OBSERVED AND PROJECTED CLIMATE CHANGE AND ITS IMPACT ON ECOSYSTEMS' PRODUCTIVITY IN FOREST-STEPPE AND STEPPE ZONES OF RUSSIA AND NEIGHBORING (FSU) COUNTRIES

NICOLAY DRONIN[*], NATALIA TELNOVA[**], ANDREY KIRILENKO[***],
ELENA MILANOVA[****], NATALIA KALUTSKOVA[*****]

Key-words: FSU region, current and future climate, impacts of climate change on agriculture, biological productivity, NDVI.

Abstract. The paper compares model projections of climate change in the main grain-producing region of Eastern Europe with currently observed climate change and its impact on biological productivity of ecosystems. Spatial pattern comparable analysis of some climate variables and NDVI time series proves projections of aridization of the forests-steppe and steppe zones for the whole region with some exclusion for the territories experienced local increase of precipitation or better land management. The study confirms continuing aridization of the forest-steppe and steppe zone of the FSU region during the 2000s.

1. INTRODUCTION

Although economic and institutional changes have been probably the dominant factor influencing the agricultural sector in post-Soviet transitional economies, agricultural production is also highly sensitive to inter-annual climate variability and in general to climate change. Generally, the geography of agriculture of the Former Soviet Union (FSU) follows two climatic factors: temperature and summer precipitation. According to the majority of GCM projections, these factors will be significantly modified in the future (Table 1). Compared with the historical climate, the temperature in the FSU region in the 2020s, averaged over the GCM projections, will increase by 1.5°C on average, with higher increase in the South Siberian region. Precipitation demonstrates high variability, with a greater increase in Siberia and the North-West regions, lower increase in the South European region, and a decrease in the Transcaucasia region. In the 2050s, the temperature change in the regions continues to follow this pattern. Annual precipitation will increase by 41–51 mm in the North-West and South Siberian regions, 11–28 mm in the South European regions, and decrease by 22–55 mm in Transcaucasia. Finally, in the 2080s the temperature will increase by 4.5°C on average, following the west-east gradient, with large differences between the regions (Kirilenko, Dronin, 2011). In the North-West region, but not in the South European and South Siberian regions, increasing precipitation will compensate additional evapotranspiration due to higher temperatures. This will lead to aridization of forest-steppe and steppe zones of the FSU countries. As projected indexes of aridity show, Transcaucasia is expected to be the most arid region (Table 1).

[*] Professor, Head of laboratory, Faculty of Geography, Moscow State University, 119991, Russian Federation, Moscow, GSP-1, Leninskie gory, ndronin@gmail.com.

[**] Senior Researcher, Faculty of Geography, Moscow State University, 119991, Russian Federation, Moscow, GSP-1, Leninskie gory, natalia.telnova@gmail.com.

[***] Associate Professor, Department of Earth System Science and Policy, University of North Dakota, USA, Grand Forks, ND 58202-9011, akirilen@aero.und.edu.

[****] Associate Professor, Faculty of Geography, Moscow State University, 119991, Russian Federation, Moscow, GSP-1, Leninskie gory, elena.v.milanova@gmail.com.

[*****] Associate Professor, Faculty of Geography, Moscow State University, 119991, Russian Federation, Moscow, GSP-1, Leninskie gory, nat_nnk@mail.ru.

Rev. Roum. Géogr./Rom. Journ. Geogr., **59**, (2), p. 91–100, 2015, București.

In general, these model projections of climate change in the FSU countries match current observations as shown in a study by Kirilenko and Dronin (2011). The best result is found for North-West and Central Russia. Moldova and Transcaucasia (Armenia, Georgia, Azerbaijan) shows deterioration of climate conditions in compliance with GCM projections (Table 1). However, in Ukraine, Northern Caucasus (South European region), South Siberian region and Northern Kazakhstan climate changes seem not to be matching well with GCM projections.

Table 1

Current (C) and future climate for four regions of the Former Soviet Union countries: mean annual temperature, annual precipitation, and two indexes of aridity.
Adapted from (Dronin, Kirilenko, 2011)

Base and projected climatic parameters	North-west (Baltic, Belarus, North-western Russia)	South European (Moldova, Ukraine, south of European Russia)	South Siberian (south of Western Siberia, northern Kazakhstan)	Transcaucasia (Armenia, Georgia, Azerbaijan)
Mean temperature, °C:				
1961–1990	6.0	6.5	1,3	10.5
2020s	7.3–7.5	7.9–8.2	2.9–3.2	11.9–12.1
2050s	8.2–9.1	9.3–9.8	4.5–5.0	13.2–13.7
2080s	9.7–11.1	10.4–12.0	5.7–7.4	14.3–15.8
Precipitation, mm				
1961–1990s	629	541	405	565
2020s	649–659	551–558	425–429	540–551
2050s	671–680	564–570	438–454	510–543
2080s	670–711	574–582	448–486	483–537
Index of aridity AIU				
1961–1990	1.0	0.69	0.53	0.54
2020s	0.95–0.97	0.64–0.65	0.51–0.52	0.47
2050s	0.89–0.95	0.59–0.62	0.49–0.50	0.4–0.44
2080s	0.84–0.93	0.54–0.60	0.41–0.49	0.34–0.49
Index of aridity AIT				
1961–1990	0.44	0.57	0.61	0.63
2020s	0.45	0.60–0.61	0.62	0.66–0.67
2050s	0.45–0.47	0.61–0.62	0.63–0.64	0.69–0.71
2080s	0.46–0.49	0.62–0.65	0.64–0.65	0.70–0.75
Growing degree days base 10 °C				
1961–1990	836	1190	914	1713
2020s	1000–1029	1414–1449	1124–1154	2025–2081
2050s	1140–1267	1587–1761	1282–1448	2262–2488
2080s	1246–1612	1722–2194	1410–1858	2442–3046

Remark to Table 1. AIU is calculated according to formula = P/PET, where PET is either average monthly or annual evapotranspiration (mm) and P (mm) is the average monthly or annual precipitation (UNEP, 1992). For example, the dry subhumid zone is characterized by $0.5<AIU<0.65$ and semiarid – $0.2<AIU<0.5$. AIT is calculated according to formula =100*d/n where water deficiency *d* is calculated as the sum of the monthly differences between precipitation and potential evapotranspiration for those months when the normal precipitation is less than normal evapotranspiration; and where *n* stands for the sum of monthly values of potential evapotranspiration in deficient months. The higher AIT value (>0.65) the drier weather conditions prevailing in the region. The difference of the values of parameters for each region and period is due to the use of different scenarios (A1FI, A2, and B1). Each of the values is a weighted mean of the values in all the cells inside the region, with the weights equal to the percentage of the cell under crops. The results were then averaged across five GCMs.

The continental climate of the Central Eurasian grain belt results in volatile weather conditions for grain production, especially in terms of rainfall and productivity of grain crops (winter wheat in the European part of Russia and Ukraine and spring wheat and barley in Kazakhstan and Russia east of the Volga River) strongly depends on spring and summer precipitation, which is particularly important during the critical phases of wheat growth, such as bushing and earring. GCMs project decreasing moisture in the forest-steppe and steppe zones caused by too high increase of temperature which would not be compensated by precipitation growth. In the meantime, many authors pointed out that current climate changes are rather favorable to agricultural production in the steppe and forest-steppe belt. Even with increasing temperatures, some observations show "greening" of some parts of the region in recent years. In Ukraine and the south of Western Siberia, this greening is likely to be caused not by precipitation (which has decreased), but by other meteorological factors such as increased cloudiness in Ukraine (Robock *et al.*, 2005) and change of wind regime in Western Siberia (Akhmadieva, 2007). Higher yields in Kazakhstan confirm continuous improvement of farming conditions, whether they relate to climate or management (DeBeurs, Henebry, 2004; Kharin *et al.*, 1998, 2004; Lioubimtseva, Henebry, 2009). Ashabokov *et al.* (2008) showed that in Northern Caucasus and especially in Low Volga, precipitation has increased significantly. Compared to 1955–1971, mean annual precipitation in 1989–2004 increased by 68.5 mm (10%) with a corresponding increase in minimum and maximum annual precipitation. This increase of precipitation is observed in winter, summer, and autumn, while spring precipitation are decreasing (Ashabokov, Bischokov, Derkach, 2008). Similarly, Badakhova *et al.* (2008) observed a 10–50% increase in annual precipitation in Northern Caucasus for the last decade as compared to 1961–1990. At the majority meteorological stations in the region, air humidity has also increased following the north – south gradient, from drier zone to humid zone, so that the humid areas have become even more humid. Increasing precipitation compensate and even over-compensate increasing evapotranspiration due to higher temperature during the growth period over a large part of the region (Ibid.) According to (Strategic prediction, 2005), the climate-related component of cereals yield in Stavropol region (Northern Caucasus) increased by 30% over the past 20 years (1985–2005). The improved growing conditions of cereals were observed in many regions with significant increases in winter and smaller ones in summer air temperatures (Strategic prediction, 2005). The authors of the report warn that, despite these improvements, increased precipitation in the near future will no longer compensate for higher potential evapotranspiration and drier climate will lower crop yields (Strategic prediction, 2005).

The forest-steppe and steppe belt is "the grain-basket" of Ukraine, Russia and Kazakhstan. The three countries have recently reemerged as leading grain exporters due to share in the global grain exports increasing from 1% in 1991 to 18% in 2013 (Liefert *et al.*, 2013; FAOSTAT, 2013). Understanding climate change impacts on the future productivity of this region is essential for predicting their future potential as a major grain supplier. Official expectations of grain exports in the three countries are very high, despite numerous projections about oncoming aridization in the major grain producing belt (Lioubimtseva, Dronin, Kirilenko, 2015). In order to understand to what extent climate change models are reliable tools for predicting future yields in the belt, it is important to investigate closely the character of recent productivity dynamic of agricultural lands on the basis of a unified approach to the entire zone. An applied comparable spatial and time series analysis of climate variables and NDVI is unified and valuable approach to studying current climate changes and the ecosystem's response to them. This approach allows to unite and verify rather discrete assumptions about oncoming climate change in FSU region and available reactions of the ecosystems' productivity.

2. DATA AND METHODS

In the forest-steppe and steppe zones of the FSU, precipitation is the primary limiting factor of biological productivity, especially on a continental scale. That is perennial changes in the ecosystems' productivity over the entire region can be used as a proxy for climate changes.

For spatial analysis of current climate changes in the study region we used two variables, extracted from NOAA PSD gridded climate database (http://www.esrl.noaa.gov/psd/data/gridded). Self-calibrated Palmer Drought Severity Index (PDSI), measured in relative units, was calculated from monthly NCAR reanalysis data with spatial resolution of 2.5 degrees. Gridded GPCC annual precipitation at a 0.5 degree resolution was extracted from monthly observations (Shneider *et al.*, 2011). The time-series analysis of these climatic variables for the 2000–2010 period was conducted with the Theil-Sen slope estimator, which is more reliable than the conventional simple linear regression for short, skewed, and/or noisy time series (Hoaglin *et al.*, 2000). The trend of PDSI (relative units per year) and precipitation (mm per year) are presented in Figs 1 and 2.

The normalized differenced vegetation index (NDVI) is frequently used as a proxy for biological productivity and as an indicator of land use and land cover (LULC) change. In particular, the total ecosystem production can be discerned from the annual sum NDVI or the growing period sum NDVI (Bai *et. al.*, 2008); the annual sum NDVI is more reliable for semiarid regions (Fensholdt, Rasmussen, 2012). For the analysis of NDVI time series, we used the MOD13A3 dataset of a 30-day maximum value NDVI composites (Huete *et al.*, 2002), gridded at a 1 km resolution and extracted for the period of February 2000 to December 2010. The significance of trend in each cell of the grid was determined using the Mann-Kendall trend test, which allows to estimate both trend significance and direction (Neeti, Eastman, 2011); 95% and 90% significance levels were treated as high and low significance of an observed trend (Fig. 3). The spatial patterns of trends in climate variables were then compared with spatial distribution of the sum of NDVI trends for the same period (Fig. 4).

3. RESULTS

Our study of changes in climate and biological productivity confirms continuing aridization of the forest-steppe and steppe zone of the FSU during the 2000s. The main centers of climate aridization in terms of decrease in PDSI are located in eastern Ukraine, Lower Don, middle section of the Volga River, and Ural River basins, and especially in Northern Kazakhstan (Fig. 1). During the same time period, in parts of Ukraine and European Russia (South of Ukraine, Eastern Caucasus) climate was more favorable with increasing precipitation and corresponding increase in PDSI (Fig. 2).

In response to these climate changes, ecosystem production also changed, which was observed as a long-term NDVI trend (Fig. 3). The most pronounced negative NDVI trends, associated with frequent droughts and aridization, were observed in the Don and Volga watersheds, the middle Ural River basin and in Western Kazakhstan, similar to other studies of droughts in the Caspian Sea region (Zolotokrylin *et al.*, 2014) and Northern Kazakhstan (Spivak *et al.*, 2008).

The changes in precipitation and sum NDVI in the 2000s were negative in the wide and long belt spreading from the middle section of the Dnepr River to north-east Kazakhstan, i.e. through the whole steppe region of Eastern Europe and Central Asia (Fig. 4). Mismatching of NDVI and precipitation trends in eastern Ukraine with decrease of sum annual NDVI in the 2000s under precipitation growth can be explained by the changes in land-use patterns, i.e. sprawling of arable lands replacing the fallows and grasslands from the mid-2000s. On the contrary, the northernmost part of central Kazakhstan and adjoining parts of Western Siberia experienced biomass growth with decreasing precipitation, evidently due to change in LULC and agricultural management, with arable lands abandoned shifting to fallows or pastures (Kraemer *et al.*, 2015) leading to biomass growth reflected in a higher sum NDVI.

Finally, in Northern Caucasus the significant aridization of its western part coincides with higher humidity in the eastern part and the North West Caspian Sea region. The last two territories experienced growth of green biomass, mainly due to changing climate (Fig. 4).

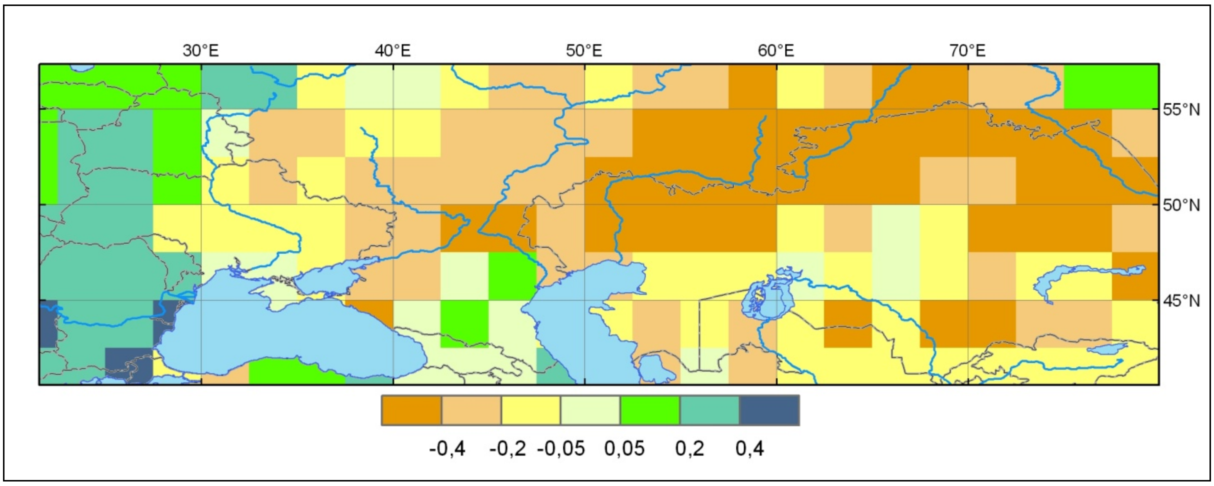

Fig. 1 – PDSI change (relative units per year) for the 2000–2010 period, computed with Theil-Shen slope estimator. Scale 1:35 000 000.

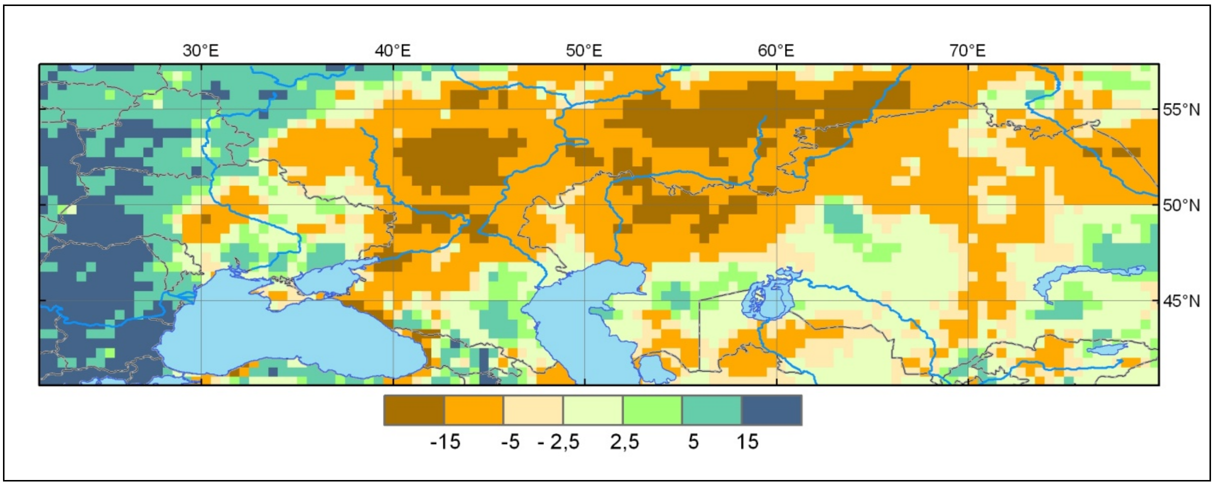

Fig. 2 – Precipitation change (mm/yr) for the 2000–2010 period, computed with Theil-Shen slope estimator. Scale 1:35 000 000.

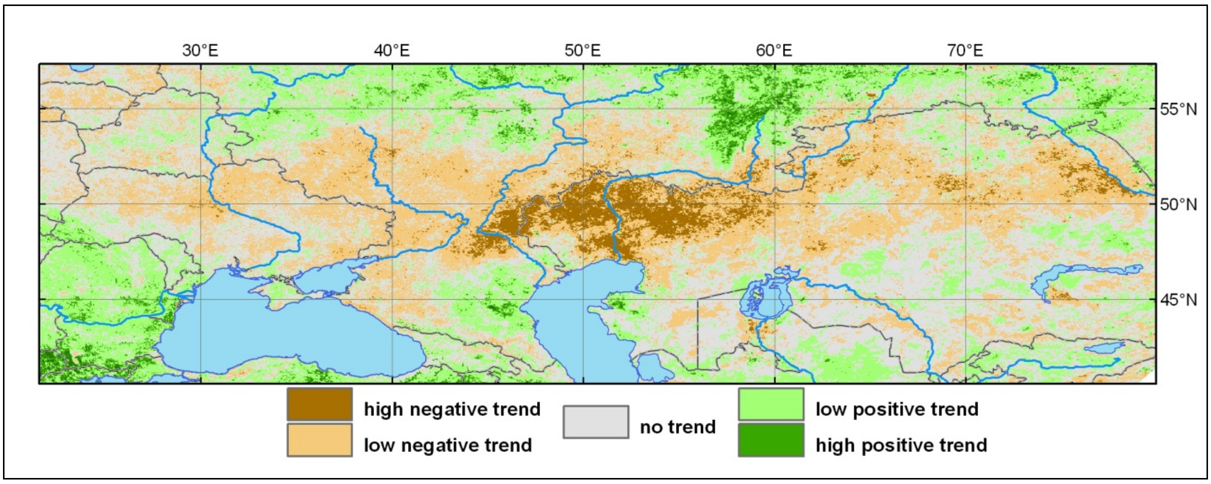

Fig. 3 – Direction and significance of trends in annual NDVI sum for the 2000–2010 period (based on Mann-Kendall trend test). Scale 1:35 000 000.

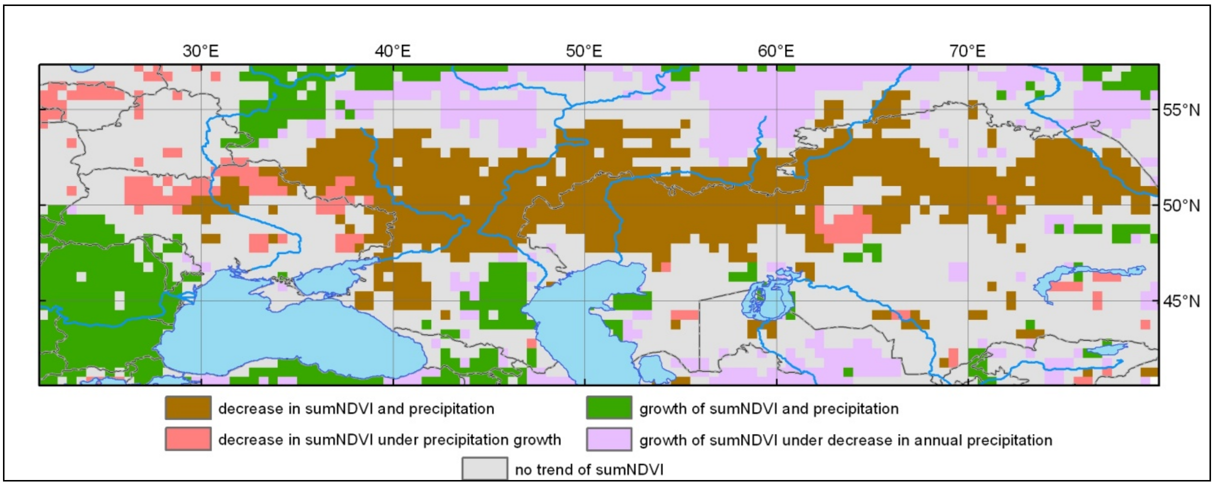

Fig. 4 – Direction of simultaneous changes in annual precipitation and annual sum NDVI for the 2000–2010 period. Grid size is resampled to 1 decimal degrees. Scale 1:35 000 000.

4. DISCUSSION

Our findings support a study of the agricultural conditions and NDVI trends in the grain belt between 2001 and 2010 by Wright *et al.* (2012), which found significant negative NDVI trends prevailing in the Eurasian grain belt. In the southern grain belt range, the pattern of increasing greenness was rather associated with agricultural abandonment (cropland to grassland) coinciding with statistically significant negative NDVI trends and likely driven by regional drought. In the northern range of the grain belt an opposite tendency toward agricultural intensification was observed. In this case the cropland mosaic was converted to pure cropland, and this is also associated with statistically significant negative NDVI trends. The severe drought which hit Russia in 2010 was not the main cause of the overall negative trend of NDVI as a similar study (de Beurs *et al.*, 2009) made for 2001–2008 revealed approximately the same geography of the negative trend of NDVI as presented in Figure 3.

The main driving force of decreasing productivity of the agricultural lands and grasslands of the grain belt was deterioration of the moisture regime. In our study, 46% of the belt experienced decrease of NDVI and precipitation and only 5% was characterized by increased NDVI and precipitation. There is a minor portion of lands where temperature growth was too higher to be compensated by increasing precipitation (as suggested by many models). We found only 3% of such an area which showed a decrease of NDVI with higher precipitation. However, it could also be explained by conversion of abandoned lands into crop areas, but not deterioration of the climate caused by a too great temperature increase. The area of the positive trend of aridity (measured by PDSI) coincided with the negative trend of precipitation (Figs 1, 2). Most of the area which shows the increase of NDVI with lower precipitation is located north of the belt, being represented mostly by forested lands (Fig. 4). Thus we discovered that precipitation change played a major role in the productivity dynamic of the belt in the 2000s. Zolokrylin and Cherenkova (2014) argued that, beginning of the 1990s, was a reverse in the long-term trend of the grain belt moisture regime took place. From the 1930s to 1990 the moisture regime showed a steady growth with a peak in the early 1990s. Since the 1990s an opposite trend was observed. Deterioration of the moisture regime (measured by indexes of aridity) was first seen in the west-northern part of the grain belt, subsequently spreading to the central and eastern parts of the belt. The only exception is the eastern part of Siberia adjoining the Kazakhstan border (Altai region), where some growth of precipitation is still noted. In northern Kazakhstan the majority of meteorological stations show a significant negative trend of precipitation during 2000–2007 despite some earlier publications about a better moisture regime of the country's grain belt (Wright *et al.*, 2009).

The complex character of observable dynamic of precipitation and bioproductivity can be explained by atmospheric circulation in the northern hemisphere. Current climate changes in the northern hemisphere are mostly associated with more intense activity of the North-Atlantic Oscillation (NAO) (Hurrell *et al.*, 2003). The increasing frequency trend of NAO positive phase during the last 30 years looks unprecedented for the entire period of observation (Visbeck *et al.*, 2001). A strong negative correlation between NAO index and the sum of winter temperatures proves that global atmospheric circulation across Northern Atlantic region determines winters weather conditions in the Baltic states, North-Western and Central parts of Russia (Klavins *et al.*, 2009; Tooming, Kadaja, 2006). Low intensity of NAO could bring colder winters and hotter summers. Wright *et al.* (2010) argue that the Russian heat wave of 2010 was caused by anomalous weakening of NAO never seen for the last 60 years.

Observable transformation of the climate in the south-western part of the region (Moldova) is also associated with intense NAO. The positive phase of NAO is characterized by fewer winter precipitation in the Mediterranean (Hurrel, 1995; Marshall *et al.*, 2001). Although decrease of precipitation is mostly seen in the western part of the Mediterranean, many countries of Central and Southern Europe experienced fewer winter precipitation when NAO intensified (Krichak, Alpert, 2005). For Romania, correlation of the two parameters is as stronger as –0.6 (Tomozeiu *et al.*, 2005; Stefan *et al.*, 2004). As for summer precipitation some authors suggest that although NAO is much weaker it still negatively impacts the moisture regime in the south of Europe (Wang *et al.*, 2010).

Climate change in the Transcaucasian region (Armenia, Georgia and Azerbaijan) is much more complex in terms of atmospheric circulation. However, even for this region the current increase of temperature and decline of precipitation are associated with stronger NAO (Shahgedanova *et al.*, 2007; Shahgedanova *et al.*, 2009). For example, neighboring Turkey experienced a decline of winter precipitation during the last 20–30 years which coincided with the positive phase of NAO. The correlation between NAO and the moisture regime of Turkey reaches –0.52, while links with other circulation systems (Southern Oscillation, Asian monsoons) was not apparent (Cullen *et al.*, 2002). Only weakening of the Siberian Anticyclone is recognized to have some impact on winter precipitation (Komuscu, 2001).

However, the influence of NAO is much weaker for the belt spreading from Northern Caucasus to south of Western Siberia and northern Kazakhstan than in Central and Western Russia (deBeurs, Henebry, 2004). Weather conditions in winter are mostly associated with the impact of the vast Siberian Anticyclone (SA) centered in Eastern Siberia. The study (Gong, Wang, 2002) shows that SA intensity has been decreasing during the last 30 years. The highest intensity of the anticyclone was observed in the 1960s. Afterward the SA would weaken, especially, at the end of the 1980s. During the 1990s, weakening of SA had an unprecedented character. The analysis of data for the last hundred years shows a significant negative correlation (–0.58) between intensity of SA and mean winter temperatures. Standard deviation from the mean value of SA activity is accompanied with a change of mean temperatures by about 0.3°C on the vast territory spreading from Western Siberia to Far East and China. The winter temperature anomaly increased up to 1.5°C (for one standard deviation) in the center of SA (Gong, Wang, 2002). The link between precipitation regime and intensity of SA looks more complex and can change considerably in different sites, even it they are located relatively close each other. On average, one standard deviation from the mean value of SA intensity is accompanied with the increase/decrease of precipitation by 5%. The stronger SA, the fewer precipitation are observed on the territory of interior Eurasia (a correlation of –0.44 over 1922–1998). Especially strong was the influence of SA on precipitation in the Ural Mts., where it could be up or down by 10–15% (Gong, Wang, 2002). The most significant change of precipitation regime is observed at the SA periphery, with a minimum in its center. Local factors can also influence the precipitation regime, making the whole picture complex. There is a problem of accurate measurement of precipitation because of the impact of many local factors (relief peculiarities, attitude, local wind regime and others) (Gong, Wang, 2002). All these factors make the projection of precipitation change a very complicated task, especially, for the south of western Siberia. Perhaps the largest uncertainty of precipitation regime change exists for the Northern Caucasus because of its location on the very peripheral zone of SA. Besides, in the Northern Caucasus a convective precipitation is common, which brings a greater bias in model projections (Shahgedanova *et al.*, 2009b).

5. CONCLUSIONS

The FSU region faces significant climate transformation forcing adaptations in the agricultural sector. According to the majority of GCMs and under any SRES climate change scenario, it is highly probable that the forest-steppe and steppe zones, which are the main grain-producing area of the region, will experience an increase of summer temperatures and a slight increase, or even some decrease of summer precipitation. The dryer climate combined with increasing drought frequency will lead to a 6% – 12% potential yield reduction for most of the crops (Alcamo *et al.*, 2007). In the current period, restorating agriculture in Russia, Ukraine and Kazakhstan can hide ongoing deterioration of climatic conditions in the grain production belt. Overall, our study supports projections of aridization of the forests-steppe and steppe zones. However, aridization is rather the result of declining precipitation than of rising temperature (as was projected by many models). Besides in some areas such as Eastern Caucasus and partly in northern Kazakhstan, observed changes are more favorable in terms of ecosystem productivity than the projection shows. The greening observed in these areas reflects local increases of precipitation, better management and/or decreasing pressure on pastures. These parts are characterized by a large uncertainty of moisture regime projections because of their location at the periphery of major atmospheric circulation systems.

REFERENCES

Akhmadieva, Z.K. (2007), *Climate change and possible changes in the water regime of crops in Northern Kazakhstan*. In: Proceedings of the NATO Advanced Research Workshop on environmental problems of Central Asia and their economic, social and security impacts. Ed. By Qi, J., and Evered, T.K. Springer.

Alcamo, J., Dronin, N., Endejan, M., Golubev, G., Kirilenko, A. (2007), *A new assessment of climate change impacts on food production shortfalls and water availability in Russia*. Global Environmental Change, **17**(*3*), pp. 429–444.

Ashabokov, B.A., Bischokov, R.M., Derkach, D.V. (2008), *Study of changes in the regime of atmospheric precipitation in the Central Northern Caucasus*. Russian Meteorology and Hydrology. **33**(*2*), pp. 125–129.

Badakhova, G.Kh., Kaplan, G.L., Knutas, A.V. (2008). *Agriculture adaptation of the south region of Russia to conditions of present climate change*.8th Annual meeting of the EMS / **7**th ECAC, *5*.

Bai, Z. G., Dent, D. L., Olsson, L., Schaepman, M. E. (2008), *Proxy global assessment of land degradation*. Soil Use and Management, **24**, 2008, pp. 223–234.

Cullen, H.M., Kaplan, A., Arko, R., deMenocal, P.B. (2005) *Impact of the North Atlantic Oscillation on middle eastern climate and streamflow.* Climate Change, **V**.*55*, pp. 315–338.

De Beurs, K.M., Henebry, G.M. (2004) *Land surface phenology, climatic variation, and institutional change: analyzing agricultural land cover change in Kazakhstan*. Remote Sensing of Environment, **89**, pp. 497–509.

De Beurs K.M., Wright, C.K., Henebry, G.M. (2009) *Dual scale trend analysis for evaluating climatic and anthropogenic effects on the vegetated land surface in Russia and Kazakhstan*. Environ. Res. Lett. **4** (2009) 045012, 11 pp. doi:10.1088/1748–9326/4/4/045012.

FAOSTAT (2013), *Food and Agriculture Organization Statistics*. http://www.fao.faostat.org, last access December 2014.

Fensholdt, R., Rasmussen, K. *et al*. (2012) *Greenness in semi-arid areas across the globe 1981–2007 – an Earth Observing Satellite based analysis of trends and drivers*/ Remote sensing of environment, 2012, **121**, pp. 124–158.

Gong, D. Y., Wang, S. W. (2002), *Siberian high and climate change over middle to high latitude.* Asia Theoretical and Applied Climatology, **72**, pp. 1–9.

Hoaglin, D. C., Mosteller, F., Tukey, J. W. (2000), *Understanding robust and exploratory data analysis*. New York: Wiley.

Huete, A., Didan, K., Miura, T., Rodriguez, E. P., Gao, X., Ferreira, L.G. (2002), *Overview of the radiometric and biophysical performance of the MODIS vegetation indices Remote Sens. Environ.* **83**, pp. 195–213.

Hurrell, J.W., Kushnir, Y., Ottersen, G., Visbeck, M. (2003), *An overview of the North Atlantic Oscillation* //The North Atlantic Oscillation / Eds. Hurrell J.W., Kushnir Y., Ottersen G. and Visbeck M.Geophysical Monograph Series, **134**, pp. 1–35.

Kharin, V.V., Zwiers, F.W. (1998), *Changes in the extremes of the climate simulated by CCC GCM2 under CO2 doubling*. Journal of Climate, **11**, pp. 2200–2222 [Corrigendum].

Kirilenko, A., Dronin, N. (2011), *Climate change and adaptations of agriculture in the countries of the Former Soviet Union.* Yadav, S.S., Redden, B., Hatfield, J.L., Lotze-Campen, H., Hall, A.E. (eds.) Crop adaptation to changing climates. Wiley-Blackwell, pp. 84–106.

Klavins, M., Briede, A., Rodinov, V. (2009), *Long term changes in ice and discharge regime of rivers in the Baltic region in relation to climatic variability*. Climatic Change. **95**(*3–4*), pp. 485–498.

Komuscu, A.U. (2001), *An analysis of recent drought conditions in Turkey in relation to circulation patterns*. Drought Network News (1994–2001). University of Nebraska – Lincoln, **5–6**.

Kraemer, R., Prishchepov, A.V., Müller, D., Kuemmerle, T., Radeloff, V.C., Dara, A., Terekhov, A., Frühauf, M. (2015). *Long-term agricultural land-cover change and potential for cropland expansion in the former Virgin Lands area of Kazakhstan*. Environmental Research Letters **10**, 054012.

Krichak, S.O., Alpert, P. (2005), *Decadal trends in the east Atlantic–west Russia pattern and Mediterranean precipitation*. Int. J. Climatol. V. **25**, Issue *2*, pp. 183–192.

Liefert, O., Liefert., W, Luebehusen, E. (2013), *Rising Grain Exports by the Former Soviet Union Region. Causes and Outlook.* A Report from the Economic Research Service, USDA, February 2013, WHS-13A-01, February 2013, www.ers.usda.gov.

Lioubimtseva, E., Dronin, N., Kirilenko, A. (2015), *Grain production trends in Russia, Ukraine and Kazakhstan in the context of climate change and international trade*. Climate change and food systems. Global assessments and implications for food security and trade. FAO: Rome, pp. 210–245.

Lioubimtseva, E., Henebry, G.M. (2009), *Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations*. Journal of Arid Environments, **73**(*11*), pp. 963–977.

Marshall, J., Kushir, Y., Battisti, D. *et al.* (2001), *North Atlantic climate variability: phenomena, impacts and mechanisms*. Int. J. Climatol. **21**, pp. 1863–1898.

Neeti, N., Eastman, J.R. (2011). *A Contextual Mann-Kendall Approach for the Assessment of Trend Significance in Image Time Series: A Novel Method for Testing Trend Significance*. Transactions in GIS **15**, pp. 599–611.

Robock, A., Mu, M., Vinnikov, K., Trofimova, I.V., Adamenko, T.I. (2005), *Forty five years of observed soil moisture in the Ukraine: no summer dessication (yet)*. Geophysical Research Letters, v. **32**.

Schneider, U., Becker, A., Finger, P., Meyer-Christoffer, A., Rudolf, B., Ziese, M. (2011), *GPCC Full Data Reanalysis Version 6.0 at 0.5°: Monthly Land-Surface Precipitation from Rain-Gauges built on GTS-based and Historic Data*. DOI: 10.5676/DWD_GPCC/FD_M_V6_050.

Shahgedanova, M., Hagg, W., Hassell, D., Stokes, C.R., Popovnin, V. (2009), *Climate change, glacier retreat, and water availability in the Caucasus region*. In: Jones, A. (ed). Global Threats to Water Security. Springer, Netherlands, pp. 131–143.

Shahgedanova, M., Popovnin, V. Aleynikov, A., Petrakov, D., Stokes, C.R. (2007), *Long-term change, interannual and intra-seasonal variability in climate and glacier mass balance in the central Greater Caucasus*, Russia. Annals of Glaciology, **46**, pp. 355–361.

Spivak, L., Vitkovskaya, I., Batyrbayeva, M. (2008), *Analysis of inter seasonal variations of productivity of vegetative cover of Kazakhstan using temporal remote sensing row*. News of Nat. Acad. of Sci. of Kazakhstan. Phys.-Math. Ser. 2008, **4**, pp. 29–32.

Stefan, S., Ghioca, M., Rimbu, N., Boroneant, C. (2004), *Study of meteorological and hydrological drought in southern Romania from observational data*. Int. J. Climatol, **24**, pp. 871–881.

Strategic prediction for the period of up to 2010–2015 of climate change expected in Russia and its impact on sectors of the Russian national economy. 2005. Roshydromet. Moscow.

Tomozeiu, R., Stefan, S., Busuioc, A. (2005) *Winter precipitation variability and large-scale circulation patterns in Romania*. Theor. Appl. Climatol. 2005. DOI 10.1007/s00704-004-0082-3.

Tooming, H., Kadaja, J. (2006), *Climate changes indicated by trends in snow cover duration and surface albedo in Estonia*. Meteorol.Zeitschrift NF**8**, pp. 16–21.

Visbeck, M., Hurrell, J. W., Polvani, L., Cullen, H. (2001) *The North Atlantic Oscillation. Present, past and future.* PNAS, **98**, pp. 12876–12877.

Wang, G., Dolman, A.J., Alessandri, A. (2010) *European summer climate modulated by NAO-related precipitation 2010*. Hydrology and Earth System Sciences Discussions, **7**, pp. 5079–5097.

Wright, C.K., de Beurs, K.M., Akhmadieva, Z.K., Groisman, P.Y. (2009) *Reanalysis data underestimate significant changes in growing season weather in Kazakhstan.* Environ. Res.Lett.**4**. 045020 (9 pp). doi: 10.1088/1748–9326/4/4/045020.

Wright, C.K., de Beurs, K.M., Henebry, G.M. (2014), *Land surface anomalies preceding the 2010 Russian heat wave and a link to the North Atlantic oscillation.* Envir.Res.Lett. **9**. 124015 (10 pp). doi: 10.1088/1748–9326/9/12/124015.

Zolotokrylin, A.N., Titkova, T.V., Cherenkova, E.A. (2014), *Humidification of drylands in European Russia: The present and future.* Arid Ecosystems, vol. **4**, issue *2*, pp. 49–54.

Received January 31, 2015