	**0.02**
	GST_{max}	22.3	1.01	24.8	20.3	0.04	0.1486	0.01
	GST_{min}	11.9	0.66	13.2	10.7	0.22	**0.0004**	**0.02**
	NDT_{max90p} (27.8°C) (d)	42.7	15.71	85	12	0.13	**0.0082**	**0.39**
	NDT_{min90p} (16.5°C) (d)	42.9	13.67	73	17	0.31	**0.0000**	**0.51**
	NDT_{max10p} (-0.1°C) (d)	33.9	13.60	72	12	0.01	0.4692	-0.09
	NDT_{min10p} (-5.6°C) (d)	33.5	12.81	65	10	0.03	0.2579	-0.14
	FD (d)	95	15.52	127	63	0.05	0.1038	-0. 24
	FFL (d)	270	15.45	303	239	0.05	0.1088	0. 24
	ND_{25} (d)	80	15.83	114	44	0.05	0.1264	0. 23
	ND_{30} (d)	21	12.42	58	2	0.13	**0.0106**	**0. 29**
	HI	2120.2	199.98	2612.3	1722.2	0.08	**0.0461**	**3. 77**
	GDD	1527.4	171.3	1924.9	1178.6	0.11	**0.0191**	**3. 77**
	DTR	10.1	0.89	12.5	7.9	0.12	**0.0146**	**-0.02**

Note: Climate variables and their abbreviations are described in Table 4-20. Bold numbers indicate significant trends at ≥95% level.

Growing season average temperatures increased for all 5 stations, driven mainly by more significant changes in maximum temperatures (**Table 4-21; Figure 4-6**). Average temperature trends ranged from 0.02°C yr^{-1} in Chisinau, Tiraspol and Cahul to 0.03°C yr^{-1} in Briceni and Balti. Rates of warming, average growing season maximum (GST_{max}) and minimum (GST_{min}) temperatures were significantly higher for both Briceni and Balti, while Tiraspol exhibited significant changes only in GST_{max}, but Chisinau and Cahul exhibited significant changes only in GST_{min} (**Figure 4-6**).

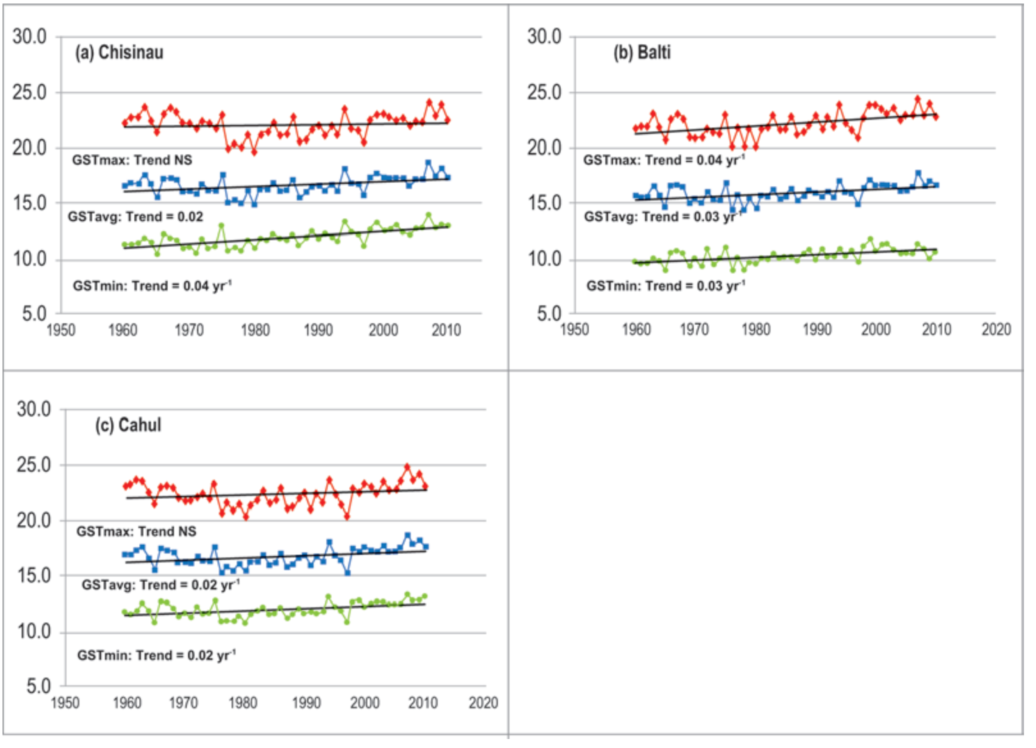


Figure 4-6: Temperature trends (average, maximum, and minimum) during the growing season (April to October) in (a) Chisinau, (b) Balti, and (c) Cahul.

Overall warming in growing season average temperatures ranged from 1.0 to 1.5°C for the 5 locations over their respective time periods. Similar results were also found in other European wine regions (Jones et al., 2005b) with growing seasons warming by 1.7°C on average over the last 30–50 yr. For Spain, Jones et al. (2005b) reported an average growing season warming of 0.8–1.2°C for Galicia (Miño river valley) and Castilla y León (Valladolid).

Interestingly, while temperature increases were evident in the studied locations, the number of frost days showed a significant decreasing trend only in 3 locations, Briceni, Balti and Chisinau, and changes in the frost-free period were also significant for these sites.

Growing season maximum temperature extremes (days with T>25°C and T>30°C) increased significantly only in 3 locations in case of average number of days with temperatures >25°C (ND_{25}), with the ND_{25} trends ranged from 0.26 yr^{-1} in Briceni to 0.40 – 0.55 yr^{-1} for Tiraspol and Balti, respectively. While in case of average number of days with temperatures >30°C (ND_{30}) significant increasing trends were observed in all locations, with the ND_{30} trends ranged from 0.19 yr^{-1} in Briceni to 0.25 – 0.30 yr^{-1} for Chisinau and Cahul, and being maximal 0.52 - 0.53 yr^{-1} in Balti and Tiraspol.

Often used to assess climate suitability for certain varieties and/or wine styles, the Winkler Index (WI) and Huglin Index (HI) are variations in degree-days, or heat accumulation formulas (**Table 4-21**). Using GDD above 10°C, Winkler et al. (1974) defined five classes of viticultural suitability based upon the style and quality of wine that could be produced in a given climate. In Region I climates (1111–1390 GDD), early ripening varieties achieve high quality. For Region II (1391–1670 GDD), most early and mid-season table wine varieties will produce good quality wines with light to medium body and good balance. Region III (1671–1950 GDD) is a favorable climate for high production of standard to good quality full-bodied dry to sweet table wines. Region IV (1951–2220 GDD) is favorable for high production, but table wine quality will be acceptable at best. Region V (2221–2499 GDD) typically makes low-quality bulk table wines or fortified wines, or is best for table grape varieties destined for early season consumption. In addition, the recent re-analysis of GDD over the western US by Jones et al. (2010) identified the upper and lower thresholds for Winkler regions I and V, which were not previously defined by Winkler et al. (1974).

Similar to the heat summation concept, the classical Heliothermal Index of Huglin (HI) (Huglin, 1978) is widely used, giving more weight to maximum temperatures above mean temperatures and applying a coefficient which expresses the day-length adjustment due to latitude varying, which takes into account the average daylight period for the latitude studied (e.g., Tonietto, Carbonneau, 2004; Jones et al., 2010; Malheiro et al., 2010; Frada et al., 2012). A lower HI threshold (900 instead of 1.200°C) is considered herein in order to include viticultural regions in Northern Europe with marginally suitable winemaking conditions. In fact, in two previous studies by Jones et al. (2010), Hall and Jones (2010), a Winkler Index (Winkler, 1974) above 850°C was found to be already suitable for winegrape growth in western United States and Australia, respectively. Additionally, Santos et al. (2012b) showed a clear correspondence between the WI and HI patterns in Europe using 850°C and 900°C as lower limits, respectively.

Growing degree-day (GDD) values range from 1069 for Briceni to 1486 and 1527 for Tiraspol and Cahul, respectively (**Table 4-21**). These values place Briceni in Winkler region Too Cool (<1111) for wine growing; Balti in Region I (1111-1389) Region I, the coolest, is similar to Côte d'Or and Champagne, the Rhine or the Willamette Valley in Oregon (it is well-suited to growing **Chardonnay, Pinot Noir**, or **Riesling**). The values for Chisinau, Tiraspol and Cahul place them in Winkler Region II (1389-1667) which indicates generally favorable climates for high production of good quality table wines. Region II is similar to Bordeaux. Suitable varietals include the Region I wines, plus **Cabernet Sauvignon, Sauvignon Blanc**, **Cabernet Franc** and **Merlot**. Average Heliothermal Huglin Index values, which may be more appropriate than the WI for European regions (Blanco-Ward et al., 2007) and worldwide (Tonietto et al., 2004), were 1700, 2032, 2085, 2221 and 2120 for Briceni, Balti, Chisinau, Tiraspol and Cahul, respectively (**Table 4-21**). These values also place Briceni in Huglin's cool viticultural climate class (1500-1800), the heliotermal potential allows a very large range of varieties of grapes, white or red, to ripen, including for instance **Riesling, Pinot noir, Chardonnay, Merlot, Cabernet franc** (for example: Tours, Loire Valley in France); Balti and Chisinau in Huglin's viticultural climate class (1800-2100) suitable for the later varieties, such as **Cabernet- Sauvignon, Ugni Blanc** and **Syrah** (for example: Bordeaux in France and Viseu in Portugal). Tiraspol and Cahul values are in Huglin's warm temperate viticultural climate class (2100-2400), **Grenache, Mourvedre** and **Carignane** can ripen. Therefore there is no more heliotermal constraint to ripen all cultivated varieties except some exception as the seedless varieties (for example: Nuriootpa in Australia and Montpellier in France). The ripening period DTR reveals similar average values (10.1°C; 9.9°C and 10.3°C) and variability (0.89°C and 1.09°C) for Cahul, Chisinau and Briceni, while Balti and Tiraspol had a greater DTR (11.8°C and 12.1°C) and variability (1.04°C and 0.89°C), respectively.

Trends in both parameters show significant changes at each location, except location Chisinau for HI (**Table 4-21; Figures 4-7** and **4-8**).

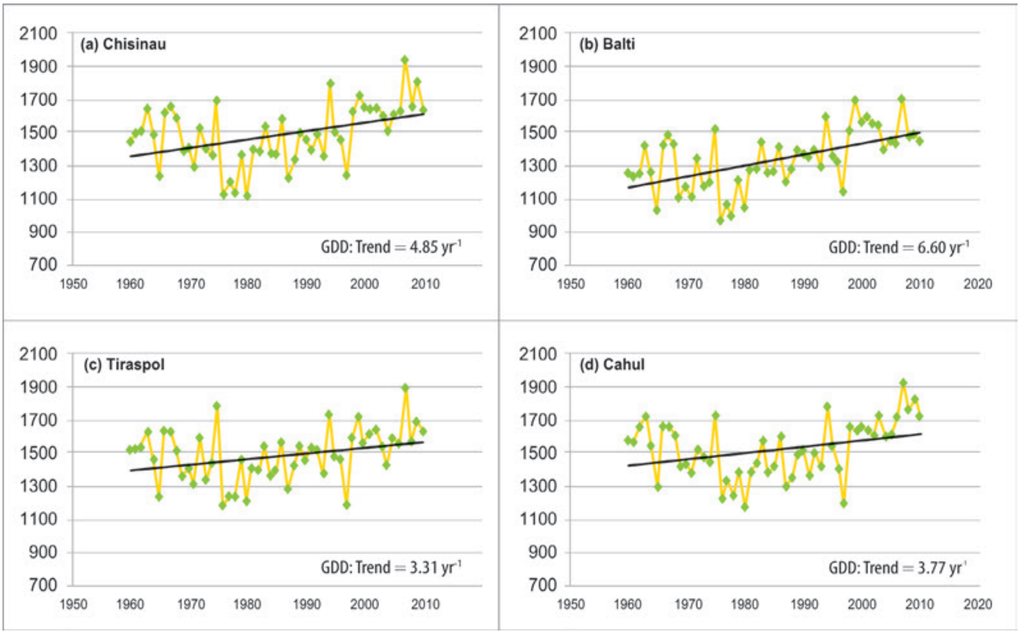


Figure 4-7: Trends in the Growing degree days (Winkler et al., 1974) for: (a) Chisinau, (b) Balti, (c) Tiraspol and (d) Cahul.

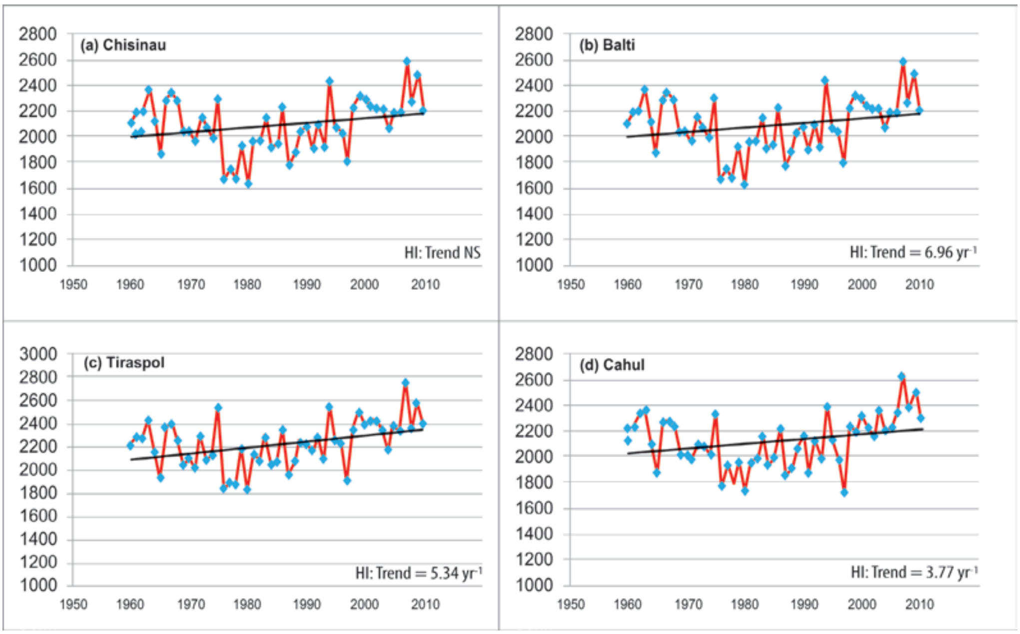


Figure 4-8: Trends in the Huglin Index (Huglin, 1978) for: (a) Chisinau, (b) Balti, (c) Tiraspol and (d) Cahul

The WI increased from 3.3 – 3.8 units yr^{-1} for Tiraspol [168 units $(51\ yr)^{-1}$], Cahul [194 units $(51\ yr)^{-1}$], 4.8 units yr^{-1} for Chisinau [225 units $(51\ yr)^{-1}$], and up to 5.7 – 6.6 units yr^{-1} for Briceni [291 units $(51\ yr)^{-1}$] and Balti [337 units $(51\ yr)^{-1}$]. These changes moves Briceni from a too cool region to a region I on the WI scale**,** Balti and Tiraspol from a region I to a high region II, and Chisinau and Cahul from a high region II to a region III, which also indicates generally favorable climates for high production of good quality table wines (Winkler et al. 1974)**.**

Huglin Index (HI) trends were similar to the WI trends, although the changes were of greater relative magnitude since the HI gives more weight to maximum temperatures. The HI increased from 3.8 units yr^{-1} for Cahul [194 units $(51\ yr)^{-1}$] up to 7.0 units yr^{-1} for Balti [357 units $(51\ yr)^{-1}$], while those for Briceni and Tiraspol were similar 5.0 and 5.3 units yr^{-1} for [255 units $(51\ yr)^{-1}$ and 270 units $(51\ yr)^{-1}$], respectively.

Greater change was observed in stations Briceni, Balti and Tiraspol, which had a significant higher increase in GST_{max}. These HI increases move Briceni from a cool to a temperate type for wine grape production, Balti from a temperate type to a warm climate type for wine grape production, and Tiraspol from warm temperate to warm, indicating potential variety shifts (Huglin, 1978). Heat accumulation trends in other European wine regions have also increased, rising from 250–300 units (Jones et al., 2005b) up to 396-464 units (Ramos et al., 2008) over the last 30–50 years. Opposite to average growing season temperatures, for diurnal temperature range during the ripening period from Aug to Oct (DTR) significant decreasing trends were observed for 3 stations. DTR trends changed from -0.02°C yr^{-1} in Cahul, -0.03°C yr^{-1} in Briceni and up to -0.05°C yr^{-1} in Chisinau.

4.5.2. Projecting Climate Change Impacts on Grape Production

The impacts of changes in climate suitability for the winemaking sector in Europe, was summarized by Fraga et al. (2012) as follow: (1) some southern regions (Portugal, Spain, Italy) may face detrimental impacts owing to both severe dryness and unsuitably high temperatures; (2) regions in western and central Europe (southern Britain, northern France, Germany), some of which are world-renowned winemaking regions, might benefit from future climate conditions (higher suitability for grapevine growth and higher wine quality); and (3) new potential wine grape growth areas are expected to arise over northern and central Europe, where conditions are currently either marginally suitable or too cold for this crop. It is still worth mentioning that the higher inter-annual variability (climate irregularity) in the future over most of Europe may lead to additional threats to this sector.

During the past few decades, the impacts of meteorology and climate on wine quantity and quality have been the subject of extensive studies undertaken in many different parts of the world. The influence of climatic variability and of recent trends in the climate in different parts of Europe has been examined by Jones et al. (2005a) and Santos et al. (2012). Moreover, some studies centered on specific areas such as Alsace, North-East of Spain, Douro and Bordeaux have also been published in recent years (Duchêne, Schneider, 2005; Ramos et al., 2008; Camps, Ramos, 2012; Santos et al., 2011; Gouveia et al., 2011). Climate change and its relationship with viticulture has also been a topic of interest (Jones et al., 2005b; Camps, Ramos, 2012; Schultz, Jones, 2010).

Improved assessment of wine grape yield responses to future climate are needed to understand potential impacts of climate change on the wine growing for prioritization of adaptation strategies. For these purposes we (1) assessed the impact of temperature and precipitation on the inter-annual variability of wine grape yield production; (2) developed quantitative multi-linear regression models of relationships between historical climate patterns and wine grape yields in the Republic of Moldova on national and district level; and (3) assessed the possible impact of climate change scenarios on the wine grape production of the Republic of Moldova on national and district level.

4.5.2.1. Observed Linear Trends for the Annual Wine Grape Yield

Currently, districts of Central and Southern AEZs, as well as UTA Gagauzia have climate conditions the most suitable for wine grape growing and produce at least 96% of the current average yield. Wine grape plantings are concentrated in these areas, demonstrating that viticulturists have selected planting areas well (**Figure 4-9**).

The linear trend of wine grape productivity variability on the territory of the Republic of Moldova for 1983–1990 years have been characterized by a tendency for decrease in crop productivity by 9.53 q/ha per decade. The greatest decrease in wine grape productivity was observed in the 1983–1994 years reaching the level of 32.6 q/ha per decade (**Figure 4-10; Table 4-22**).

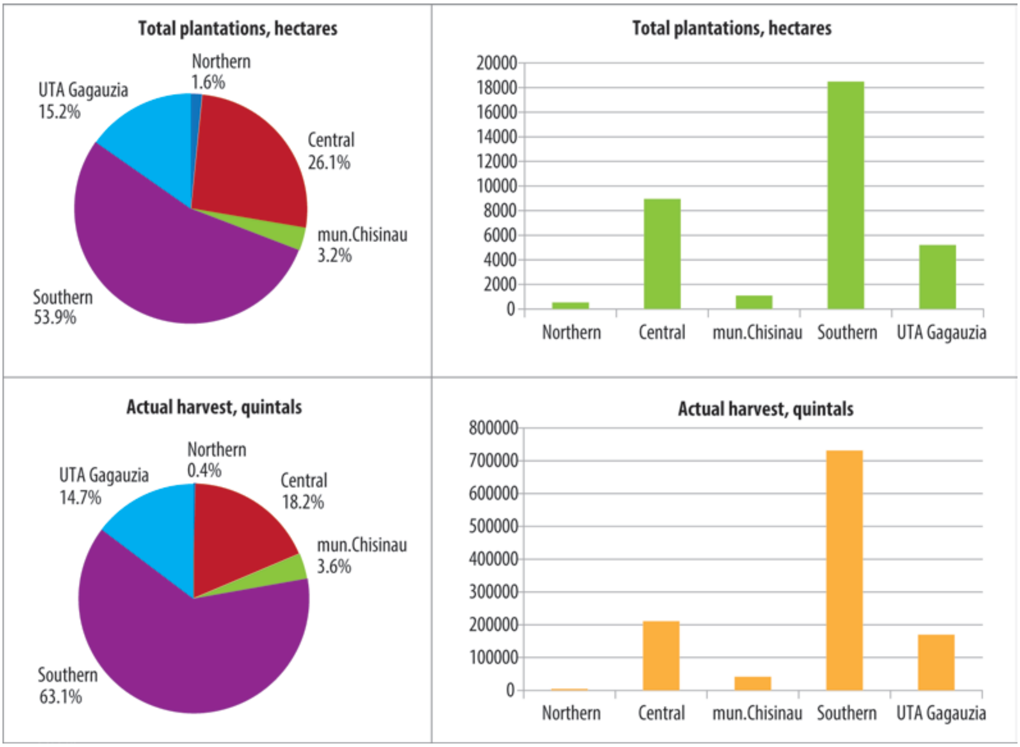
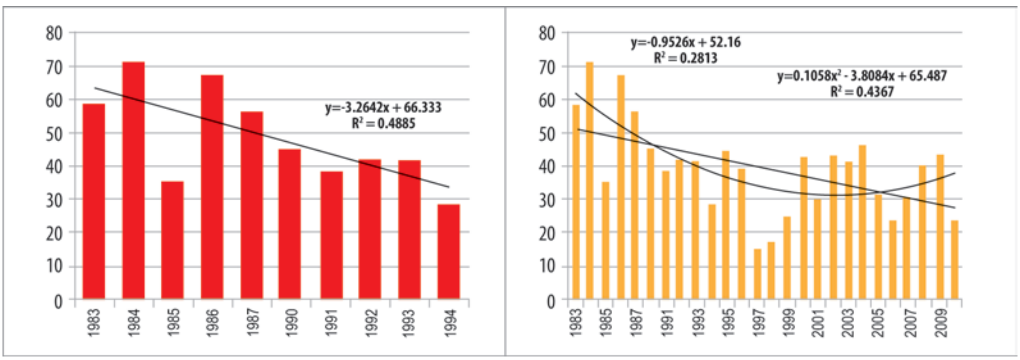


Figure 4-9: Total Plantations, Hectares and Actual Harvest, Quintiles for Wine Grape and Their Percentage Ratio by Development Regions in the Republic of Moldova, 2012



A) B)

Figure 4-10: Yield Variability Trends for the Wine Grape and Their Coefficients of Determination (R^2) for (A) 1983–1994 and (B) 1983–2010 observed periods in the Republic of Moldova

Table 4-22: Linear Yield Trend (quintal/year) of Wine Grape and their Statistical Significance *(p-value)* for the 1983–1994 and 1983–2010 Observation Periods in the Republic of Moldova

Crop	1983-1994			1983-2010		
	Trend	R^2,%	*p-value*	*Trend*	R^2,%	*p-value*
Wine grape	-3.2642	0.49	**0.0245**	-0.9526	0.28	**0.0053**

Note: Bold is used to mark statistically significant values.

4.5.2.2. The Relationship of Wine Grape Yield Variability with Temperature and Precipitation during the Vegetation Period (1983-2010)

Climate plays a predominant role in grapevine growth (van Leeuwen et al., 2004; Santos et al., 2011), as vine physiology and its development phases are determined mostly by specific environmental conditions (Magalhães, 2008). In fact, monthly mean temperatures and precipitation totals in the growing season present significant correlations with grapevine yield in many regions (Makra et al., 2009; Santos et al., 2012a). Although grapevines are also resistant to relatively low temperatures (lower thermal lethal limit of approximately −17 °C) during early stages (Hidalgo, 2002), frost occurrences during spring can severely damage crop production (Spellman 1999). Further, excessive humidity in spring can trigger pests and diseases, such as downy mildew (Carbonneau, 2003), while severe dryness during the growing season can also lead to harmful water stress (Koundouras et al., 1999), thus leading to reductions in grapevine productivity (Moutinho-Pereira et al., 2004; Frada et al., 2012).

The analysis of the data presented in the **Table 4-23** shows that the influence of climatic conditions during growing season on wine grape yield in the 1983-2010 years was statistically significant. Coefficient of determination R^2 shows that the combined effect of precipitation and temperature defined about 49.3% of the variability of average annual productivity of wine grape during this period.

Table 4-23: The relationship of Wine Grape Yield Variability with Temperature and Precipitation during the Vegetation Period (1983-2010)

Crop	Regression equation	*p* – value	R^2, %
Wine grape	$Y = 126.357 - 3.14996*T_{VII} - 3.12125*T_{VIII} + 3.8859*T_{IX} - 0.0906228*P_{V} - 0.133596*P_{VIII}$	**0.0132**	49.03

Note: Y - yield, quintal/ha; T - average monthly air temperature, ^0C; P - average monthly precipitations, mm; with Roman numerals are noted the corresponding months of vegetation period: since April (IV) to October (X).

Until now in the Republic of Moldova the vulnerability assessment of agricultural crops production was carried out only at the national level, while the development of adaptation programs require at least district or local level. Proceeding from this, additionally to the national level, we have assessed the impact of temperature and precipitation during the growing season on wine grape yield for the Republic of Moldova's territorial administrative units (district level) in order to distinguish the most and least vulnerable for wine grape cultivation districts in the 1983-2010 years[2].

The analysis of the data presented in the **Table 4-24** reveals that the influence of climatic conditions during growing season on wine grape yield in the 1983-2010 years (for central and southern AEZs) and in the 1983-2004 (for northern AEZ) was statistically significant in the majority of districts, except Anenii Noi and Straseni districts. Coefficient of determination R^2 shows that the combined effect of precipitation and temperature defined from 60.7 to 81.4% of the variability of average annual yield of wine grape during this period in the northern AEZ; from 40.9 to 72.7% of the variability of yield in the central AEZ; and from 29.3 to 66.5% of the variability of yield in the southern AEZ.

The greatest impact of climatic conditions during growing season in the 1983-2010 reference period on productivity of wine grape was observed in districts: Donduseni, Edinet, Falesti, Riscani, Singerei, Calarasi, Nisporeni, Soldanesti, Taraclia and UTA Gagauzia, coefficient of determination R^2 is from 59.1 to 81.4%; and the lowest one in the districts: Criuleni, Hincesti, Ialoveni, Orhei, Telenesti, Ungeni, Basarabeasca, Cahul, Cantemir, Causeni, Cimislia and Stefan Voda, coefficient of determination R^2 is from 29.3 to 56.6%.

[2] For northern AEZ districts data were available for 1983-2004.

Table 4-24: The Relationship of Wine Grape Yield Variability with Temperature and Precipitation during the Vegetation Period (1981-2010)

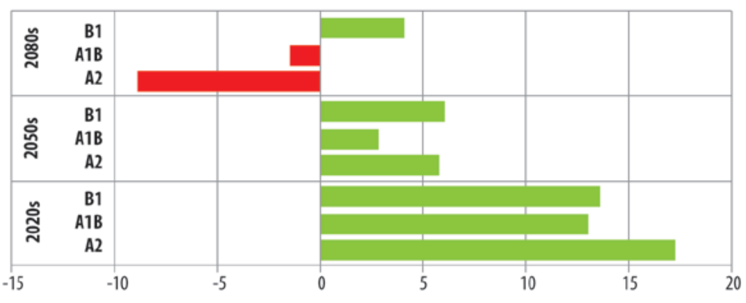
District	Regression equation	p – value	R^2, %
Northern AEZ			
Donduseni	$Y = 68.37 - 6.60*T_{VII} + 4.778*T_{IX} + 0.46*P_{III} + 0.22*P_{VIII} - 0.19*P_{X}$	**0.0001**	81.38
Edinet	$Y = 11.58 - 1.72*T_{III} - 0.01*T_{IX} + 0.42*P_{III} + 0.17*P_{VIII} - 0.13*P_{IX} - 0.16*P_{X}$	**0.0051**	71.62
Falesti	$Y = 29.57 - 7.00*T_{VII} + 5.81*T_{VIII} + 0.40*P_{III} + 0.68*P_{VIII} - 0.28*P_{X}$	**0.0148**	60.20
Riscani	$Y = 29.58 + 3.22*T_{IV} - 7.41*T_{X} + 0.91*P_{III} + 0.30*P_{VIII} - 0.33*P_{X}$	**0.0008**	74.62
Singerei	$Y = 61.978 + 2.92*T_{IV} - 3.66*T_{VII} + 0.38*P_{III} + 0.32*P_{VIII} - 0.29*P_{X}$	**0.0137**	60.73
Central AEZ			
Anenii Noi	$Y = -31.11 - 2.18*T_{IV} + 6.34*T_{IX} - 0.23*P_{III} - 0.19*P_{VIII} + 0.13*P_{IX}$	0.0890	35.99
Calarasi	$Y = 227.60 - 6.18*T_{VII} - 5.89*T_{VIII} + 5.80*T_{IX} - 0.24*P_{IV} - 0.14*P_{VIII}$	**0.0014**	60.46
Criuleni	$Y = -52.45 + 7.74*T_{IX} - 0.40*P_{III} - 0.12*P_{VI} - 0.36*P_{VIII} + 0.14*P_{IX}$	**0.0161**	47.86
Hincesti	$Y = 139.60 - 5.49*T_{VIII} + 3.18*T_{IX} - 0.20*P_{III} - 0.21*P_{IV} - 0.26*P_{VIII}$	**0.0032**	56.61
Ialoveni	$Y = 65.05 - 4.73*T_{VII} + 5.69*T_{IX} - 0.30*P_{III} - 0.16*P_{VIII} + 0.16*P_{IX}$	**0.0143**	48.56
Nisporeni	$Y = 24.96 + 4.19*T_{V} - 7.19*T_{VIII} + 9.17*T_{IX} - 0.44*P_{IV} - 0.40*P_{VIII}$	**0.0027**	59.06
Orhei	$Y = 141.70 - 4.75*T_{VII} - 3.46*T_{VIII} + 5.90*T_{IX} - 0.20*P_{V} - 0.16*P_{VIII}$	**0.0467**	40.88
Straseni	$Y = 27.84 - 2.07*T_{IV} - 2.98*T_{VII} + 7.07*T_{IX} - 0.17*P_{VIII} + 0.10*P_{IX}$	0.0902	35.89
Şoldaneşti	$Y = 8.09228 - 3.47193*T_{VIII} + 6.77*T_{IX} - 0.34*P_{IV} + 0.13*P_{VII} - 0.29*P_{VIII}$	**0.0023**	72.71
Telenesti	$Y = 193.86 - 3.26*T_{V} - 8.94*T_{VII} + 6.00*T_{IX} - 0.26*P_{V} + 0.12*P_{IX}$	**0.0310**	43.71
Ungheni	$Y = 73.02 - 7.28*T_{VII} + 7.89*T_{IX} - 0.30*P_{III} - 0.17*P_{VIII} + 0.19*P_{IX}$	**0.0124**	49.40
Southern AEZ			
Basarabeasca	$Y = 198.25 - 5.69*T_{VI} - 3.01*T_{VIII} + 2.20*T_{IX} - 0.17*P_{III} - 0.18*P_{VI}$	**0.0117**	49.75
Cahul	$Y = 109.09 - 2.21*T_{V} - 5.66*T_{VII} + 6.29*T_{IX} - 0.19*P_{VI} + 0.13*P_{IX}$	**0.0082**	51.72
Cantemir	$Y = -38.90 + 1.37*T_{III} + 5.72*T_{IX} - 0.23*P_{VI} + 0.11*P_{IX}$	**0.0095**	45.71
Causeni	$Y = -121.54 + 3.21*T_{V} + 6.69*T_{IX} + 0.18*P_{V} - 0.20*P_{VI}$	**0.0175**	42.09
Cimislia	$Y = 178.37 - 4.14*T_{VI} - 2.35*T_{VIII} - 0.11*P_{VI}$	**0.0508**	29.26
Stefan Voda	$Y = 134.99 - 3.69*T_{VIII} - 0.08*P_{VI} - 0.22*P_{VIII} - 0.07*P_{IX}$	**0.0131**	43.82
Taraclia	$Y = 295.50 - 7.00*T_{VI} - 4.26*T_{VIII} - 0.07*P_{V} - 0.19*P_{VI} - 0.06*P_{VII}$	**0.0003**	66.50
UTA Gagauzia	$Y = 220.58 - 4.65*T_{VI} - 2.47*T_{VII} - 2.97*T_{VIII} + 2.68*T_{IX} - 0.17*P_{VI}$	**0.0004**	65.44

Note: Bold is used to mark statistically significant values.

4.5.2.3. Projections of Future Changes in Yield of Wine Grape

Several studies in different areas of research used ensembles of model runs in assessing climate change projections under anthropogenic radiative forcing. As simple illustrations, (Lobell et al., 2006) used a set of regional climate models to assess the impacts of climate change on perennial crop yields in California. In Europe, Frada et al. (2012) used a 16-member ensemble of model transient experiments (generated by the ENSEMBLES project) under a greenhouse gas emission scenario and for two future periods (2011–2040 and 2041–2070) in assessing climate change projections for six viticultural zoning indices, while Heinrich and Gobiet (2011) used an 8-member ensemble for future projections of dry/wet spells in Europe. The use of multi-model ensemble projections enables quantification of numerical model uncertainties arising from differences in physics and modeling approaches, model parameterizations and initializations, among others. This is important because model uncertainty may lead to different outcomes (Deser et al., 2012). Another advantage of this approach is that multimodel ensembles commonly outperform studies based on projections from a single model (Knutti et al., 2010).

The analysis of the obtained results revealed that due to the impact of the main climate indicators (temperature and precipitation) based on datasets of a 10-member multi-model ensemble under the SRES A2, A1B, and B1 emission scenarios in the Republic of Moldova, productivity of the wine grape on national level may increase from 14% (SRES B1) to 17% (SRES A2) by 2020s (**Figure 4-11**).



	2020s			2050s			2080s		
	A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Wine grape	17	13	14	6	3	6	-9	-1	4

Figure 4-11: Projections of Future Changes in Productivity of Wine Grape in the Republic of Moldova, (%/30 years) Relative to 1983-2010 Current Period, According to an Ensemble from 10 GCMs for SRES A2, A1B and B1 Emission scenarios in the XXI century

In comparison with the 1983-2010[3] time periods, by 2050s the crop productivity may increase by 6% (SRES A2, B1). The maximum values of productivity decrease may be reached by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of wine grape may increase by +4% under SRES B1 and may decrease by 9% under SRES A2.

Using statistical regression equations relationship in the yield variability of wine grape with the temperature and precipitation of the growing season in three AEZs, there were calculated projections of future wine grape yield changes in the Republic of Moldova's districts (%/30 years) according to an ensemble from 10 Global Climate Models (GCMs) for three SRES A2, A1B and B1 emission scenarios relative to 1983-2010 recent periods. Without application of adaptation measures the most vulnerable to climate change in the Republic of Moldova in territorial aspect would be the southern and central AEZs and in less extent the northern AEZ (**Table 4-25**).

According to projections the most favorable districts for wine grape cultivation will be Donduseni, Edinet, Falesti, Riscani, and Singerei in the northern AEZ; Calarasi, Cruleni, Nisporeni, Nisporeni, Orhei, Hincesti, Ialoveni, Soldanesti and Ungeni in the central AEZ; Cahul, Cantemir and Causeni in the southern AEZ, in which productivity of the wine grape by 2020s could increase from 16 to 73% (SRES A2) and/or from 11 to 58% (SRES B1). In comparison with the 1983-2010 time series, by 2050s the grape productivity may increase in these districts, in dependence of the assessed emission scenario, from 4 to 76% under SRES A2 and/or from 4 to 63% under SRES B1. For Calarasi and Telenesti districts is projected a slight decrease in productivity, by 9-13% under SRES A2 and/or from 3 to 10% under SRES B1. The maximum values of productivity increase may be reached in some districts by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of wine grape may increase from 11 to 132% under SRES A2; respectively, from 10 to 79 % under SRES B1. For Calarasi and Telenesti districts is projected a slight decrease in productivity, by 48-50% under SRES A2 and/or from 11 to 21% under SRES B1.

[3] For northern districts data were available for 1983-2004 years.

Table 4-25: Projected Wine Grape Yield Changes Relative to the Current situation (%/30 Year) under the Ensemble of 10 GCMs for SRES A2, A1B and B1 scenarios

AEZs/district	1983-2010, q/ha	2020s			2050s			2080s		
		A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Northern AEZ										
Donduseni	21.0	73	52	58	61	41	54	46	38	50
Edinet	14.8	55	44	53	40	36	43	30	27	40
Falesti	39.2	27	21	29	27	19	32	13	12	17
Riscani	22.4	36	33	40	8	19	29	-25	7	19
Singerei	32.6	32	23	29	26	20	28	11	14	22
Central AEZ										
Anenii Noi	37.4	24	23	20	40	40	30	68	48	38
Călăraşi	38.9	21	12	14	-9	-16	-3	-48	-28	-11
Criuleni	39.8	33	35	31	61	64	46	106	82	61
Hincesti	42.1	16	11	11	4	2	4	-9	-2	3
Ialoveni	41.5	18	17	17	18	16	16	19	19	18
Nisporeni	47.0	40	37	36	51	52	43	71	66	53
Orhei	38.1	25	20	20	13	10	12	-1	5	10
Străşeni	50.6	21	18	17	27	24	21	37	28	25
Şoldăneşti	22.4	57	46	49	70	69	56	96	85	70
Teleneşti	31.4	16	8	9	-13	-22	-10	-52	-40	-21
Ungheni	29.5	34	32	32	31	26	29	27	30	31
Southern AEZ										
Basarabeasca	36.3	-5	-12	-10	-28	-35	-24	-54	-53	-33
Cahul	43.3	20	15	15	16	10	14	13	9	12
Cantemir	49.4	18	19	17	41	42	32	76	59	41
Causeni	36.7	36	39	37	74	78	63	132	111	79
Cimislia	35.5	-9	-15	-13	-34	-40	-29	-66	-60	-38
Stefan Voda	33.5	-2	-5	-5	-13	-20	-14	-33	-30	-17
Taraclia	41.4	-16	-24	-22	-51	-60	-46	-97	-90	-59
UTA Gagauzia	38.9	0	-8	-6	-26	-34	-21	-60	-54	-31

The most vulnerable districts for grape cultivation will be Basarabeasca, Cimislia, Stefan Voda, Taraclia in the southern AEZ and UTA Gagauzia, in which the productivity of the wine grape by 2020s could decrease up to 16% under SRES A2 and/or from 5 to 22% under SRES B1. In comparison with the 1983-2010 time series, by 2050s the grape productivity may decrease, in dependence of the assessed emission scenario, from 13 to 51% under SRES A2 and/or from 14 to 46% under SRES B1. The maximum values of productivity decrease may be reached by 2080s. Due to changes in values of main climate indicators – precipitation and temperature – the productivity of vine grape in these districts may decrease from 17-59% under SRES B1 and/or from 33 to 97% under SRES A2.

Santos et al. (2011) also reported that a slight upward trend in yield is projected to occur until 2050, followed by a steep and continuous increase until the end of the twenty-first century, when yield is projected to be about 800 kg/ha above current values. While this estimate is based on meteorological parameters alone, changes due to elevated CO_2 may further enhance this effect. In spite of the associated uncertainties, it can be stated that projected climate change may significantly benefit wine yield in the Douro Valley.

Reductions in suitability for grapevine are expected in most of the wine producing regions (Hall, Jones, 2009; White et al., 2009; Jones et al., 2010). Wine grape production and quality will be affected in Europe, USA, Australia (Jones et al., 2005; Wolfe et al., 2008; Cozzolino et al., 2010), although it could be a benefit in Portugal (Santos et al., 2011) and British Columbia in Canada (Rayne et al., 2009).

Adaptation measures are already occurring in some vineyards (e.g., vine management, technological measures, production control and to a smaller extent relocation) (Battaglini et al., 2009; Duarte Alonso, O'Neill, 2011; Holland, Smit, 2010; Malheiro et al., 2010; Moriondo et al., 2011; Santos et al., 2011).Vineyards may be displaced geographically beyond their traditional boundaries ('terroir' linked to soil, climate and traditions) (Metzger, Rounsevell, 2011), and in principle, wine producers could adapt to this problem by growing grape varieties that are more suited to warmer climates. Such technical solutions, however, do not account for the unique characteristics of wine production cultures and consumer perceptions of wine quality that strongly affect the prices paid for the best wines (Metzger, Rounsevell, 2011; White et al., 2009). It would become very difficult, for example, to produce fine wines from the cool-climate Pinot Noir grape within its traditional 'terroir' of Burgundy under many future climate scenarios, but consumers may not be willing to pay current day prices for red wines produced from other grape varieties (Metzger, Rounsevell, 2011). An additional barrier to adaptation is that wine is usually produced within rigid, regionally-specific, regulatory frameworks that often prescribe, amongst other things, what grapes can be grown where, e.g., the French AOC or the Italian DOC and DOCG designations. Suggestions have been made to replace these rigid concepts of regional identity with a geographically flexible 'terroir' that ties a historical or constructed sense of culture to the wine maker and not to the region (White et al., 2009; Kovats et al, 2014).

CONCLUSIONS

We have developed statistical models that were successful in using simple climate variables to explain a substantial amount of historical wine grape yield variability within the 1983–2010 time series. Coefficient of determination R^2 shows that the combined effect of precipitation and temperature defined from 60.7 to 81.4% the variability of average annual yield of wine grape during this period in the northern AEZ; from 40.9 to 72.7% the variability of yield in the central AEZ; and from 29.3 to 66.5% the variability of yield in the southern AEZ. When we applied these models to future climate projections, we found a high likelihood of climate change benefiting wine grape yields in the republic of Moldova mainly in the central and northern districts of the country.

According to projections, the most favorable districts for wine grape cultivation will be Donduseni, Edinet, Falesti, Riscani and Singerei in the North; Criuleni, Nisporeni, Nisporeni, Orhei, Ialoveni, Soldanesti and Ungeni in the Center; Cahul, Cantemir and Causeni in the South, in which productivity of the wine grape by 2080s may increase from 11 to 132% under SRES A2 and/or from 10 to 79% under SRES B1. For Calarasi and Telenesti districts is projected a decrease in productivity, by 48-50% under SRES A2 and/or from 11 to 21% under SRES B1.

Climatic conditions for high-quality grape-growing regions in the Republic of Moldova are different under higher and lower emissions scenarios, although in comparison with the annual crops, the higher scenario SRES A2 is projected to result in conditions likely to favor different grape varieties than those favored by historical conditions mainly in the northern and central districts of the country. More differences between emissions scenarios are expected towards the end of the century, when areas of now optimal high-quality grape-growing conditions will gradually deteriorate in southern districts, including UTA Gagauzia, covering about 40.2% of planted area and 36.5% of total yield in 2012 (and even more, if including also the most vulnerable Calarasi and Telenesti districts), and are more likely under the lower emissions scenario. By 2080s, due to changes in values of main climate indicators – precipitation and temperature – the productivity of vine grape in Basarabeasca, Cimislia, Stefan Voda, Taraclia districts and UTA Gagauzia, may decrease from 17-59% under SRES B1 and/or from 33 to 97% under SRES A2.

Significant adjustments may be required to adapt wine grape varieties, management, and growing regions to a changing climate over the coming century. Greater warming will likely place greater stresses on high-quality wine grape regions, particularly by the end of the 21st century. This work is useful in establishing a baseline for understanding the effects of climate and climate change on wine grape regions in the republic of Moldova. Still, more work is needed to examine in more detail the effects of climate change on wine grape suitability, phenology, quality, and yields for particular varieties and high-quality wine grape regions, as Purcari, Romanesti etc., since there is likely to be considerable variability between regions and varieties not evident at the district scale. Future work should also explicitly include the role of vineyard management in affecting wine grape quality and yields, as this will make this line of research of greater interest and use to viticulturists.

Bibliography

1. **Ainsworth, E.A., Long, S.P. (2005),** *What have we learned from 15 years of free-air CO_2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2*. New Phytol., 165, 351–372.
2. **Alcamo, J., Moreno, J.M., Nováky, B. et al. (2007),** *Europe. Climate change 2007: Impacts, Adaptation and Vulnerability*. In: Parry ML. et al (eds.), Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 541–580.
3. **Amerine, M., Berg, H., Kunkee, R., Ough, C., Singleton, V. and Webb, A. (1980),** *The Technology of Wine Making*. Westport, CT: AVI Publishing Comp. Inc.
4. **Asseng, S., Foster, I.T., Turner, N.C. (2011),** *The impact of temperature variability on wheat yields*. Glob. Change Biol., 17, 997–1012.
5. **Avnery, S., Mauzerall, D.L. J. Liu, Horowitz, L.W. (2011b),** *Global crop yield reductions due to surface ozone exposure: 2. Year 2030 potential crop production losses and economic damage under two scenarios of O_3 pollution*. Atmospheric Environment, 45, 2297-2309.

6. **Avnery, S., Mauzerall, D.L., Liu, J., Horowitz, L.W. (2011a),** *Global crop yield reductions due to surface ozone exposure: 1. Year 2000 crop production losses and economic damage*. Atmospheric Environment, 45, 2284-2296.

7. **Babinszky, L., Dunkel, Z., T□thi, R., Kazinczi, G., Nagy, J. (2011),** *The impacts of climate change on agricultural production*, Hungarian Agricultural Research, in press, ISSN:1216-4526

8. **Babinszky, L., Halas, V., Verstegen, M. (2011),** *Impacts of Climate Change on Animal Production and Quality of Animal Food Products*. In: Climate Change – Socioeconomic Effects. Ed: J. Blanco and H. Kheradmand. In Tech. 454 p. DOI: 10.5772/23840. Available on: <http://www.intechopen.com/books/climate-change-socioeconomic-effects/impacts-of-climate-change-on-animal-production-and-quality-of-animal-food-products>.

9. **Baettig, M.B., Wild, M., Imboden, D.M. (2007),** *A climate change index: Where climate change may be most prominent in the 21st century*. *Geophys. Res. Lett.* 34, L01705.

10. **Barriopedro, D., Fischer, Luterbacher, E.M. J., Trigo, R.M., García-Herrera, R. (2011),** *The hot summer of 2010: redrawing the temperature record map of Europe*. Science, 332(6026), 220-224.

11. **Battaglini, A., Barbeau, G., Bindi, M., Badeck, F.W., (2009),** *European winegrowers' perceptions of climate change impact and options for adaptation*. Regional Environmental Change, 9(2), 61-73.

12. **Ben Salem, H., Rekik, M., Lassoued, N., Darghouth M.-A. (2011),** *Global Warming and Livestock in Dry Areas: Expected Impacts, Adaptation and Mitigation, Climate Change - Socioeconomic Effects*, Dr. Houshan Kheradmand (Ed.), InTech, DOI: 10.5772/24734. Available from: <http://www.intechopen.com/books/climate-change-socioeconomic-effects/global-warming-and-livestock-in-dry-areas-expected-impacts-adaptation-and-mitigation>.

13. **Bindi, M., Olesen, J.E. (2011),** *The responses of agriculture in Europe to climate change*. Regional Environmental Change, 11 (suppl. 1), 151-158.

14. **Blanco-Ward, D., Garcia-Queijeiro, J.M., Jones, G.V. (2007),** *Spatial climate variability and viticulture in the Miño River Valley of Spain*. Vitis, 46, 63–70.

15. **Bottcher, K., Haastrup, P., Le Bas, C. (2010),** *Common criteria for the redefinition of Intermediate Less Favoured Areas in the European Union*. *Environmental Science & Policy*, 13, 766–777.

16. **Brassard, J.P., Sigh, P. (2008),** *Impact of climate change and CO_2 increase on agricultural production and adaptation options for Southern Quebec, Canada*. Mitig. Adapt. Strategies Glob. Change, Vol. 13, 241-265.

17. **Brisson, N., Gate, P., Gouache, D., Charmet, G., Oury, F., Huard, F. (2010),** *Why are wheat yields stagnating in Europe? A comprehensive data analysis for France*. Field Crops Research, 119(1), 201-212.

18. **Calderini, D., Slafer, G. (1998),** *Changes in yield and yield stability in wheat during the 20th century*. Field Crops Research, 57, 335–347.

19. **Camps, J.O., Ramos, M.C., (2012),** *Grape harvest and yield responses to inter-annual changes in temperature and precipitation in an area of north-east Spain with a Mediterranean climate*. Int. J. Biometeorology, 56(5), 853-64.
20. **Carbonneau, A., (2003),** *Ecophysiologie de la vigne et terroir. In: Terroir, zonazione, viticoltura. Trattato internazionale*. Phytoline, 61–102.
21. **Cattivelli, L., Rizza, F., Badeck, F-W. et al. (2008),** *Drought tolerance improvement in crop plants: an integrated view from breeding to genomics*. Field Crops Research, 105, 1–14. DOI: 10.1016/j.fcr.2007.07.004.
22. **Challinor, A.J., Slingo, J.M., Wheeler, T.R., Craufurd, P.Q., Grimes, D.I.F. (2003),** *Toward a combined seasonal weather and crop productivity forecasting system: Determination of the working spatial scale*. J. Appl. Meteor., 42, 175–192.
23. **Challinor, A.J., Wheeler, T.R. (2008a),** *Use of a crop model ensemble to quantify CO_2 stimulation of water stressed and well-watered crops*. Agric. For. Meteor., 148, 1062–1077.
24. **Challinor, A.J., Wheeler, T.R. (2008b),** *Crop yield reduction in the tropics under climate change: Processes and uncertainties*. Agric. For. Meteor., 148, 343–356.
25. **Challinor, A.J., Wheeler, T.R, Osborne, T.M., Slingo, J.M. (2006),** *Assessing the vulnerability of crop productivity to climate change thresholds using an integrated crop–climate model*. Avoiding Dangerous Climate Change, J. Schellnhuber et al., Eds, Cambridge University Press, 187–194.
26. **Challinor, A.J., Wheeler, T.R., Slingo, J.M. (2005),** *Simulation of the impact of high temperature stress on the yield of an annual crop*. Agric. For. Meteorol., 135, 180–189.
27. **Challinor, A.J., Wheeler, T.R., Slingo, J.M., Craufurd, P.Q., Grimes, D.I.F. (2005b),** *Simulation of crop yields using the ERA-40 re-analysis: Limits to skill and nonstationarity in weather–yield relationships*. J. Appl.Meteor., 44, 516–531
28. **Challinor, A.J., Wheeler, T.R., Slingo, J.M., Craufurd, P.Q., Grimes, D.I.F. (2004),** *Design and optimization of a large-area process-based model for annual crops*. Agric. For. Meteor., 124, 99–120.
29. **Ciais, P., M. Reichstein, N., Viovy, A., Granier, J., Ogee, V., Allard, M., Aubinet, N., Buchmann, C., Bernhofer, A., Carrara, F., Chevallier, N., De Noblet, A.D., Friend, P., Friedlingstein, T., Grunwald, B., Heinesch, P., Keronen, A., Knohl, G., Krinner, D., Loustau, G., Manca, G., Matteucci, F., Miglietta, J.M., Ourcival, D., Papale, K., Pilegaard, S., Rambal, G., Seufert, J.F., Soussana, M.J., Sanz, E.D., Schulze, T., Vesala, Valentini, R. (2005),** *Europe-wide reduction in primary productivity caused by the heat and drought in 2003*. Nature, 437(7058), 529-533.
30. **Ciscar, J.C., Iglesias, A., Feyen, L., Szabó, L., Van Regemorter, D., Amelung, B., Nicholls, R., Watkiss, P., Christensen, O.B., Dankers, R., Garrote, L., Goodess, C.M., Hunt, A., Moreno, A., Richards, J., Soria, A. (2011),** *Physical and economic consequences of climate change in Europe*. Proceedings of the National Academy of Sciences of the United States of America, 108(7), 2678-2683.
31. **Close, W.H. (1989),** *The influence of thermal environment on the voluntary food intake of pigs*. In: The voluntary food intake of pigs, J.M. Forbes, M.A. Varley, T.L.J. Lawrence, (Eds), 87-96. British Society of Animal Production, Edinburgh.

32. **Collin, A., van Milgen, J., Dubois, S., Noblet, J. (2001),** *Effect of high temperature on feeding behavior and heat production in group-housed young pigs*. British Journal of Nutrition, 86, 63-70.
33. **Coombe, B.G. (1987),** *Influence of temperature on composition and quality of grapes*. Acta Hortic, 206, 23–35.
34. **Cozzolino, D., Cynkar, W.U., Dambergs, R.G., Gishen, M., Smith, P. (2010),** *Grape (Vitis vinifera) compositional data spanning ten successive vintages in the context of abiotic growing parameters*. Agriculture, Ecosystems &Environment, 139, 565-570.
35. **Constantinov, T., Taranu, L., Mironova, T., Toderas, V. (2009),** *Assessment of vulnerability some agricultural crops productivity in the Republic of Moldova, without adaptation measures, to new climate conditions according to the CSIRO-Mk2, HADCM2 and ECHAM4 general atmospheric models*. The Bulletin of the Academy of Sciences of Moldova, Series of "Biological, Chemical and Agricultural Sciences". Republic of Moldova, Chisinau, 2009, 2 (308), 124-132.
36. **Cox, G.M., Gibbons, J.M., Wood, A.T.A., Craigon, J., Ramsden, S.J., Crout, N.M.J. (2006),** *Towards the systematic simplification of mechanistic models*. Ecol. Model., 198**,** 240–246.
37. **Craine, J.M., Elmore, A.J., Olson, K.C., Tolleson, D. (2010),** *Climate change and cattle nutritional stress*. Global Change Biology, 16(10), 2901-2911. Doi: 10.1111/j.1365-2486.2009.02060.x
38. **Daghir, N.J. (2009),** *Nutritional Strategies to Reduce Heat Stress in Broilers and Broiler Breeders*, Lohmann Information, 44 (1), 6-15.
39. **Daux, V., Garcia de Cortazar-Atauri, I., Yiou, P., Chuine, I., Garnier, E., Le Roy Ladurie, E., Mestre, O., Tardaguila, J. (2011)**, *An open-database of grape harvest dates for climate research: data description and quality assessment*. Clim. Past. Discuss. 7(6), 3823–3858. DOI: 10.5194/cpd-7-3823-2011.
40. **Diffenbaugh, N.S., Giorgi, F., Raymond, L., Bi, X. (2007),** *Indicators of 21st century socioclimatic exposure*. Proceedings of the National Academy of Sciences 104, 20195 –20198.
41. **Donatelli, M., Duveiller, G., Fumagalli, D., Srivastava, A., Zucchini, A., Angileri, V., Fasbender, D., Loudjani, P., Kay, S., Juskevicius, V., Toth, T., Haastrup, P. et al. (2012)**, *Assessing agriculture vulnerabilities for the design of effective measures for adaptation to climate change (AVEMAC project)*. Luxembourg: Publications Office of the European Union, 176 pp.
42. **Donatelli, M., Srivastava, A.K., Duveiller, G., Niemeyer, S. (2012),** *Estimating Impact Assessment and Adaptation Strategies under Climate Change Scenarios for Crops at EU27 Scale*. In: Environmental Modelling and Software [R. Seppelt, R., A.A. Voinov, S. Lange, D. Bankamp (eds.)]. Proceedings of Managing Resources of a Limited Planet, Sixth Biennial Meeting, July 2012, Leipzig, Germany, pp. 1-8.
43. **Dronin, N., Kirilenko, A. (2011),** *Climate change, food stress, and security in Russia*. Regional Environmental Change*,* 11(SUPPL. 1), 167-178.
44. **Duarte Alonso, A., O'Neill, M.A. (2011),** *Climate change from the perspective of Spanish wine growers: a three region study*. British Food Journal, 113(2), 205-221.

45. **Duchêne, E., Schneider, C. (2005),** *Grapevine and climatic changes: a glance at the situation in Alsace*. Agron. Sustain. Dev., 25, 93–99. DOI:10.1051/agro:2004057
46. **Easterling, D.R., Evans, J.L., Groisman, P.Ya., Karl, T.R., Kunkel, K.E., Ambenje, P. (2000a),** *Observed variability and trends in extreme climate events: a brief review*. Bull. Am. Meteorol. Soc., 81, 417–425.
47. **Easterling, D.R., Meehl, G.A., Parmensan, C., Chagnon, S.A., Karl, T., Mearns, L.O. (2000b),** *Climate extremes: observation, modelling and impacts*. Science, 289, 2068–2074.
48. **Easterling, W., Apps, M. (2005),** *Assessing the consequences of climate change for food and forest resources: a view from the IPCC*. Climate Change, 70, 165–189.
49. **EEA (2010a),** *The European Environment, State and Outlook 2010. Water Resources: Quantity and Flows*. European Environment Agency, Copenhagen, Denmark, pp. 32.
50. **Eliasson, A., Jones, R.J.A., Nachtergaele, F., Rossiter, D.G., Terres, J.-M., Van Orshoven, J., van Velthuizen, H., Falloon, P., Betts, R. (2010),** *Climate impacts on European agriculture and water management in the context of adaptation and mitigation–The importance of an integrated approach*. Special Section: Integrating Water and Agricultural Management under Climate Change 408, 5667–5687.
51. **FAO (2009a),** *The state of food and agriculture: Livestock in the balance*.
52. **Farooq, M., Bramley, H., Palta, J.A., Siddique, K.H.M. (2011),** *Heat Stress in Wheat during Reproductive and Grain-Filling Phases*. Crit. Rev. Plant Sci., 30, 491–507.
53. **FASS (Federation of Animal Science Societies) (2010),** *Guide for the Care and Use of Agricultural Animals in Research and Teaching*, (January 2010), Champaign, Illinois, USA. <www.fass.org/docs/agguide3rd/Ag_Guide_3rd_ed.pdf>.
54. **Feenstra, J.F., Burton, I., Smith, J.B., Tol, R.S.J. (1998),** *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies*. UNEP/IVM, Nairobi/Amsterdam.
55. **Fels-Klerx, H.J. van der, Olesen, J.E., Naustvoll, L.-J., Friocourt, Y., Mengelers, M.J.B., Christensen, J.H. (2012),** *Climate change impacts on natural toxins in food production systems, exemplified by deoxynivalenol in wheat and diarrhetic shellfish toxins*. Food Additives and Contaminants: doi: 10.1080/19440049.2012.714080.
56. **Felzer, B., Kicklighter, D.W., Melillo, J.M., Wang, C., Zhuang, Q., Prinn, R.G. (2004),** *Effects of ozone on net primary production and carbon sequestration in the conterminous United States using a biogeochemistry model*. Tellus, 56B, 230–248.
57. **Ferrara, R.M., Trevisiol, P., Acutis, M., Rana, G., Richter, G.M., Baggaley, N. (2010),** *Topographic impacts on wheat yields under climate change: two contrasted case studies in Europe*. Theoretical and Applied Climatology, 99(1-2), 53-65.
58. **Ferrise, R., Moriondo, M., Bindi, M. (2011),** *Probabilistic assessments of climate change impacts on durum wheat in the Mediterranean region*. Natural Hazards and Earth System Sciences, 11(5), 1 293–1 302. doi: 10.5194/nhess-11-1293-2011.
59. **Finger, R. (2010),** *Evidence of slowing yield growth - the example of Swiss cereal yields*. Food Policy, 35, 175–182. DOI: 10.1016/j.foodpol.2009.11.004.

60. **Fischer, G., Shah, M., Tubiello, F.N., van Velthuizen, H. (2005),** *Socioeconomic and climate change impacts on agriculture: an integrated assessment, 1990–2080.* Philosophical Transactions of the Royal Society, 1463, 2067–2083.

61. **Forster, P., Ramaswamy, V., Artaxo, P. et al. (2007),** *Changes in atmospheric constituents and in radiative forcing.* In: Solomon S., et al (eds.) 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.

62. **Fuhrer, J., Beniston, M., Fischlin, A., Frei, C., Goyette, S., Jasper, K., Pfister, C. (2006),** *Climate risks and their impact on agriculture and forests in Switzerland*. Climatic Change, 79(1-2), 79-102.

63. **Fraga, H., Malheiro, A.C., Moutinho-Pereira, J., Santos, J. A. (2012),** *Future scenarios for viticultural zoning in Europe: ensemble projections and uncertainties*. Int. J. Biometeorology., 57 (6), 909-925.

64. **Gaughan, J.B. et al. (2009),** *Response of domestic animals to climate challenges.* In: Ebi, K.L., Burton, I. and McGregor, G.R., Eds., Biometeorology of Adaptation to Climate Variability and Change, Springer Science, Heidelberg, 131-170.

65. **Giannakopoulos, C., Le Sager, P., Bindi, M. et al. (2009),** *Climatic changes and associated impacts in the Mediterranean resulting from global warming.* Global Planet Change, 68, 209–224.

66. **Giorgi, F. (2006),** *Climate change hot-spots*. Geophys. Res. Lett. 33, L08707.

67. **Gouveia, C., Liberato, M.L.R., DaCamara, C.C., Trigo, R.M., Ramos, A.M. (2011),** *Modelling past and future wine production in the Portuguese Douro Valley*. Clim. Res. 48, 349–362. DOI: 10.3354/cr01006.

68. **Gregory, P.J., Marshall, B. (2012),** *Attribution of climate change: a methodology to estimate the potential contribution to increases in potato yield in Scotland since 1960*. Global Change Biology, 18(4), 1372-1388.

69. **Hai, L., Rong, D., Zhang, Z. Y. (2000),** *The effect of thermal environment on the digestion of broilers.* Journal of Animal Physiology and Animal Nutrition (Berl.), 83, 57–64.

70. **Hall, A., Jones, G.V. (2009),** *Effect of potential atmospheric warming on temperature-based indices describing Australian wine grape growing conditions.* Australian Journal of Grape and Wine Research, 15, 97-119.

71. **Hall, A., Jones, G.V. (2010),** *Spatial analysis of climate in wine grape growing regions in Australia*. Aust. J. Grape Wine R., 16(3), 389–404. doi:10.1111/j.1755-0238-.2010.00100.x

72. **Hanson, C.E., Palutikof, J.P., Livermore, M.T. J. et al. (2007),** *Modeling the impact of climate extremes: an overview of the MICE Project.* Climate Change, 81, 163–177.

73. **Hatfield, J.L., Boote, K.J., Kimball, B.A. et al. (2011),** *Climate impacts on agriculture: implications for crop production.* Agron. J., 103, 351–370.

74. **Hawkins, E., Fricker, T.E., Challinor, A.J., Ferro, C.A.T., Ho, C.K., Osborne, T.M. (2013),** *Increasing influence of heat stress on French maize yields from the 1960s to the 2030s*. Global Change Biology, 19(3), 937-947.

75. **Hawkins, E., Sutton, R. (2011),** *The potential to narrow uncertainty in projections of regional precipitation change*. Climate Dynamics, 37, 407–418. DOI: 10.1007/s00382-010-0810-6.
76. **Heinrich, G., Gobiet, A. (2011),** *The future of dry and wet spells in Europe: a comprehensive study based on the ENSEMBLES regional climate models*. Int. J. Clim. DOI:10.1002/joc.2421.
77. **Herrero, M., Hanotte, O., Notenbaert, A., Thornton, P.K. (2008),** *Potential of modeling animal genetic resources data in relation to other existing data sets*. In: Pilling, D., Rischkowsky, B. and Scherf, B., Eds., Report on the FAO/WAAP Workshop on Production Environment Descriptors for Animal Genetic Resources Report, Caprarola, 6-8 May 2008. www.fao.org/docrep/meeting/022/mb386e.pdf.
78. **Hidalgo, L. (2002),** *Tratado de viticultura general*. Mundi-Prensa Libros Spain.
79. **Hoffman, M.T., Vogel, C. (2008),** *Climate change impacts on African rangelands*. Rangelands, 30, 12–17.
80. **Holland, T., Smit, B., (2010),** *Climate change and the wine industry: current research themes and new directions*. Journal of Wine Research, 21(2-3), 125-136.
81. **Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M., Meinke, H. (2007),** *Adapting agriculture to climate change*. Proceedings of the National Academy of Sciences of the United States of America, 104(50), 19691-6.
82. **Huglin, P. (1978),** *Nouveau mode d'évaluation des possibilities héliothermiques d'un milieu viticole*. In: Proc Symp Int sur l'ecologie de la Vigne. Ministère de l'Agriculture et de l'Industrie Alimentaire, Contança, 89–98.
83. **Huynh, T.T.T., Aarnink, A.J.A., Verstegen, M.W.A., Gerrits, W.J.J., Heetkamp, M.J.W., Kemp, B., Canh, T.T. (2005),** *Effects of increasing temperatures on physiological changes in pigs at different relative humidity*. Journal of Animal Science, 83, 1385-1396.
84. **Iglesias, A., Garrote, L., Diz, A., Schlickenrieder, J., Moneo, M. (2012),** *Water and people: Assessing policy priorities for climate change adaptation in the Mediterranean*. In: Regional Assessment of Climate Change in the Mediterranean. [Navarra, A. and L. Tubiana (eds.)]. Springer, Dordrecht, Netherlands, pp. 201-233.
85. **Iglesias, A., Mougou, R., Moneo, M. and Quiroga, S. (2010),** *Towards adaptation of agriculture to climate change in the Mediterranean*. Regional Environmental Change, 11, 159–166. doi: 10.1007/s10113-010-0187-4.
86. **Iglesias, A., Orlandini, S., Dubrovsky, M., Hlavinka, P., Balek, J., Eckersten, H., Cloppet, E., Calanca, P.,Gobin, A., Vucetic, V., Nejedlik, P., Kumar, S., Lalic, B., Mestre, A., Rossi, F., Kozyra, J., Alexandrov, V., Semeradova, D., Zalud, Z. (2011),** *Agroclimatic conditions in Europe under climate change*. Global Change Biology. doi: 10.1111/j.1365-2486.2011.2396.x
87. **Iglesias, A., Quiroga, S. (2007),** *Measuring the risk of climate variability to cereal production at five sites in Spain*. Clim. Res., 34, 47–57.
88. **Iglesias, A., Rosenzweig, C., Pereira, D. (2000),** *Agricultural impacts of climate change in Spain: Developing tools for a spatial analysis*. Global Environ. Change, 10, 69–80.

89. **International Food Policy Research Institute (IFPRI) (2009),** *Climate change impact on agriculture and costs of adaptations.* Food Policy Report.

90. **IPCC (2014),** *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, XXX pp.

91. **IPCC, (2007),** *Climate Change: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the International Panel on Climate Change. Cambridge, UK and New York: Cambridge University Press.

92. **Irmak, A., Jones, J.W., Jagtap, S.S. (2005),** *Evaluation of the CROPGRO-soybean model for assessing climate impacts on regional soybean yields.* Trans. ASAE, 48, 2343–2353.

93. **Izaurralde, R.C., Rosenberg, N.J., Brown, R.A., Thomson, A.M. (2003),** *Integrated assessment of Hadley Centre (HADCM2) climate-change impacts on agricultural productivity and irrigation water supply in the conterminous United States. Part II: Regional agricultural production in 2030 and 2095.* Agric. For. Meteor., 117, 97–122.

94. **Jakobi, G., Ahas, R., Scheifinger, H., Estrella, N. (2003)**, *Variations of the climatological growing season (1951–2000) in Germany compared with other countries.* International Journal of Climatology 23(7), 793–812. doi: 10.1002/joc.915.

95. **Jenkins, G., Lowe, J. (2003),** *Handling uncertainties in the UKCIP02 scenarios of climate change.* Met Office Tech. Note, 44, 15 pp.

96. **Jones, G.V., Duff, A.A., Hall, A., Myers, J.W. (2010),** *Spatial analysis of climate in wine grape growing regions in the Western United States.* Am. J. Enol. Vitic., 61(3), 313–326.

97. **Jones, G.V. (2006),** *Climate and terroir: impacts of climate variability and change on wine.* In: Macqueen RW, Meinert LD (eds.) Fine wine and terroir. The geoscience perspective. Geoscience Canada Reprint Series No. 9, Geological Association of Canada, St. John's, Newfoundland, p 247.

98. **Jones, G.V., White, M.A., Cooper, O.R., Storchmann, K. (2005),** *Climate change and global wine quality*. Climatic Change, 73 (3), 319-343.

99. **Jones, G.V., Duchêne, E., Tomasi, D., Yuste, J. et al. (2005a),** *Changes in European wine grape phenology and relationships with climate.* In: Proceedings of the Groupe d'Etude des Syste`mes de Conduite de la vigne (GESCO 2005), Geisenheim.

100. **Jones, G.V., White, M.A., Cooper, O.R., Storchmann, K. (2005a),** *Climate change and global wine quality.* Clim. Change, 73, 319–343.

101. **Jones, G.V., Duchêne, E., Tomasi, D., Yuste, J. et al. (2005b),** *Changes in European wine grape phenology and relationships with climate.* GESCO (Groupe d'Etude des Systèmes de Conduite de la Vigne), Proc. XIV GESCO Symposium, Geisenheim, Germany, 23–26 August, Vol. I, 55–61.

102. Jones, G.V., Davis, R.E. (2000), *Climate influences on grapevine phenology, grape composition, and wine production and quality for Bordeaux*. France. Am. J. Enol. Vitic., 51, 249–261.

103. Jones, D., Barnes, E.M. (2000), *Fuzzy composite programming to combine remote sensing and crop models for decision support in precision crop management*. Agric. Syst., 65, 137–158.

104. Kadzere, C.T., Murphy, M.R., Silanikove, N., Maltz, E. (2002), *Heat stress in lactating dairy cows: a review*. Livestock Production Science, 77(1), 59-91.

105. Keane, M.G., Allen, P. (1998), *Effects of production system intensity on performance, carcass composition and meat quality of beef cattle*. Livestock Production Science, 56, 203–214.

106. Kenny, G.J. and Harrison, P.A. (1992), *The effects of climate variability and change on grape suitability in Europe*. J. Wine Res, 3, 163–183.

107. Kerr, B.J., Yen, J.T., Nienaber, J.A., Easter, R.A. (2003), *Influences of dietary protein level, amino acid supplementation and environmental temperature on performance, body composition, organ weights and total heat production of growing pigs*, Journal of Animal Science, 81, 1998-2007.

108. Klein Tank, A.M.G., Können, G.P. (2003), *Trends in indices of daily temperature and precipitation extremes in Europe, 1946–99*. J. Clim., 16, 3665–3680.

109. Knutti, R., Furrer, R., Tebaldi, C., Cermak, J., Meehl, G.A. (2010), *Challenges in combining projections from multiple climate models*. J. Clim., 23 (10), 2739–2758. doi:10.1175/2009jcli3361.1.

110. Koundouras, S., Van Leeuwen, C., Seguin, G., Glories, Y. (1999), *Influence of water status on vine vegetative growth, berry ripening and wine characteristics in mediterranean zone (example of Nemea, Greece, variety Saint-George, 1997)*. J. Int. Sci. Vigne. Vin., 33, 149–160.

111. Kovats, R.S., Valentini, R., Bouwer, L.M., Georgopoulou, E., Jacob, D., Martin, E., Rounsevell, M., Soussana, J.-F. (2014), *Europe*. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. XXX-YYY.

112. Kristensen, K., Schelde, K., Olesen, J.E. (2011), *Winter wheat yield response to climate variability in Denmark*. Journal of Agricultural Science, 149(1), 33-47. doi: 10.1017/S0021859610000675.

113. Ladanyi, M. (2008), *Risk methods and their applications in agriculture*. Applied Ecology and Environmental Research, 6(1), 147-164.

114. Launay, M., Graux, A.I, Brisson, N., et al. (2009), *Carbohydrate remobilization from storage root to leaves after a stress release in sugar beet (Beta vulgaris L.): experimental and modelling approaches*. Journal of Agricultural Science, 147, 669–682.

115. **Lavalle, C., Micale, F., Houston, T.D., Camia, A., Hiederer, R., Lazar, C., Conte, C., Amatulli, G., Genovese, G. (2009),** *Climate change in Europe. 3. Impact on agriculture and forestry. A review.* Agronomy for Sustainable Development, 29(3), 433-446.

116. **Le Bellego, L., van Milgen, J., Noblet, J. (2002),** *Effect of high ambient temperature on protein and lipid deposition and energy utilization in growing pigs*. Animal Science, 75, 85-96.

117. **Lebonvallet, S., Brisson, N., Raffaillac, J.P., et al. (2009),** *Establishment of quinoa (Chenopodium quinoa Willd.) and simulation of its cultivation with the STICS crop model*. Proceedings of the conference on integrated assessment of agriculture and sustainable development: Setting the Agenda for Science and Policy (AgSAP 2009). The Netherlands: Egmond aan Zee, 10–12 March 2009, 224–225.

118. **Lin, H., Jiao, H.C., Buyse, J., Decuypere, E. (2006),** *Strategies for preventing heat stress in poultry*. World's Poultry Science Journal, 62, 71-86.

119. **Liu, J.G, Fritz, S., van Wesenbeeck, C.F.A., et al. (2008),** *A spatially explicit assessment of current and future hotspots of hunger in Sub-Saharan Africa in the context of global change*. Global and Planetary Change, 64, 222–235.

120. **Lobell, D.B., Sibley, A., Ortiz-Monasterio, J.I. (2012),** *Extreme heat effects on wheat senescence in India*. Nature Climate Change, 2, 186–189. doi: 10.1038/nclimate1356.

121. **Lobell, D.B., Schlenker, W., Costa-Roberts, J. (2011),** *Climate Trends and Global Crop Production since 1980*. Science, 333(6042), 616–620.

122. **Lobell, D.B., Banziger, M., Magorokosho, C., Vivek, B. (2011a),** *Nonlinear heat effects on African maize as evidenced by historical yield trials*. Nature Climate Change, 1(1), 42-45.

123. **Lobell, D.B., Burke, M.B. (2010),** *On the use of statistical models to predict crop yield responses to climate change*. Agric. Forest Meteorology, DOI:10.1016/j.agrformet.2010.07.008

124. **Lobell, D.B., Burke, M.B. (2008),** *Why are agricultural impacts of climate change so uncertain? The importance of temperature relative to precipitation*. Environmental Research Letters, 3 (034), 007. DOI: 10.1088/1748-9326/3/3/034007.

125. **Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P., Naylor, R.L. (2008),** *Prioritizing climate change adaptation needs for food security in 2030. Science,* 319, 607–610.

126. **Lobell, D.B., Field, C.B. (2007),** *Global scale climate–crop yield relationships and the impacts of recent warming*. Environmental Research Letters 2, 014002. doi:10.1088/1748-9326/2/1/014002.

127. **Lobell, D.B., Field, C.B., Cahill, K.N., Bonfils, C. (2006),** *Impacts of future climate change on California perennial crop yields: model projections with climate and crop uncertainties*. Agric. For Meteorology, 141(2–4), 208–218.

128. **Lobell, D.B., Asner, G.P. (2003),** *Climate and management contributions to recent trends in U.S agricultural yields*. Science, 299, 1032. DOI: 10.1126/science.1078475.

129. Luo, Q.Y. (2011), *Temperature thresholds and crop production: a review*. Climatic Change, 109, 583–598.

130. Luo, Q.Y., Lin, E. (1999), *Agricultural vulnerability and adaptation in developing countries: The Asia–Pacific region*. Climatic Change, 43, 729–743.

131. Magalhães, N. (2008), *Tratado de viticultura: a videira, a vinha e o terroir*. Chaves Ferreira Publicações, Lisboa.

132. Makra, L., Vitanyi, B., Gal, A., Mika, J., Matyasovszky, I., Hirsch, T. (2009), *Wine quantity and quality variations in relation to climatic factors in the Tokaj (Hungary) Winegrowing Region*. Am. J. Enol. Vitic., 60 (3), 312–321.

133. Malheiro, A.C., Santos, J.A., Fraga, H., Pinto, J.G. (2010), *Climate change scenarios applied to viticultural zoning in Europe*. Clim. Res., 43, 163–177.

134. Mandryk, M., Reidsma, P., Ittersum, M. (2012), *Scenarios of long-term farm structural change for application in climate change impact assessment*. Landscape Ecology, 27(4), 509-527.

135. Marai, I.F.M., Haeeb, A.A.M. (2010), *Buffalo's biological functions as affected by heat stress: A review*. Livestock Science, 127, 89-109. DOI:10.1016/j.livsci.2009.08.001

136. Marai, I.F.M., El-Darawany, A.A., Fadiel, A., Abdel-Hafez, M.A.M. (2007), *Physiological traits as affected by heat stress in sheep — a review*. Small Rumin. Res. 71, 1-12.

137. Mashaly, M.M., Hendricks, G.L., Kalama, M.A. (2004), *Effect of Heat Stress on Production Parameters and Immune Responses of Commercial Laying Hens*. Poultry Science, 83, 889–894.

138. McManus, C. et al. (2009), *Heat tolerance in Brazilian sheep: Physiological and blood parameters*. Tropical Animal Health and Production, 41, 95-101. DOI:10.1007/s11250-008-9162-1_

139. Meehl, G.A., Stocker, T.F., Collins, W. et al. (2007), *Global climate projections.* In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds: Solomon S. et al.). Cambridge University Press, UK.

140. Menzel, A., Sparks, T.H., Estrella, N., Koch, E., Aasa, A., Ahas, K.A., Bissolli, P., Braslavská, O., Briede, A., Chmielewski, F.M., Crepinsek, Z., Curnel, Y., Dahl, Å. Defila, C., Donnelly, A., Filella, Y., Jatczak, K., Måge, F., Mestre, A., Nordli, Ø., Peñuelas, J., Pirinen, P., Remišová, V., Scheifinger, H., Striz, M., Susnik, A., Van vliet, A., Wielgolaski, F., Zach, S., Zust, A. (2006), *European phenological response to climate change matches the warming pattern*. Global Change Biology, 12(10), 1969-1976.

141. Metzger, M.J., Rounsevell, M.D.A. (2011), *A need for planned adaptation to climate change in the wine industry*. Environmental Research Letters, 6(3), 031001. DOI:10.1088/1748-9326/6/3/031001).

142. Ministerul Mediului şi Amenajării Teritoriului, PNUD Moldova (2000), *Prima Comunicare Naţională a Republicii Moldova elaborată în cadrul Convenţiei Naţiunilor Unite privind Schimbarea Climei*. Chişinău, 2000, 74 p.

143. **Moriondo, M., Bindi, M., Fagarazzi, C., Ferrise, R., Trombi, G. (2011),** *Framework for high-resolution climate change impact assessment on grapevines at a regional scale*. Regional Environmental Change, 11(3), 553-567.

144. **Moriondo, M., Giannakopoulos, C., Bindi, M. (2011),** *Climate change impact assessment: the role of climate extremes in crop yield simulation*. Climatic Change, 104, 679–701. DOI: 10.1007/s10584-010-9871-0.

145. **Moriondo, M., Bindi, M., Kundzewicz, Z.W., Szwed, M., Chorynski, A., Matczak, P., Radziejewski, M., McEvoy, D., Wreford, A. (2010),** *Impact and adaptation opportunities for European agriculture in response to climatic change and variability*. Mitigation and Adaptation Strategies for Global Change, 15(7), 657-679.

146. **Moriondo, M., Pacini, C., Trombi, G., Vazzana, C., Bindi, M. (2010b),** *Sustainability of dairy farming system in Tuscany in a changing climate*. European Journal of Agronomy, 32(1), 80-90.

147. **Moriondo, M., Bindi, M. (2006),** *Comparison of temperatures simulated by GCMs, RCMs and statistical downscaling: potential application in studies of future crop development*. Clim. Res., 30, 149–160.

148. **Morrison, M.J., Stewart, D.W. (2002),** *Heat stress during flowering in summer brassica*. Crop Sci., 42, 797–803.

149. **Moutinho-Pereira, J.M., Correia, C.M., Goncalves, B.M., Bacelar, E.A., Torres-Pereira, J.M. (2004),** *Leaf gas exchange and water relations of grapevines grown in three different conditions*. Photosynthetica, 42(1), 81–86.

150. **Mullins, M.G., Bouquet, A., Williams, L.E. (1992),** *Biology of the grapevine*. Cambridge University Press, p. 239.

151. **Musshoff, O., Odening, M., Xu, W. (2011),** *Management of climate risks in agriculture - will weather derivatives permeate?* Applied Economics, 43(9), 1067-1077.

152. **Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M.S., Bernabucci, U. (2010),** *Effects of climate changes on animal production and sustainability of livestock systems*. Livestock Science, 130, 57-69. DOI:10.1016/j.livsci.2010.02.011_

153. **Noblet, J., Le Dividich, J., van Milgen, J. (2001),** *Thermal environment and swine nutrition*, In: Swine Nutrition, A.J. Lewis & L.L. Southern (Eds), pp. 519-544, CRC Press, ISBN:0-8493-0696-5, Boca Ration, Florida, US.

154. **Nuernberg, K., Dannenberger, D., Nuernberg, G., Ender, K., Voigt, J., Scollan, N.D, Wood, J.D., Nute, GR., Richardson, R.I. (2005),** *Effect of a grass-based and a concentrate feeding system on meat quality characteristics and fatty acid composition of longissimus muscle in different cattle breeds*. Livestock Production Science, 94 (1-2), 137– 147.

155. **OECD–FAO (Organisation for Economic Cooperation and Development–Food and Agriculture Organization of the United Nations) (2008),** *OECD–FAO Agricultural Outlook: 2008–2017*. Paris.

156. **Olesen, J.E., Trnka, M., Kersebaum, K. C., Skjelvåg, A. O., Seguin, B., Peltonen-Sainio, P., Rossi, F., Kozyra, J. and Micale, F. (2011),** *Impacts and adaptation of European crop production systems to climate change*. European Journal of Agronomy, 34(2), 96–112. doi:10.1016/j.eja.2010.11.003.

157. Olesen, J.E. and 16 co-authors (2007), *Uncertainties in projected impacts of climate change on European agriculture and terrestrial ecosystems based on scenarios from regional climate models.* Climatic Change, 81, 123–143.

158. Olesen, J.E., Bindi, M. (2002), *Consequences of climate change for European agricultural productivity, land use and policy*. European Journal of Agronomy, 16(4), 239–262.

159. Oort, P.A.J., Timmermans B.G.H., van Swaaij, A.C.P.M. (2012), *Why farmers' sowing dates hardly change when temperature rises*. European Journal of Agronomy, 40, 102-111.

160. Paeth, H., Capo-Chichi, A., Endlicher, W. (2008), *Climate change and food security in tropical West Africa: a dynamic-statistical modeling approach*. Erdkunde., 62, 101–115.

161. Parent, B., Tardieu, F. (2012), *Temperature responses of developmental processes have not been affected by breeding in different ecological areas for 17 crop species*. New Phytologist, 194(3), 760-774.

162. Parry, M., Rosenzweig, C., Livermore, M. (2005), *Climate change, global food supply and risk of hunger*. Philos. Trans. Roy. Soc., 360, 2125–2138.

163. Parry, M., Rosenzweig, C., Iglesias A. et al. (2004), *Effects of climate change on global food production under RSES emissions and socio-economic scenarios*. Global Environ. Change, 14, 53–67.

164. Peltonen-Sainio, P., Jauhiainen, L., Hakala, K. (2010), *Crop responses to temperature and precipitation according to long-term multi-location trials at high-latitude conditions*. The Journal of Agricultural Science, 149(01), 49-62.

165. Peltonen-Sainio, P., Jauhiainen, L., Trnka, M., Olesen, J. E., Calanca, P., Eckersten, H., Eitzinger, J., Gobin, A., Kersebaum, K. C., Kozyra, J., Kumar, S., Marta, A. D., Micale, F., Schaap, B., Seguin, B. et al. (2010), *Coincidence of variation in yield and climate in Europe*. Agriculture, Ecosystems & Environment, 139(4), 483–489. doi:10.1016/j.agee.2010.09.006.

166. Peters, D.P.C., Herrick, J.E., Monger, H.C., Huang, H. (2010), *Soil-vegetation-climate interactions in arid landscapes: Effect of the North American monsoon on grass recruitment*. J. Arid Environ. 74, 618-623.

167. Peterson, T.V., Folland, C., Gruza, G., Hogg, W., Mokssit, A., Plummer, N. (2001), *Report on the activities of the Working Group on climate change detection and related rapporteurs 1998–2001*. World Meteorological Organisation Rep WCDMP-47, WMO-D 1071, Geneva, Switzerland, 143.

168. Porter, J.R., Semenov, M.A. (2005), *Crop responses to climatic variation*. Philosophical Transactions of the Royal Society B: Biological Sciences, 360, 2021–2035.

169. Quiniou, N., Dubois, S., Noblet, J. (2000), *Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and body weight*. Livestock Production Science, 63 (3), 245–253.

170. Quiroga, S., Iglesias, A. (2010), *A comparison of the climate marginal productivity on representative crop yields in Spain*. Princip: Estud Econ Política, 16, 55–70.

171. **Quiroga, S., Iglesias, A. (2009),** *A comparison of the climate risks of cereal, citrus, grapevine and olive production in Spain*. Agric Syst., 101, 91–100.

172. **Rahmstorf, S., Cazenave, A., Church, J.A., Hansen, J.E., Keeling, R.F., Parker, D.E., Somerville, R.C. J. (2007),** *Recent climate observations compared to projections*. Science, 316, 709.

173. **Ramos, M.C., Jones, G.V., Martínez-Casasnovas, J.A. (2008),** *Structure and trends in climate parameters affecting winegrape production in northeast Spain*. Clim. Res. 38, 1–15.

174. **Ramos, M.C., Martínez-Casasnovas, J.A. (2006b),** *Nutrient losses by runoff in vineyards of the Mediterranean Alt Penedès region (NE Spain)*. Agric. Ecosyst. Environ., 113, 356–363.

175. **Ravagnolo, O., Misztal I. (2000),** *Genetic Component of Heat Stress in Dairy Cattle, Parameter Estimation*. Journal of Dairy Science, 83 (9), 2126-2130.

176. **Rayne, S., Forest, K., Friesen, K. (2009),** *Projected Climate Change Impacts on Grape Growing in the Okanagan Valley, British Columbia, Canada*. Nature Proceedings, 1-46.

177. **Reidsma, P., Ewert, F.A., Lansink, A.O., Leemans, R. (2010),** *Adaptation to climate change and climate variability in European agriculture: The importance of farm level responses*. European Journal of Agronomy, 32(1), 91–102. doi: 10.1016/j.eja.2009.06.003.

178. **Reidsma, P., Ewert, F.A. (2008),** *Regional farm diversity can reduce vulnerability of food production to climate change*. Ecology and Society, 13(1), 1–16.

179. **Report CNFA, PDBA, MEPO (2005),** *Opportunities for Developing a Competitive Table Grape Production Sector in Moldova*. National Institute of Wine and Vineyards, Chisinau, 31p.

180. **Rosenzweig, C., Tubiello, F. (2007),** *Adaptation and mitigation strategies in agriculture: an analysis of potential synergies*. Mitigation and Adaptation Strategies for Global Change, 12, 855–873. DOI: 10.1007/s11027-007-9103-8.

181. **Rosenzweig, C., Ritchie, J.T., Jones, J.W., Tsuji, G.Y., Hildebrand, P. (1995),** *Climate change and agriculture: analysis of potential international impacts*. Madison WI: ASA Special Publication No. 59. American Society of Agronomy.

182. **Rötter, R.P., Palosuo, T., Pirttioja, N.K., Dubrovski, M., Salo, T., Fronzek, S., Aikasalo, R., Trnka, M., Ristolainen, A., Carter, T. (2011),** *What would happen to barley production in Finland if global warming exceeded 4 °C? A model-based assessment*. European Journal of Agronomy, 35(4), 205-214.

183. **Rowlinson, P. (2008),** *Adapting livestock production systems to climate change – temperate zones*. In: P. Rowlinson, M. Steele & A. Nefzaoui, eds. Livestock and global change. Proceedings of an international conference, Hammamet, Tunisia, 17–20 May 2008. Cambridge, UK, Cambridge University Press. 61-63.

184. **Santos, J.A., Malheiro, A.C., Pinto, J.G., Jones, G.V. (2012),** *Macroclimate and viticultural zoning in Europe: observed trends and atmospheric forcing*. Clim. Res., 51, 89–103.

185. Santos, J.A., Grätsch, S.D., Karremann, M.K., Jones, G.V., Pinto, J.G. (2012a), *Ensemble projections for wine production in the Douro Valley of Portugal*. Clim Chang. doi:10.1007/s10584-012-0538-x

186. Santos, J.A., Malheiro, A.C., Karremann, M.K., Pinto, J.G. (2011), *Statistical modelling of grapevine yield in the Port Wine region under present and future climate conditions*. Int. J. Biometeorology, 55 (2), 119–131. DOI: 10.1007/s00484-010-0318-0.

187. Schlenker, W., Roberts, M.J. (2009), *Nonlinear temperature effects indicate severe damages to US crop yields under climate change*. Proceedings of the National Academy of Sciences, USA 106, 15594–15598.

188. Schmidhuber, J., Tubiello, F. (2007), *Global food security under climate change*. Proc. Natl. Acad. Sci. USA, 104, 19703–19708.

189. Schneider, S.H., Semenov, S., Patwardhan, A. et al. (2007), *Assessing key vulnerabilities and the risk from climate change*. In: Parry ML et al. (eds.) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 779–810.

190. Scholtz, M., McManus, C., Leeuw, K., Louvandini, H., Seixas, L., Melo, C., Theunissen, A., Neser, F. (2013), *The effect of global warming on beef production in developing countries of the southern hemisphere. Natural Science*, 5, 106-119. DOI: 10.4236/ns.2013.51A017.

191. Scholtz, M.M. et al. (2010), *Environmental-genotype responses in livestock to global warming: A Southern African perspective*. South African Journal of Animal Science, 40, 408-413. http://www.sasas.co.za/journals/2010/5.

192. Schultz, H.R. Jones, G.V. (2010), *Climate induced historic and future changes in viticulture*. Journal of Wine research, 21, 137-145.

193. Schultz, H.R., Jones, G.V. (2008), *Veranderungen in der Landwirtschaft am Beispiel des Weinanbaus,* in: J.L. Lozan, H. Graßl, G. Jendritzky, L.karbe and K. Reise (eds.). Warnsignal Klima: Gesundheitsrisiken, Gefahren für Pflanzen, Tiere, und Menschen. Frankfurt: GEO-Wissenschaftliche Auswertungen, pp. 268-272.

194. Spellman, G. (1999), *Wine, weather and climate*. Weather, 54, 230–239.

195. Spellman, G., Scollan, N. Hocquette, J.F., Nuernberg, K., Dannenberger, D., Richardson, I., Moloney, A. (2006), *Innovations in beef production systems that enhance the nutritional and health value of beef lipids and their relationship with meat quality*. Meat Science, 74, 17–33.

196. Semenov, M.A., Shewry, P.R. (2011), *Modelling predicts that heat stress, not drought, will increase vulnerability of wheat in Europe*. Science Report, 1, 66. DOI: 10.1038/srep00066.

197. Semenov, M.A. (2009), *Impacts of climate change on wheat in England and Wales*. Journal of the Royal Society Interface, 6(33), 343-350.

198. Semenov, M.A. (2007), *Development of high-resolution UKCIP02-based climate change scenarios in the UK*. Agric. For. Meteor., 144, 127–138.

199. Semenov, M.A., Barrow, E.M. (1997), *Use of a stochastic weather generator in the development of climate change scenarios*. Clim Change, 35, 397–414.

200. Seo, S.N., Mendelsohn, R. (2008), *A structural ricardian analysis of climate change impacts and adaptations in African agriculture*. Policy Research Working Paper Series 4603, World Bank. https://openknowledge.worldbank.org/bitstream/WPS4603.txt

201. Siebert, S., Ewert, F. (2012), *Spatio-temporal patterns of phenological development in Germany in relation to temperature and day length*. Agricultural and Forest Meteorology, 152, 44-57.

202. Smith, P., Olesen, J.E. (2010), *Synergies between mitigation of, and adaptation to, climate change in agriculture*. Journal of Agricultural Science, 148(5), 543-552.

203. Soussana, J.F., Graux, A.I. Tubiello, F.N. (2010), *Improving the use of modelling for projections of climate change impacts on crops and pastures*. Journal of Experimental Botany, 61(8), 2217–2228. DOI:10.1093/jxb/erq100

204. Southworth, J., Pfeifer, R.A., Habeck, M., Randolph, J.C., Doering, O.C., Rao, D.G. (2002), *Sensitivity of winter wheat yields in the Midwestern United States to future changes in climate, climate variability, and CO_2 fertilization*. Climate Res., 22, 73–86.

205. Stöckle, C.O., Donatelli, M., Nelson, R. (2001), *CropSyst, a cropping systems simulation model*. European Journal of Agronomy, 18, 289–307.

206. Supit, I., van Diepen, C.A., de Wit, A.J.W., Kabat, P., Baruth, B., Ludwig, F. (2010), *Recent changes in the climatic yield potential of various crops in Europe*. Agricultural Systems, 103, 683-694.

207. Taranu, L, Mironova, T., Mleavaia, G. (2014), *Projections of changes in agroclimatic conditions in the Republic of Moldova according to an ensemble from 10 GCMs for SRES A2, A1B and B1 emission scenarios in the XXI century*. Proceedings of the International Conference ADAPTtoCLIMATE", Nicosia, Cyprus, 27-28 March 2014.

208. Taranu, L. (2014), *Climate change impacts on main agriculture crops in the Republic of Moldova*. Proceedings of the International Conference ADAPTtoCLIMATE", Nicosia, Cyprus, 27-28 March2014.

209. Taranu, L. (2013), Climate Change and Agroclimatic Conditions in the Republic of Moldova. Communication I: Temperature-Based Indices. Mediul Ambiant. Nr.5 (71), P.33-43.

210. Taranu, L. (2013), *Projections of Changes in Productivity of Major Agricultural Crops in the Republic of Moldova According to an Ensemble from 10 GCMs for SRES A2, A1B and B1 Emission Scenarios in the XXI century*. Mediul Ambiant. Nr.4 (70), P.27-37.

211. 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, 3 (63), 33-42.

212. Tardieu, F. (2012), *Any trait or trait-related allele can confer drought tolerance: just design the right drought scenario. Journal of Experimental Botany,* 63(1), 25-31.

213. Thomson, A.M., Brown, R.A., Rosenberg, N.J., et al. (2005), *Climate change impacts for the conterminous USA: an integrated assessment—part 3 dry land production of grain and forage crops*. Clim. Change, 69, 43–65.

214. Tonietto, J., Carbonneau, A. (2004), *A multicriteria climatic classification system for grape-growing regions worldwide*. Agric. For Meteorology, 124, 81–97.

215. Trnka, M., Olesen, J.E., Kersebaum, K.C., Skjelvåg, A.O., Eitzinger, J., Seguin, B., Peltonen-Sainio, P., Rötter, R., Iglesias, A., Orlandini, S., Dubrovský, M., Hlavinka, P., Balek, J., Eckersten, H., Cloppet, E., Calanca, P., Gobin, A., Vučetić, V., Nejedlik, P., Kumar, S., Lalic, B., Mestre, A., Rossi, F., Kozyra, J., Alexandrov, V., Semerádová, D., Žalud, Z. (2011), *Agroclimatic conditions in Europe under climate change*. Global Change Biology, 17(7), 2298-2318. doi:10.1111/j.1365-2486.2011.02396.x.

216. Trnka, M., Eitzinger, J., Semerádová, D., Hlavinka, P., Balek, J., Dubrovský, M., Kubu, G., Štěpánek, P., Thaler, S., Možný, M., Žalud, Z. (2011), *Expected changes in agroclimatic conditions in Central Europe*. Climatic Change, 108, 261–289. doi: 10.1007/s10584-011-0025-9.

217. Trnka, M., Kocmánková, E., Baleka, J., Eitzinger, J., Ruget, F., Formayer, H., Hlavinka, P., Schaumberger, M., Horáková, V., Možný, M., Žaluda, Z. (2010), *Simple snow cover model for agrometeorological applications*. Agricultural and Forest Meteorology, 150, 1115-1127.

218. Tsuji, G.Y., Uehara, G., Balas, S. (1995), *DSSAT v3*. Honolulu: University of Hawaii.

219. Tubiello, F.N., Fischer, G. (2007), *Reducing climate change impacts on agriculture: global and regional effects of mitigation, 2000–2080*. Technological Forecasting and Social Change, 74, 1030–1056.

220. Tubiello, F.N., Rosenzweig, C., Goldberg, R.A., et al. (2002), *Effects of climate change on US crop production: simulation results using two different GCM scenarios. I. Wheat, potato, maize, and citrus*. Climate Research, 20, 259–270.

221. van Leeuwen, C., Friant, P., Choné, X., Tregoat, O., Koundouras, S., Dubordieu, D. (2004), *Influence of climate, soil, and cultivar on terroir*. Am. J. Enol. Vitic., 55(3), 207–217.

222. Van der Fels-Klerx, H.J., van Asselt, E.D., Madsen, M.S., Olesen, J.E. (2013), *Impact of Climate Change Effects on Contamination of Cereal Grains with Deoxynivalenol*. PLoS ONE 8(9), e73602. doi:10.1371/journal.pone.0073602

223. Ventrella, D., Charfeddine, M., and Bindi, M. (2012), *Agronomic adaptation strategies under climate change for winter durum wheat and tomato in southern Italy: irrigation and nitrogen fertilization*. Regional Environmental Change, 12(3), 407-419.

224. Wallach, D., Makowski, D., Jones, J. (2006), *Working with dynamic crop models: evaluation, analysis, parameterization, and applications*. Amsterdam, the Netherlands: Elsevier, 462p.

225. West, J.W., Mullinix, B.G., Bernard, J.K. (2003), *Effects of Hot, Humid Weather on Milk Temperature, Dry Matter Intake, and Milk Yield of Lactating Dairy Cows*. Journal of Dairy Science, 86, 232–242.

226. Wheeler, T.R., Craufurd, P.Q., Ellis, R.H. et al. (2000), *Temperature variability and the yield of annual crops*. Agric. Eco. Environ. 82, 159–167.

227. White, M.A., Diffenbaugh, N.S., Jones, G.V., Pal, J.S., Giorgi, F. (2006), *Extreme heat reduces and shifts United States premium wine production in the 21st century*. Proc Natl Acad Sci USA 103:11217–11222.

228. **White, M.A., Whalen, P., Jones, G.V. (2009),** *Land and wine*. Nature Geoscience, 2, 82-84.
229. **Williams, J.R. (1995),** *The EPIC model*. In: Singh VP, ed. Computer models of watershed hydrology. Highlands Ranch: CO Water Resources Publications.
230. **Winkler, A.J., Cook, J.A., Kliewer, W.M., Lider, L.A. (1974),** *General viticulture*. University of California Press, Berkeley.
231. **Wit, A.J.W. Boogaard, H.L., van Diepen, C.A. (2005),** *Spatial resolution of precipitation and radiation: The effect of regional crop yield forecasts*. Agric. For. Meteor., 135, 156–168.
232. **Wolf, J., Van Oijen, M. (2003),** *Model simulation of effects of changes in climate and atmospheric CO_2 and O_3 on tuber yield potential of potato (cv. Bintje) in the European Union*. Agriculture, Ecosystems and Environment, 94, 141–157.
233. **Wolfe, M.J. et al. (2008),** *Developments in breeding cereals for organic agriculture*. Euphytica, 163, 323-346. DOI:10.1007/s10681-008-9690-9_
234. **Wolfe, D.W., Ziska, L., Petzoldt, C., Seaman, A., Chase, L., Hayhoe, K. (2008),** *Projected change in climate thresholds in the Northeastern U.S.: implications for crops, pests, livestock, and farmers*. Mitigation and Adaptation Strategies for Global Change, 13, 555-575.
235. **Xiong, W., Matthews, R., Holman, I., Erda, L., Xu, Y. (2007),** *Modelling China's potential maize production at regional scale under climate change*. Climatic Change, 85, 433–451.
236. **Yahdjian, M.L., Sala, O.E. (2008),** *Climate change impacts on South America Rangelands*. Rangelands, 30(3), 34-39. DOI:10.2111/1551-501X(2008)30[34:CCIOSA]2.0.CO;2
237. **Дарадур, М.И. (2001),** *Изменчивость и оценки риска экстремальных условий увлажнения*. Кишинев, 160 р.
238. **Коробов, Р., Чалык, С., Буюкли, П. (2004),** *Оценка чувствительности растениеводства к возможному изменению климата*. В кн.: Климат Молдовы в XXI веке: проекции изменений, воздействий, откликов. Кишинев, 213 – 253.