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Causes, consequences and countermeasures to climate change in Ukraine and the world

Anatoliy Vidmachenko¹, Oleksandr Mozghovyi²

¹ National University of Life and Environmental Sciences of Ukraine, Department of Physics; Main Astronomical Observatory of the National Academy of Sciences of Ukraine, Department of Physics of Substellar and Planetary Systems; Kyiv, Ukraine

avidmachenko@gmail.com

<https://orcid.org/0000-0002-0523-5234>

² National Transport University, Department of Information and Analytical Activities and Information Security, Kyiv, Ukraine

mavimfto@gmail.com

<https://orcid.org/0000-0002-0797-8779>

Abstract. The current rapid changes in the Earth's climate are due to a significant increase in the global average temperature. Greenhouse gases participate in these changes. The concentrations of carbon dioxide, methane, and nitrous oxide in the atmosphere are currently the highest in the last 800,000 years. To counteract this climate crisis, it is considered necessary to achieve carbon neutrality by the middle of the 21st century. Since the middle of the 19th century, due to the burning of huge amounts of fossil fuels, the concentration of greenhouse gases in the atmosphere began to increase sharply. And the concentration of CO₂ has increased from 280 ppm (parts per million) to over 400 ppm. The average global temperature since 1880 has increased by 1.1°C. In Ukraine, temperature changes in the last half century have been about 0.3°C per decade. The water level in the rivers of Ukraine in summer periods is becoming lower than normal in previous years. It is estimated that the greatest decrease in runoff is observed in the river basins of the Pripyat, Dniester, and Southern Bug. On the rivers of Polissya, the climatically determined increase in water runoff at the end of winter threatens the formation of persistent spring floods; the increase in water runoff in the rivers of the Western region of Ukraine is manifested in the formation of catastrophic floods on the mountain rivers of the Carpathians. Climate change increases the likelihood of more frequent floods and droughts. This makes agriculture, transport, energy, and the social sphere more vulnerable. After all, these are the sectors that are highly dependent on water resources. Due to the increase in the average annual temperature, the agroclimatic zones of Polissya, forest-steppe and steppe have changed their boundaries, moving north by up to 200 km. From the rise in sea level due to climate change in the southern regions of Ukraine by 2100, we should expect flooding of an area of from 650 thousand to 1 million hectares. If global temperature changes at the end of the 21st century. exceeds 1.5°C, climate change will lead to a significant increase in extreme hot days and sea levels will continue to rise. Increased ocean acidity will lead to the extinction of marine animals and the destruction of food chains. Hurricanes, storms, fires will be stronger and more frequent. All this will cause a decrease in crop yields, changes in animal habitats, loss of water supplies and significant economic consequences.

Keywords: global climate change, air temperature, water regime of the river, rainfall, river basin.

1. Introduction

Reasons for global climate change. Climate change is the nature of weather changes over a long period of time over a large area. During the existence of our planet, the Earth's climate has changed many times [2]. The last seven ice ages are well studied, after which warming set in again [3-5]. Nowadays, warming is occurring an order of magnitude faster than ever before. Therefore, the term "climate change" is increasingly used, but the term "climate crisis". This phrase emphasizes the seriousness of the existing problem, which requires its solution as soon as possible. After all, modern rapid climate changes are occurring due to a significant increase in the global average temperature. To counteract such a climate crisis, in order to adapt to global climate change, the need to achieve so-called carbon neutrality is being considered by the middle of the 21st century.

When sunlight hits the Earth's surface, its energy is absorbed and returned to space in the form of heat [7]. The presence of certain gases in the atmosphere prevents the release of this heat, as a result of which the surface layers of the planet heat up. The higher the concentration of these gases, the more heat is trapped. The concentration of carbon dioxide, methane, and nitrous oxide in the atmosphere is now the highest it has been in 800,000 years [10, 13]. Conditions on Earth have changed throughout its history. In the past 650,000 years alone, there have been seven cycles of glacial expansion and retreat. And the abrupt end of the last ice age about 11,700 years ago marked the beginning of the modern climate era. Most of these natural phenomena are explained by small variations in individual elements of the Earth's orbit, which change the amount of solar energy that our planet receives.

Most climate changes in the past, as well as today, have involved so-called greenhouse gases. When there was too much of them, the Earth warmed. But these changes occurred gradually, and so the planet had millions of years to adjust to the updated levels, such as carbon dioxide. In the same cases, when the concentration of greenhouse gases increased suddenly, for example, due to strong eruptions of many volcanoes, the consequences for the Earth's biosphere were also more catastrophic. Now human activity creates carbon emissions 3–8 times faster than ancient volcanoes [2].

The greenhouse effect currently maintains more or less comfortable temperature values for humanity on our planet. In the absence of such an effect, the average global temperature would not be +15°C, but -18°C. Thus, the greenhouse effect is a normal natural phenomenon. However, with the beginning of the industrial revolution in the middle of the 19th century due to the burning of huge amounts of fossil fuels, the concentration of greenhouse gases in the atmosphere began to increase sharply. Such gases include carbon dioxide CO₂, ozone O₃, methane CH₄, nitrogen oxide N₂O, water vapor, etc. Typically, the first four compounds remain in the atmosphere for months or even years without undergoing physical and chemical changes. For example, the conducted research shows [6], an ozone molecule does not change for almost 100 days, and methane molecules can remain in the atmosphere unchanged for up to a dozen or so years. This contributes to an increase in global temperatures for several decades [9]. Water vapor may not change in the atmosphere for only a few days, responding quite quickly to temperature changes. After all, the warmer it gets, the more water will evaporate into the atmosphere, intensifying global warming processes.

2. Statement of problem

Impact of human activity on global climate. Human activity significantly changes the concentration of greenhouse gases in the Earth's atmosphere through the burning of such types of fossil fuels as coal, gas, oil, etc. When they are burned, carbon is released, which, combining with oxygen in the air, forms carbon dioxide CO₂. Over the past 140 years, CO₂ concentrations have increased from 280 ppm (parts per million) to over 400 ppm (Fig. 1). This is the first time in several hundred thousand years that such a rapid increase in the carbon

dioxide content in the Earth's atmosphere has occurred. According to observations, the average global temperature on Earth has increased by almost 1.1°C since 1880.

But global warming is occurring unevenly across the planet's surface. For example, in the Arctic regions of the Earth, the average temperature has increased by almost 2°C. That is, warming in the Arctic region is occurring almost twice as fast as in the low-latitude regions of the planet. Therefore, glaciers in the Arctic are melting faster.

According to satellite observations, the volume of ice in the Arctic after 1979 in the warmest season has decreased by almost a third (Fig. 2). If such trends continue, by the middle of the 21st century the Arctic may be completely ice-free in the summer. Such melting of glaciers may have several serious global consequences. After all, a significant reduction in the area of the white cover of the Earth's surface, which reflects from 20% to 50% of solar radiation, will cause an increase in the area of the world's oceans. Namely, it absorbs more than 95% of the incident solar energy. Therefore, the water will heat up even more; this will accelerate the melting of glaciers, causing even greater climate change and will again lead to a rise in the level of the world's oceans. At the beginning of the 21st century some of the islands in the Seychelles, Maldives, Fiji, Marshall and Canary Islands, Micronesia, Polynesia, the Philippines, etc. began to disappear under water; and the Solomon Islands, due to rising water levels in the oceans, have already lost 5 of their islands by 2020.

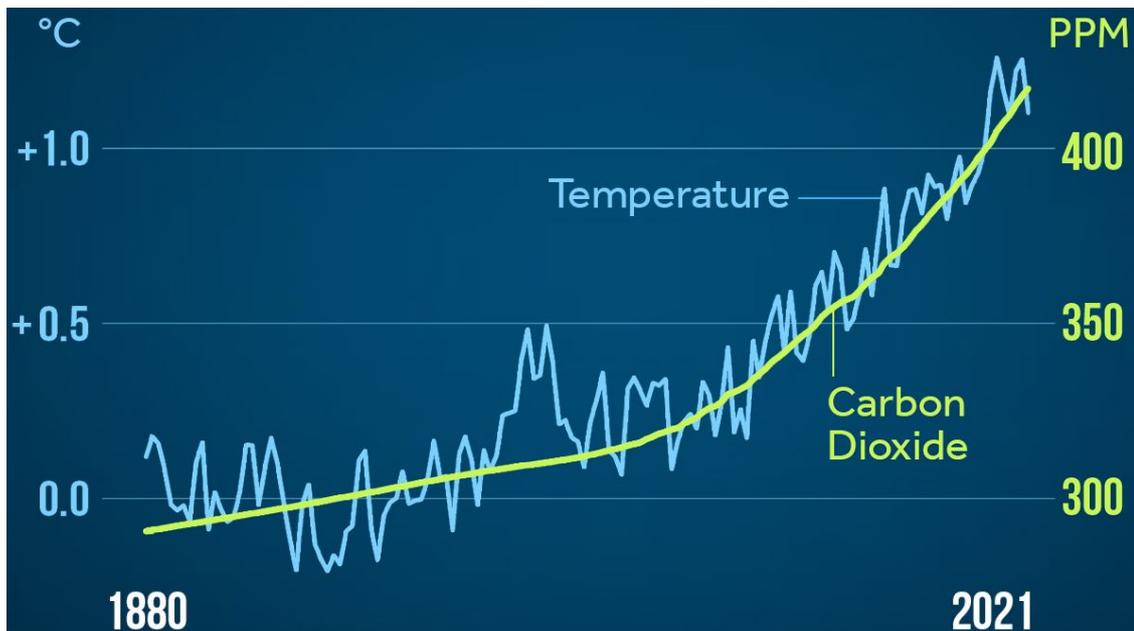


Fig. 1. Global changes in temperature and carbon dioxide concentration CO₂
 (<https://www.climatecentral.org/graphic/peak-co2-heat-trapping-emissions?graphicSet=Annual%20CO2%20Peak%20and%20Temperature>)

According to estimates, the permafrost of the circumpolar regions currently holds more than 1,400 gigatons of carbon dioxide. This amount is almost twice as much as that currently contained in the entire Earth's atmosphere. Rising global temperatures are causing the surface layers of permafrost to melt, releasing these "deposits". Along with CO₂, methane is also released into the atmosphere, for which the greenhouse effect is about a hundred times stronger than carbon dioxide.

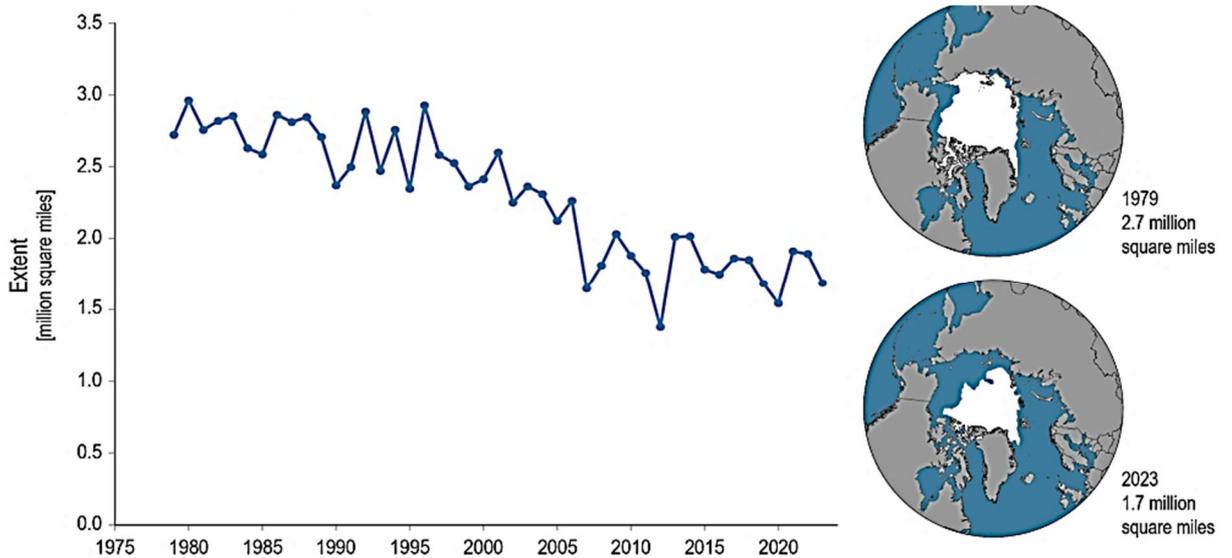


Fig. 2. Shows a 37% decrease in Arctic sea ice extent from September 1979 to September 2023

(https://www.globalchange.gov/sites/default/files/styles/max_1024x1024/public/images/arctic_sea_ice_extent_2024.png?itok=sKt-MOXE)

The graph in Fig. 3 shows that the world ocean level has risen by more than 10 cm from 1870 to mid-2024.



Fig. 3. According to NASA high-resolution satellite measurements, sea level in 2024 was 103.3 mm higher than in 1993, and the rate of rise is accelerating (<https://d39raawggefpx.cloudfront.net/media/0724GLOBALbncGreenSealevelrise10cms.jpg>)

The purpose of the study is to show the causes of global climate change and the impact of human activity. To consider the consequences of such changes in Ukraine and the world and to propose actions to reduce the impact of global warming.

3. Main result

Climate change in Ukraine. In Ukraine, the average annual temperature has increased by more than 1.2°C over the past few decades. The rate of change in the average, maximum and minimum temperatures over the past half century has been about 0.3°C for every ten years. Moreover, all seasons in Ukraine have become warmer. Thus, in Ukraine, the average summer temperature has increased by 1.3°C, winter temperature by 0.9°C, spring temperature by 0.9°C, and autumn temperature by 0.4°C. The largest temperature increases occurred in January (by 2.3°C) and July (by 1.4°C). With the increase in the average global temperature, extremely high temperature values have become more frequent in Ukraine; and warming in the warm seasons has become longer and more frequent.

Therefore, droughts are intensifying, the water content of lakes and rivers is decreasing, and extreme weather phenomena that were not previously typical for Ukraine are observed more often. It is believed that by the middle of the 21st century, every second summer season will be dry, and the average annual air temperature is expected to increase by more than 1.5°C. In recent years, the water level in the rivers of Ukraine in summer periods has been lower than the norm in previous years. It is also expected that in the following years the amount of precipitation in summer will decrease, and droughts will become more frequent [14].

Compared with the base period of 1961-1990, in the last three decades there has been a noticeable redistribution of precipitation both by seasons and by regions of Ukraine. And although the average value of precipitation per year has not changed significantly, there have been changes in the nature of their precipitation and in their intensity. For example, sometimes almost a monthly norm of precipitation fell within a few hours. And during another almost monthly period, rains can only sometimes barely drip, and then rainless weather was observed.

Such an increase in average monthly temperature values, an increase in moisture evaporation and a decrease in the amount of atmospheric precipitation should lead to a change in surface moisture regimes, to a further decrease in surface water runoff in rivers and water supply in certain regions of Ukraine [11]. Estimates show that the greatest decrease in runoff will be observed for the river basins of the Dnieper tributary Pripyat, as well as the Dniester and Southern Bug. By the end of the 21st century, their water content may decrease by a third. According to forecasts for the period 2030-2040, water in the Dnieper River will be 30% less, and in the Dniester River – by 37%.

Water runoff in small rivers is also gradually decreasing. And, for example, on the rivers of Polissya, the climatically determined increase in water flow at the end of winter threatens the formation of persistent spring floods; and the increase in water flow in the rivers of the Western region of Ukraine may manifest itself in the formation of catastrophic floods on the mountain rivers of the Carpathians. That is, climate change increases the likelihood of more frequent floods and droughts. This makes agriculture, transport, energy, and the social sphere more vulnerable [12]. After all, these are the industries that are highly dependent on water resources. This can also lead to a decrease in crop yields and cause certain problems in the operation of nuclear power plants. Let us recall that nuclear power in Ukraine supplies consumers with more than half of the electricity, and it requires constant cooling. Therefore, a decrease in the water content of rivers may cause a high risk of overheating of reactors at nuclear power plants.

Main risks of climate change for Ukraine. In Ukraine, there are three main agroclimatic zones - Polissya, forest-steppe and steppe. This classification was introduced based on the balance between the amount of precipitation and the amount of accumulated heat. Since now the ratio between the average annual temperature and the amount of accumulated heat has changed, the above-mentioned agroclimatic zones have also changed

their boundaries. According to updated synoptic data, these zones are gradually moving further and further north. Estimates show that an increase in the average annual temperature by 1°C shifts the boundary of the above-mentioned agroclimatic zones by approximately one hundred kilometers in the northerly direction. Since over the past few decades the average temperature has increased by more than 2°C, their boundaries have shifted by approximately two hundred kilometers.

The results of many studies also indicate a number of risks from sea level rise due to climate change for the coastal areas of the southern regions of Ukraine. According to estimates, in 2100, we should expect flooding of an area of about 650 thousand hectares, and taking into account seasonal flooding of the sea, these areas increase to 1 million hectares. The Kherson and Odesa regions and the Crimean Peninsula will be most affected. Rising sea levels in the Black and Azov Seas will threaten the flooding of many important industrial facilities, infrastructure, residential areas, and cultural heritage sites. Coastal regions will experience significant changes, even the death of some ecosystems. Even some higher educational institutions in the Kherson and Odessa regions, as well as a number of sea trade ports, are in the zone of possible predicted flooding.

However, some studies show that the Earth's climate should now also demonstrate trends opposite to the above. After a hot period, the climate has been gradually cooling over the past 50 million years. Analysis of solar activity also indicates that the amount of solar energy [11] received by the Earth has begun to decrease since the 1960s (Fig. 4). But despite this, global temperatures continue to rise significantly. That is, global warming is now most likely caused not by natural climate change and not by the activity of the Sun.

A decrease in solar activity over a long period of time is called a Great Solar Minimum. The last such phenomenon led to the so-called Little Ice Age, which lasted from the 16th to the 19th centuries. But modern human-induced warming is six times greater than the effect of the possible cooling that occurred during the Great Solar Minimum. That is, temperatures continue to rise.

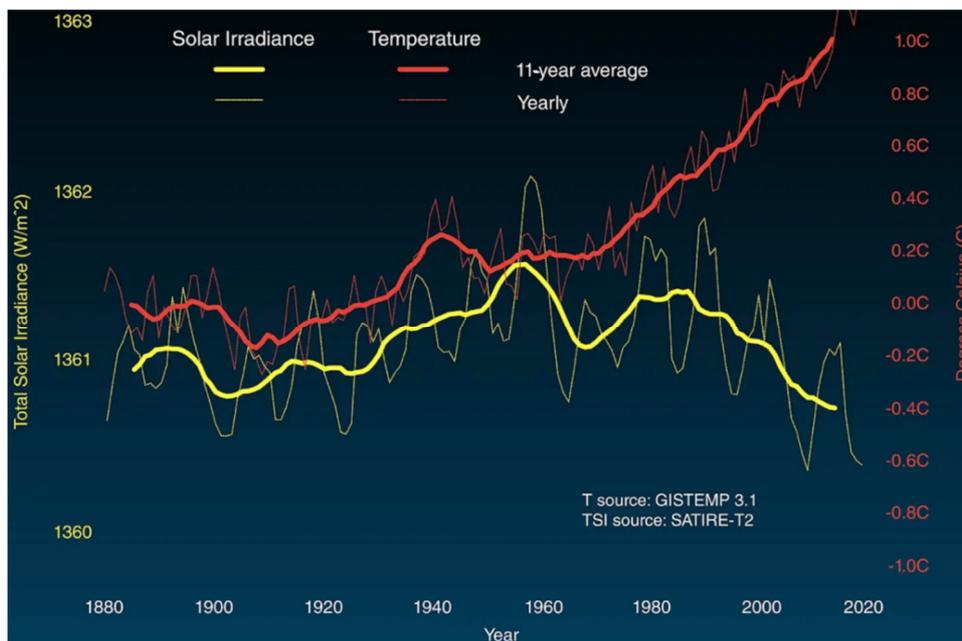


Fig. 4. Comparison of global changes in surface temperature (red line) and solar energy received by the Earth (yellow line) in 1880-2020 (https://upload.wikimedia.org/wikipedia/commons/f/f1/Solar_irradiance_and_temperature_1880-2018.jpeg)

After all, global temperature mainly depends on how much energy the planet receives from the Sun and how much it radiates back into space. And currently, the average global surface temperature is about +15°C. In the past, a drop in global temperature by one or two degrees caused the already mentioned Little Ice Age. And 20,000 years ago, during the last glacial maximum, the global temperature was only five degrees lower. This was enough for permafrost to cover most of Europe at that time.

According to a special report by the Intergovernmental Panel on Climate Change, there are two scenarios for further developments: bad and even worse. In the first case, the global change in surface temperature by the end of the 21st century will exceed 1.5 degrees Celsius, in the second – it will exceed 2°C. The impact of climate change is felt on every continent and in the oceans. However, these changes are not spread evenly across the planet, so different parts of the world will face different impacts. If global temperatures rise by 1.5 degrees, rather than 2 degrees, this could reduce the risks. However, they cannot be avoided completely.

Moreover, if warming exceeds 2 degrees, there are certain tipping points that cannot be corrected, even if warming is reduced to 1.5 degrees. For example, the melting of the Greenland and Antarctic ice sheets is such a tipping point. In both scenarios, climate change will lead to a significant increase in extreme hot days. The amount of heavy precipitation in some regions, especially at high latitudes in the Northern Hemisphere, will also increase, leading to frequent flooding. Some regions, such as the Mediterranean, will become drier [1]. But sea levels will continue to rise in both scenarios. Because of this, the coast and many islands will be flooded. Increasing ocean acidity will lead to the extinction of marine animals and the destruction of food chains. The weather will become more extreme: hurricanes, storms, fires will be stronger and more frequent. All this will cause a decrease in crop yields, a change in animal habitats, loss of water supplies and significant economic consequences.

Actions to reduce the impact of global warming. To stop global warming, humanity is taking certain measures. Ukraine is one of seven countries that, together with the countries of the European Union, have pledged to reduce their greenhouse gas emissions by at least 40% by 2030 compared to 1990. According to the generally accepted rating "Climate Change Performance Index" for 2019, Ukraine ranked 17th out of 61 countries in terms of the effectiveness of combating climate change. Although, it is clear that our state received such high ratings not because of an effective climate policy, but because of the impact of the political and economic crisis in previous years. Many experts criticize the lack of a coal phase-out plan and emphasize that the "Low-carbon Development Strategy of Ukraine until 2050" adopted in 2018 does not provide for an absolute reduction in greenhouse gas emissions compared to the current level.

Conclusions. Observational data indicate that drought-like weather conditions have begun to prevail in Ukraine, and their intensity is increasing. And with the expected increase in air temperature, even by 1.5°C, in 2025-2050 every second season may be dry. In recent years, the water level in the rivers of Ukraine during the summer period has been lower than normal. Along with more frequent droughts and a decrease in precipitation in summer periods, the situation is getting worse.

The above outlines a list of prospects for further research on the possible impact of climate change in Ukraine on changes in water resources, changes in the boundaries of agroclimatic zones, risks for agriculture, transport, energy, flooding of coastal regions, etc.

Conflict of interest and ethics. The authors declare that they have no conflicts of interest. The authors also declare full compliance with all rules of ethics for journal research, namely regarding the anonymity of human participation and/or consent to publication.

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Причини, наслідки та протидії змінам клімату в Україні і світі

Анатолій Відьмаченко¹, Олександр Мозговий²

Анотація. Сучасні стрімкі зміни клімату Землі відбуваються через значне підвищення глобальної середньої температури. У цих змінах приймають участь парникові гази. Концентрації вуглекислого газу, метану, оксиду азоту в атмосфері наразі є найбільшими за останні 800000 років. Для протидії цій кліматичній кризі розглядають необхідність досягти вуглецевої нейтральності до середини XXI ст. Від середини XIX ст. через спалювання величезних обсягів викопного палива концентрація парникових

газів в атмосфері почала різко зростати. І концентрація CO₂ зросла від 280 ppm (часток на мільйон) до понад 400 ppm. Середня глобальна температура з 1880 р. зросла на 1.1°C. В Україні зміни температури в останні півстоліття становили близько 0.3°C за десятиліття. Рівень води в річках України у літні періоди стає все нижчим від норми в попередні роки. Оцінено що найбільше зниження стоків спостерігається в річкових басейнах Прип'яті, Дністра і Південного Бугу. На річках Полісся кліматично обумовлене зростання водного стоку у кінці зими загрожує формуванню стійких весняних паводків; зростання водних стоків в річках Західного регіону України проявляється у формуванні катастрофічних повеней на гірських річках Карпат. Кліматичні зміни збільшують імовірність частіших і повеней, і посух. Це робить вразливішим сільське господарство, транспорт, енергетику і соціальну сферу. Адже саме ці галузі є сильно залежними від водних ресурсів. Через зростання середньорічної температури агрокліматичні зони полісся, лісостепу і степу змінили свої межі, перемістившись на північ до 200 км. Від підвищення рівня моря внаслідок зміни клімату у південних областях України до 2100 р. слід очікувати затоплення території площею від 650 тис. до 1 млн. га. Якщо глобальна зміна температури на кінець XXI ст. перевищить 1.5°C, то зміна клімату призведе до значного збільшення екстремальних спекотних днів і рівень моря продовжить підвищуватися. Підвищення кислотності океанів призведе до вимирання морських тварин і руйнування ланцюгів харчування. Урагани, шторми, пожежі будуть сильнішими і траплятимуться частіше. Усе це викликатиме зменшення врожайності сільськогосподарських культур, зміні ареалів тварин, втраті запасів води і значним економічним наслідкам.

Ключові слова: глобальні зміни клімату, температура повітря, водний режим річки, кількість опадів, річковий басейн.

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Про авторів / About the authors

Анатолій Відьмаченко, доктор фізико-математичних наук, професор, академік АН ВШ України, професор кафедри фізики Національного університету біоресурсів і природокористування України, головний науковий співробітник відділу фізики субзоряних і планетних систем Головної астрономічної обсерваторії НАН України; вул. Героїв Оборони, 15, м. Київ, 03041, Україна;

Anatoliy Vidmachenko, Doctor of Science in Physics and Mathematics, Professor, Academician of the Academy of Sciences of the Higher School of Ukraine, Professor of the Department of Physics of the National University of Life and Environmental Sciences of Ukraine, Chief Researcher of the Department of Physics of Substellar and Planetary Systems of the Main Astronomical Observatory of the National Academy of Sciences of Ukraine, 15 Heroiv Oborony Str., Kyiv, 03041, Ukraine;

Олександр Мозговий, кандидат технічних наук, доцент, кафедра інформаційно-аналітичної діяльності та інформаційної безпеки, Національний транспортний університет, вул. М. Омеляновича-Павленка, 1, м. Київ, 01010, Україна;

Oleksandr Mozghovyi, Candidate of Science in Engineering, Associate Professor, Department of Information and Analytical Activities and Information Security, National Transport University, 1, Mykhaila Omelianovycha – Pavlenka Str. Kyiv 01010, Ukraine;

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