The projections of air temperature in the Northern region of Ukraine following the intermediate scenario (RCP 4.5) and the high-end scenario (RCP 8.5)

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SUMMARY

The current climate of Ukraine is characterized by asymmetric warming (more significant in the north than in the south), pronounced in the winter and summer months. There is a dangerous tendency to increase the recurrence of arid conditions in the northern region of Ukraine. There is an arid climate rising every year during the vegetation period in this region. The northern region of Ukraine is the most vulnerable to climate change. The trends in surface air temperature change in the region in the 21st century have been studied using modern RCP-scenarios and the global climate model GFDL-ESM2M. The results of the international project ISIMIP in the form of projections of climatic indicators (daily values) for modern trajectories of greenhouse gas concentrations (RCP 2.6, RCP 4.5 and RCP 8.5), obtained for 171 nodes of the regular climate network with a step 0.5° for the studied and adjacent territories have been used for research. It is established that warming in the region will be formed due to the growth of mean monthly temperatures in winter from 2.6°C in the south to 3.2°C in the north during the period from 2041 to 2070, and from 4.2°C in the south of the region to 5.0°C in the north and 5.2°C in the east of Sumy region at the end of the 21st century. The smallest changes in surface air temperature are expected in the summer. The largest territorial range of temperature changes will be observed in the spring. Autumn will be characterized by the uniformity of the spatial temperature distribution on the territory.

Introduction

The studies of the climate of Ukraine (Hnatiuk, 2016; Didovets et al., 2017; Shevchenko and Snizhko, 2019; Shevchenko et al., 2020a, 2020b) show that in recent decades temperature and other meteorological parameters differ significantly from the values from the normal climatic period 1961 to 1990. The mean annual air temperature for the 1991–2010 increased by 0.8°C when compared with the normal climatic period. There was a redistribution of precipitation by the regions of Ukraine and by seasons.

Since 1991, each next decade in Ukraine has been warmer than the previous one. The mean annual air temperature in 1991–2000 increased by 0.5°C, in 2001–2010 by 1.2°C, in 2011–2019 by 1.7°C. Climatic zones are shifting to the north and west, heat and droughts are becoming more catastrophic, many extreme weather events, which were previously rare, often repeat in unusual seasons and in atypical areas for them. This is due to climate change, which affects crop production, forest condition and water bodies, livestock and fisheries, and so on (Adamenko, 2019). Climate change leads to the expansion of the zone of risky agriculture and even to the desertification of some areas. There is a dangerous tendency to increase the frequency of arid conditions in the zone of sufficient atmospheric humidity, which covers Polissia and the northern areas of the forest-steppe. There is an increase in arid climate in the areas that were previously regarded to sufficient moisture during the vegetatively active period of the year. The area of the humid agroclimatic zone (Polissia) is decreasing. Thus, the northern region of Ukraine is the most vulnerable to climate change from the point of view of climatology.

Method and Theory

The aim of the work is to establish trends in regional climate change in the northern region of Ukraine in the 21st century based on projections of surface air temperature and precipitation using modern RCP-scenarios and the global climate model GFDL-ESM2M. The results of the international project ISIMIP (ISIMIP2b of the second phase of the project) (ISIMIP) in the form of projections of climatic indicators (daily values) for modern trajectories of greenhouse gas concentrations (RCP 2.6, RCP 4.5 and RCP 8.5), built for 171 nodes of the regular climate network with a step of 0.5° for the studied and adjacent areas (Figure 1) have been used for the research.

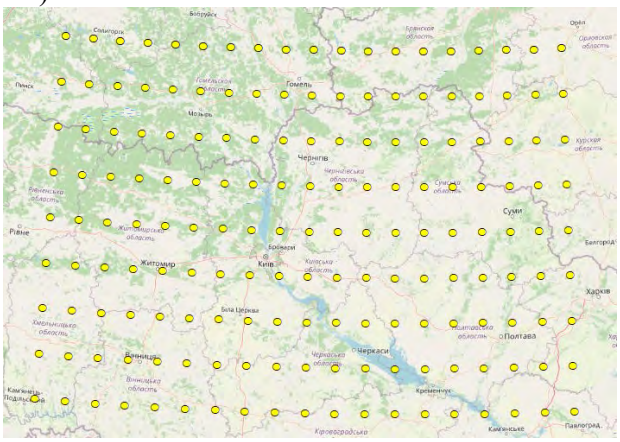


Figure 1 *Location of regular grid points used in the study*

The historical period is represented by simulations from the period from 1861 to 2010, the future period is from 2011 to 2099. All simulations have been prepared on the basis of Atmosphere-Ocean General Circulation Models (AOGCM) with the use of deviation correction based on EWEMBI (Taylor, 2012).

The most ambitious RCP 2.6 scenario with a minimum increase in radiation forcing of 2.6 W/M2 by the end of the century with the earliest peak of greenhouse gas emissions to 2020 has not been used

for forecasting. It became clear in 2018 that measures provided for this scenario to mitigate global warming are not implemented.
The time interval from 1981 to 2010 has been used as a reference time period according to the recommendations of the ISIMIP project. Changes in the climate characteristics of the northern region of Ukraine until 2099 have been determined for this period.
The calculations were performed for all nodes of the calculation grid, covering the entire region and the adjacent territory (171 nodes). The data were calculated in the software package FME Workbench 2018 (Safe Software) according to self-created algorithms.
The change in the relative values of climatic characteristics by seasons of 30-year projection periods (2011–2040, 2041–2070, 2071–2099) regarding to the reference period (1981–2010) has been calculated by the formula:

$$\Delta t = t' - t_0 \qquad (1)$$

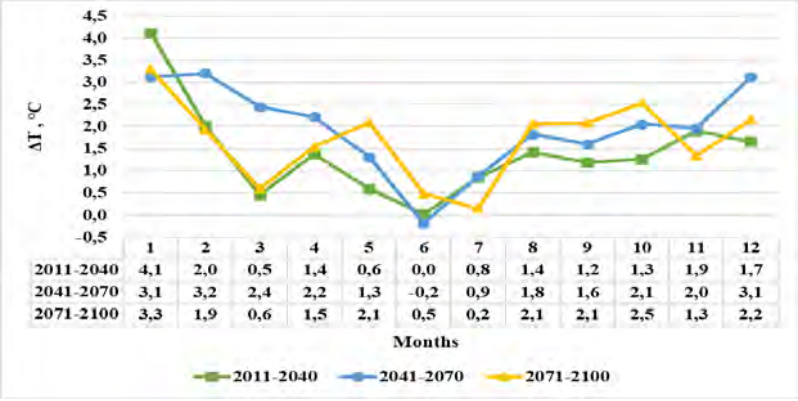
where t' is the value of air temperature for the season of the selected period, t_0 is the value of air temperature for the corresponding season of the reference period.
The change in the relative values of precipitation amounts for the seasons of the 30-year projection periods regarding to the reference period has been calculated by the formula:

$$\Delta r = (\frac{r'}{r_0} \times 100\%) - 100\% \qquad (2)$$

where r' is precipitation amounts for the season of the selected period, r_0 is the precipitation amounts for the corresponding season of the reference period.
The calculated mean monthly, seasonal and certain periods values have been collected in the resulting tables for further visualization and analysis in the software environment ArcMap 10.8 (ArcGIS Online).

Projections of air temperature following the intermediate scenario (RCP 4.5)

Our researches on the intermediate scenario (RCP 4.5) have showed (Figure 2) that in the near future (2011–2040) air temperature will increase in the northern region. The average monthly values of air temperature will rise the most in cold period of the year: in January (by 4.1°C) and in February (by 2.0°C). Changes in the thermal regime will be minimal in warm period of the year: warming up to 0.4°C is expected in most parts of Sumy region and up to 1.1°C in the north of Zhytomyr region.



	1	2	3	4	5	6	7	8	9	10	11	12
2011-2040	4,1	2,0	0,5	1,4	0,6	0,0	0,8	1,4	1,2	1,3	1,9	1,7
2041-2070	3,1	3,2	2,4	2,2	1,3	-0,2	0,9	1,8	1,6	2,1	2,0	3,1
2071-2100	3,3	1,9	0,6	1,5	2,1	0,5	0,2	2,1	2,1	2,5	1,3	2,2

Figure 2 *Projections of changes in mean monthly values of air temperatures in different 30-year periods of the 21st century following the intermediate scenario (RCP 4.5) compared to the base period from 1981 to 2010*

The rest of the territory of the northern region is characterized by a more equitable rise in temperature in the range of 0.6–0.9°C. Temperature changes range from 0.4°C in the southern part of the region to 1.0°C in its northern part and up to 1.1°C in the north-eastern part in the spring season. The minimum

values of air temperature change are observed in the southwest (1.0°C), the maximum values are in the north (1.6°C) and northwest (1.7°C) in autumn. Temperatures are expected to rise from 2.1°C in the southeast to 2.7°C in the north and northwest in winter.
Projections of changes in surface air temperature for the period from 2041 to 2070 indicate unambiguous warming in all months of the year (Figure 2). Unlike the previous period, the maximum value of warming is in February by 3.2°C. The cold season is expected to be much warmer. The smallest changes are forecasted for summer – up to 1.2°C in the south of Kyiv region. The greatest warming will be due to the growth of average monthly temperatures in winter from 2.6°C to 3.2°C in the south and north respectively. The spring season shows a spatial change in values in the range of values from 1.5°C in the southwest of Zhytomyr region to 2.3–2.5°C in the northeast of Sumy region. Autumn is characterized by the smallest amplitude of values in the studied territory from 1.6 °C in the southwest of Zhytomyr region to 2.0°C in most parts of the territory.
The mean annual surface air temperature rise by 1.7 °C (Figure 2) is predicted at the end of the 21st century (2071–2099) following the scenario RCP 4.5 in the region territory. The largest growth is expected in winter, namely by 3.3 °C in January. Spatially, it will increase in winter from 2.2 °C in the southern part and up to 2.6 °C in the north of the region and 2.8 °C in the east of the city of Sumy. In the spring of 2071-2100, air temperature will vary from 1.2 °C in the west and southeast to 1.5 °C in the east and 1.7 °C in the northeast. The amplitude of changes will be smaller in summer, from 0.3 °C in the northeast to 1.4 °C in the south. Temperatures range from 1.7 °C in the south to 2.3 °C in the north in autumn, and from 2.2 °C in the south to 2.7 °C in the north and 2.9 °C in the northeast in winter. There are no significant changes regarding to the previous two periods.

Projections of air temperature following the high-end scenario (RCP 8.5)

The greatest warming should be expected in January and December – 2.5°C and 2.0°C respectively (Figure 3) following to the RCP 8.5 scenario in 2011–2040. Surface air temperatures will change the least in March (+0.2°C). In most areas it is expected to increase in the range of 0.5–0.6°C, the most – in the northern part of Zhytomyr region and in the east of Sumy region up to 0.8–1.0°C. Temperature will rise from southeast to northwest, from 0.5°C to 1.3°C respectively, with local rises in the south of Zhytomyr region and southwest of Kyiv region in summer. Temperature rising will be more equitable throughout the region, with a minimum of 1.3°C in the southwest of Zhytomyr region and a maximum of 1.9°C in most of Sumy region in autumn.

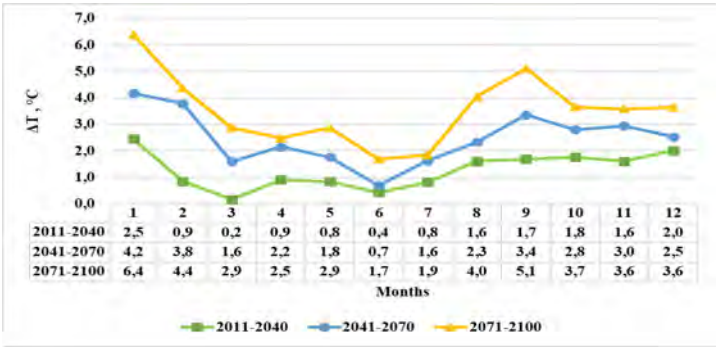


Figure 3 *Projections of changes in mean monthly values of air temperatures in different 30-year periods of the 21st century following the high-end scenario (RCP 8.5) compared to the base period from 1981 to 2010*

Projections of surface air temperature for the period from 2041 to 2070 indicate a general warming from 1.0°C to 3.7°C throughout the territory. Warming is expected from 1.6°C (March) to 2.2°C (April) in the spring. Uneven temperature rising is expected from the southwest of the region (1.6°C) to the north (2.0°C) and the east (2.2°C). The smallest changes in air temperature are expected in summer from 1.1°C in the east of Sumy region, 1.3°C in the west of Zhytomyr region, 1.6–1.7°C in

the rest of the territory. There will be a meridional increase in air temperature values from east and west to the central and southern parts of Kyiv region. It is expected that the warmest month will be August with a tendency to increase temperatures. Temperatures in the autumn months will also increase, with the average from 2.8°C to 3.4°C. The greatest warming is expected in January, and the least in March and June.

The mean values of surface air temperature will increase the most in January (by 6.4°C) and in September (by 5.1°C) in the period from 2071 to 2100. In general, this period is forecasted to be by 1.0°C warmer than the previous one. A characteristic clear rising in air temperatures from south to north is forecasted from 3.0–3.1°C in the south-western part of Zhytomyr region to 2.9–3.2 °C in the north of the region and in most of Sumy region for the spring seasons of the last 30-year periods of the 21st century. There is a clear meridional distribution with increasing values from east (1.9°C) and west (2.4°C) in the direction of Kyiv region and the southern part of Zhytomyr region (2.7–2.8°C) in summer. The autumn season is characterized by a equitable distribution of air temperature rising in the meridional direction from west to east from 3.7 °C in the western part of Zhytomyr region to 4.0–4.3 °C in the rest of the region with rising in the latitudinal direction. The largest temperature rising will be observed in comparison with other seasons of this period from 4.2 °C in the south of the region to 5.0 °C in the north and 5.2 °C in the east of Sumy region in the period from 2071 to 2100 in winter. In general, this scenario is characterized by a significant surface air temperatures rising, mostly in the winter and autumn months. The total mean temperature in the territory will increase by 3.5°C compared to 1981–2010.

Conclusions

It is established that global warming in the region will be formed due to the growth of mean monthly temperatures in winter from 2.6°C in the south to 3.2°C in the north during the period from 2041 to 2070, and from 4.2°C in the south of the region to 5.0°C in the north and 5.2°C in the east of Sumy region at the end of the 21st century. The smallest changes in temperature compared to the reference period are expected in the summer. The largest territorial range of temperature changes will be observed in the spring. Autumn, on the contrary, will be characterized by uniformity of spatial temperature distribution on the territory.

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