https://doi.org/10.31891/csit-2024-2-1
UDC 004.89: 004.4: 551.509.331

Olga PAVLOVA, Vitalii ALEKSEIKO
Khmelnytskyi National University

THE CONCEPT OF AN INFORMATION SYSTEM FOR FORECASTING THE TEMPERATURE REGIME OF THE EARTH'S SURFACE BASED ON MACHINE LEARNING

The paper presents the concept of an information system for forecasting the temperature regime of the Earth's surface using machine learning. Forecasting is based on historical data for a specific area. In order to increase the accuracy of forecasting results, an analysis of the features of climate zones was carried out to identify patterns. A comparison of the dependence of the average earth's surface monthly temperatures in countries depending on their location in climate zones was carried out.

The analysis of sources and scientific publications confirmed the relevance of the chosen research topic. Historical aspects of forecasting changes in climatic indicators are considered. Modern methods and approaches to temperature forecasting, their advantages and disadvantages are analyzed. An overview of the subject area was conducted and the regularities of temperature changes according to climate features were determined.

A comparison of temperature regimes for countries located in different climate zones was made. For clarity, graphs of temperature changes were plotted and average indicators were calculated for each climate zone.

The results of the study confirm the need to adjust the temperature forecast for certain areas, taking into account their location in a specific climate zone. The revealed regularities in the temperature regime of the countries indicate the need for an individual approach to forecasting and the use of such machine learning methods that are best adapted to the dependencies observed in the climate zone.

The architecture of the information system for forecasting future temperatures depending on the climatic features of the studied territories is proposed. A concept has been formed for further research to find more accurate and effective approaches to predicting climate parameters and achieving the goals of sustainable development.

Keywords: machine learning (ML), forecasting, temperature regime, climate zone, information system.

Ольга ПАВЛОВА, Віталій АЛЕКСЕЙКО
Хмельницький національний університет

КОНЦЕПЦІЯ ІНФОРМАЦІЙНОЇ СИСТЕМИ ДЛЯ ПРОГНОЗУВАННЯ ТЕМПЕРАТУРНОГО РЕЖИМУ ЗЕМНОЇ ПОВЕРХНІ НА ОСНОВІ МАШИННОГО НАВЧАННЯ

В роботі представлено концепцію інформаційної системи для прогнозування температурного режиму земної поверхні з використанням машинного навчання. Прогнозування здійснюється на основі історичних даних для певної території. Для підвищення точності результатів прогнозування здійснено аналіз особливостей кліматичних зон для виявлення закономірностей. Проведено порівняння залежностей середніх місячних температур земної поверхні у країнах, залежно від їх розташування у кліматичних поясах.

Аналіз джерел та наукових публікацій підтвердив актуальність обраної тематики дослідження. Розглянуто історичні аспекти прогнозування змін кліматичних показників. Проаналізовано сучасні методи та підходи до прогнозування температури, їх переваги та недоліки. Проведено огляд предметної області та визначено закономірності зміни температури відповідно до кліматичних особливостей.

Проведено порівняння температурних режимів для країн, розташованих у різних кліматичних зонах. Для наочності побудовано графіки зміни температур та обраховано середні показники для кожної кліматичної зони.

Результати дослідження підтверджують необхідність коригування температурного прогнозу для певних територій, з врахуванням їх розташування у конкретному кліматичному поясі. Виявлені закономірності у температурному режимі країн свідчать про необхідність індивідуального підходу до прогнозування та використання таких методів машинного навчання, які найкраще адаптуються до залежностей, що спостерігаються у кліматичній зоні.

Запропоновано архітектуру інформаційної системи для прогнозування майбутніх температур в залежності від кліматичних особливостей досліджуваних територій. Сформовано концепцію для подальших досліджень для пошуку більш точних та ефективних підходів до прогнозування кліматичних параметрів та досягнення цілей сталого розвитку.

Ключові слова: машинне навчання (ML), прогнозування, температурний режим, кліматичний пояс, інформаційна система.

Introduction

People have been interested in predicting the weather since ancient times. Such interest was due to a number of factors that depended on the quality of life of entire communities, in particular, the need to grow crops, prepare their settlements for the cold or wet season, etc. Changes in weather conditions often became the cause of famine, epidemics, droughts or floods. Therefore, the spread of pathogens of infectious and viral diseases depends, among other things, on climatic factors. Epidemiological data suggest that the seasonality of many diseases is influenced by the following factors:

– abnormal one-time weather events;
– long-term climate events;
– anthropogenic factors.

Several researches provided the impact of climate on spreading plague [1], malaria, pediatric pneumonia [2] and other infectious and viral diseases.

Climate change forecasting can greatly help reduce risks and prevent negative consequences.

The growing interest of scientists in forecasting numeric quantities is largely due to the rapid development of artificial intelligence (AI). Modern technologies make it possible to predict various indicators with high accuracy, in particular such climate parameters as air and earth surface temperature, humidity, sea level and others. These values play an extremely important role, since many factors depend on them. Information about the future climate is important for policymakers, planners, investors and vulnerable communities to prepare for expected changes [3]. One of the most relevant parameters in climate study is temperature of earth's surface or land temperature.

Land surface temperature measures how hot the ground feels to the touch. Unlike air temperature, it fluctuates more rapidly, as the land heats up and cools down faster than the air [4]. Understanding land temperature patterns helps in creating accurate climate models. These models are crucial for predicting future climate scenarios, assessing the impacts of climate change, and composing adaptation and mitigation strategies.

The topic of our research is determined to Sustainable Development Goals (SDGs) [5] provided in 2015 by United Nations (UN). UN Member States identify the SDGs as a key concept for their development. SDG 13 identifies climate change as a real and undoubted threat to all human civilization [6].

Moreover, the impact of land temperature forecasts on the SDGs could be significant not only in the area of climate change, but also in many other areas.

Thus, forecasting changes in the temperature of the earth's surface influences agricultural productivity and food security. Farmers rely on temperature forecasts to make decisions about planting, irrigation, and crop management practices. Accurate predictions can help optimize agricultural yields, prevent crop failures due to heat stress or frost, and ensure food availability for communities, thereby contributing to the goal of zero hunger (SDG 2).

Abnormal weather events such as extreme temperatures or sudden changes in temperature can pose serious health risks, such as heatstroke, heat exhaustion, dehydration, cardiovascular disease, respiratory problems or vector-borne diseases [1; 2]. They can also have an impact on mental health. Predicting land temperatures allows for the implementation of public health measures, such as heatwave early warning systems and disease surveillance programs. By mitigating health hazards associated with temperature extremes, accurate forecasts contribute to promoting good health and well-being among populations (SDG 3).

Temperature changes affect water resources such as rivers, lakes, and groundwater. Predicting land temperatures can assist in assessing water availability, managing water allocation, and predicting drought conditions. This information is essential for ensuring access to clean and sustainable water sources, promoting water conservation practices, and improving sanitation facilities, all of which are crucial for achieving SDG 6 targets.

Land temperature prediction can have economic implications, particularly for sectors sensitive to climate variability such as agriculture, tourism, and energy. Reliable temperature forecasts enable businesses to plan operations, manage risks, and invest in climate-resilient infrastructure. By supporting sustainable economic activities and livelihood opportunities, accurate predictions contribute to the promotion of decent work and inclusive economic growth (SDG 8).

Land temperature prediction directly impacts ecosystems and biodiversity. Temperature changes influence habitat suitability for various species, migration patterns, and the timing of biological events such as flowering or hibernation. Accurate temperature forecasts can inform conservation efforts, ecosystem management strategies, and wildlife protection initiatives, contributing to the preservation of biodiversity and terrestrial ecosystems (SDG 15).

Domain analysis

The analysis of scientific publications [7-14] showed the existing problem in predicting temperature. There are several methods used for temperature prediction, each with its own strengths, limitations, and applications. Some common methods include: Statistical Methods, Numerical Weather Prediction (NWP), Ensemble Forecasting, Analog Forecasting, Remote Sensing, Machine Learning (ML) and Artificial Intelligence (AI) etc. Quite often, the mentioned methods are used in combination, since each of them has not only its advantages, but also certain limitations. Thus it allows to provide more robust temperature predictions across different time scales and spatial resolutions.

The idea of using numerical weather prediction (NWP) was first described in the pioneering work of Norwegian physicist Vilhelm Bjerknes, who is called the father of modern meteorology. In 1904, Bjerknes proposed in a paper that weather forecasting could be achieved by solving a set of nonlinear partial differential equations. The first successful one-day nonlinear weather prediction was completed in April, 1950. This effort demanded continuous attention from the modelers and, due to multiple ENIAC malfunctions, took more than 24 hours to process. Nevertheless, this groundbreaking forecast demonstrated to the meteorological community that numerical weather prediction was indeed possible [7].

NWP models solve a system of partial differential equations derived from physical laws to predict the future state of the atmosphere. Although these models are used in work, they are computationally intensive. [8].

Machine learning algorithms, such as neural networks, deep learning, and genetic algorithms, are increasingly being used to predict temperatures. These algorithms can capture complex patterns in large datasets and may outperform traditional statistical methods in certain cases. Nowadays, AI technologies are increasingly being used to forecast weather.

Most studies are devoted to identifying temperature patterns over a limited area or with limited methods. For example, analysis of climate change taking into account differences in data sources and disparate forecasts in Mexico City [9] or using remote sensing data from Reykjavik (Iceland) to study and predict temperatures for 1987–2030 [10]. The study of forecasting in specific territories is considered in article [11] using the example of long-term forecasting of average monthly temperatures for different types of climate in Iran using the SARIMA, SVR and SVR-FA models. Researches on the use of special technologies of artificial intelligence and machine learning to create a climate change forecast is considered from the point of view of using an autoregressive model of long short-term memory [12] and just neural network [13]. In addition, the relationships between temperature and other quantities, such as CO_2, CH_4, N_2O and others are considered [14]. These studies may allow the model to better predict the parameters of a specific region, but their application is impossible for areas with different climate conditions.

Analysis of climate zones patterns

Due to the tilt of the Earth's axis, our planet is illuminated and heated unevenly. Different latitudes, from the equator to the poles, account for different amounts of heat. The territories of the Earth, which differ in temperature and humidity, the amount and frequency of precipitation, can be divided into conditional zones. These zones are called climate zones.

Weather conditions that are observed in a certain area over a long period of time are called climate [15]. In other words climate is a stable weather regime in a certain area, repeated from year to year. Climate zones are regions with similar climate conditions. According to the concept of climate zoning, territories are divided into zones that are similar in some respects, such as geographic latitude, altitude, weather conditions and their patterns, predominant flora and fauna [16]. The division into zones is carried out on the basis of climate factors that determine the similarities of certain territories. Thus, there are several climate classifications that are based on different factors. In general, climate zoning makes it possible to classify territories according to certain characteristics, which contributes to a better understanding of climate patterns and conducting research for different regions of the Earth.

Although, there are several classifications of climate zones, as it was mentioned, but due to the context of our research, it was decided to use the Köppen climate classification system [17] because it is one of the most widely used climate classification systems globally. This system categorizes the world into five zones, primarily based on temperature, which influences the growth of different types of vegetation. There are five main climate zones:

– tropical or equatorial zone (Zone A);
– arid or dry zone (Zone B);
– warm or mild temperate zone (Zone C);
– continental zone (Zone D);
– polar zone (Zone E).

In addition, based on the criteria of temperature and dryness, each zone is divided into subzones [18]. They are indicated by letters. Table 1 presents a detailed description of the abbreviations.

Table 1

Description of climate zones abbreviation

<table>
<tr><th>1st symbol</th><th>2nd symbol</th><th>3rd symbol</th></tr>
<tr><td rowspan="4">A – Tropical</td><td>f – Rainforest</td><td rowspan="4"></td></tr>
<tr><td>m – Monsoon</td></tr>
<tr><td>s – Savanna, dry summer</td></tr>
<tr><td>w – Savanna, dry winter</td></tr>
<tr><td rowspan="2">B – Arid</td><td>W – Arid Desert</td><td>h – Hot</td></tr>
<tr><td>S – Semi-Arid or steppe</td><td>k – Cold</td></tr>
<tr><td rowspan="3">C – Temperate</td><td>w – Dry winter</td><td>a – Hot summer</td></tr>
<tr><td>f – No dry season</td><td>b – Warm summer</td></tr>
<tr><td>s – Dry summer</td><td>c – Cold summer</td></tr>
<tr><td rowspan="6">D – Continental</td><td rowspan="2">w – Dry winter</td><td>a – Hot summer</td></tr>
<tr><td rowspan="2">b – Warm summer</td></tr>
<tr><td rowspan="2">f – No dry season</td></tr>
<tr><td rowspan="2">c – Cold summer</td></tr>
<tr><td rowspan="2">s – Dry summer</td></tr>
<tr><td>d – Very cold winter</td></tr>
<tr><td rowspan="2">E – Polar</td><td rowspan="2"></td><td>T – Tundra</td></tr>
<tr><td>F – Ice cap</td></tr>
</table>

The different colors and shades on the Köppen map are used to visualize climate zones. The main climate zones represents with blue (Zone A), red (Zone B), green (Zone C), purple (Zone D) and gray (Zone E) colors. Subgroups indicates by shades of the primary color of the group.

Figure 1 demonstrates world climate map due to The Köppen climate classification system. Maps [19] developed on the basis of the publication [18] are shown for clarity.

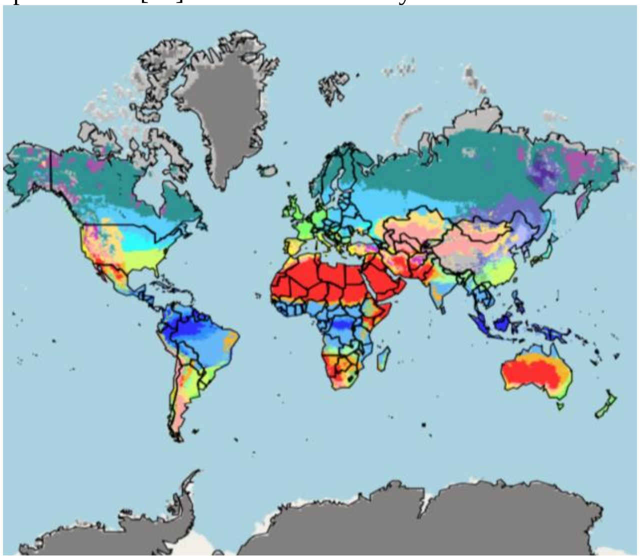


Fig. 1. Köppen's climate map [18; 19]

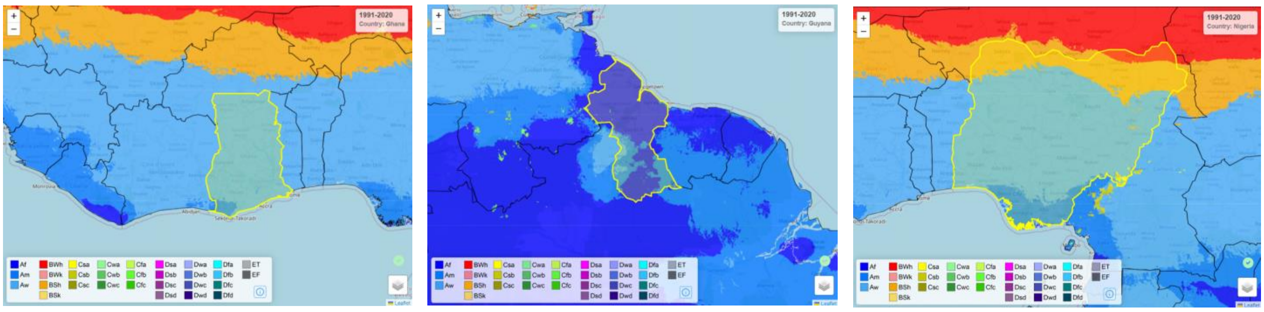
Based on the patterns observed in each of the climate zones, for better temperature forecasting, it is proposed to conduct separate researches for different climate zones.

Hypothesis. *It is advisable to predict temperature for different climatic zones using different methods selected individually for each climatic zone.*

In order to make sure of the regularities of the temperature regime, consider the temperature change in the countries of one climate zone for the period from 2000 to 2010. By countries of the same climatic zone, we mean countries whose entire or almost entire territory is located within the same climate zone. The country's belonging to the climate zone was established according to the World Climate Data [20]. For the research the dataset of the Earth's surface temperatures [21] have been used.

To consider the difference in temperature regimes of countries belonging to different climate zones, for example, we compare temperature in countries of tropical climate zone and temperature in countries of other zones.

Figure 2 shows Köppen's climate maps of countries of equatorial/tropical climate zone (Zone A). Nigeria is situated in Western Africa. Its climate is tropical. Ghana also is situated in Western Africa and also has tropical climate. Another country with tropical climate is Guyana. But, unlike Nigeria and Ghana, it is located on the continent of South America, in its northeastern part.



a) b) c)

Fig. 2. Köppen's climate maps [18; 19] of countries of equatorial/tropical climate zone (Zone A): a) Ghana; b) Guyana c) Nigeria

Figures 3–5 shows temperature in Ghana, Guyana and Nigeria for the period from 2000 to 2010. Plots were build using python on basis of dataset [21].

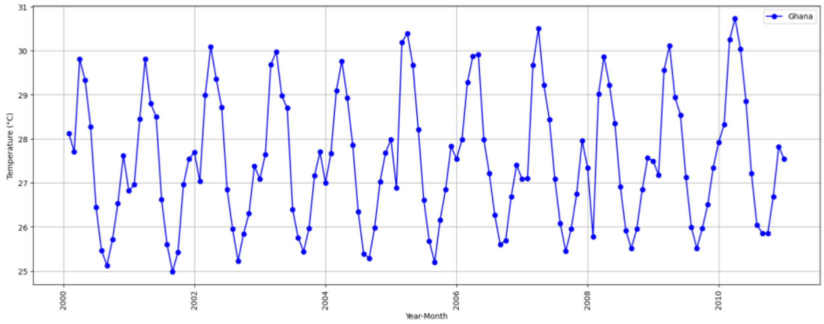


Fig. 3. Temperature in Ghana

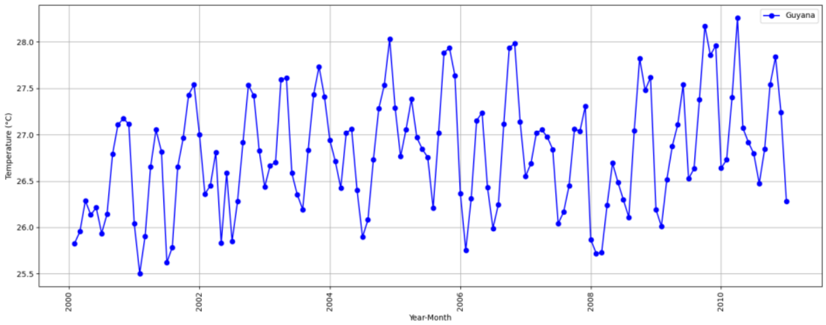


Fig. 4. Temperature in Guyana

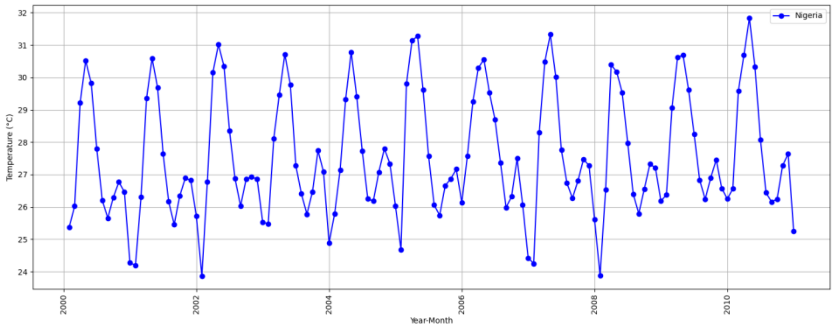


Fig. 5. Temperature in Nigeria

Although each country's temperature chart is unique, there are similarities in the patterns of temperature changes. The results obtained confirm the correctness of the distribution of countries by climate zones. It should be noted that countries in the same subgroup are more similar in altitude of the chart.

Figure 6 demonstrates graphs of temperature regimes for countries with different climate zones. The data of the following countries were used: Ghana (Climate zone Aw), Guyana (Af), Nigeria (Af), Burkina Faso (BSh), Iraq (BWh), Israel (BSh), Georgia (Cfa), Germany (Cfb), New Zealand (Cfb), Estonia (Dfb), Moldova (Dfb), South Korea (Dwb), Greenland (EF), Iceland (ET), Svalbard And Jan Mayen (ET).

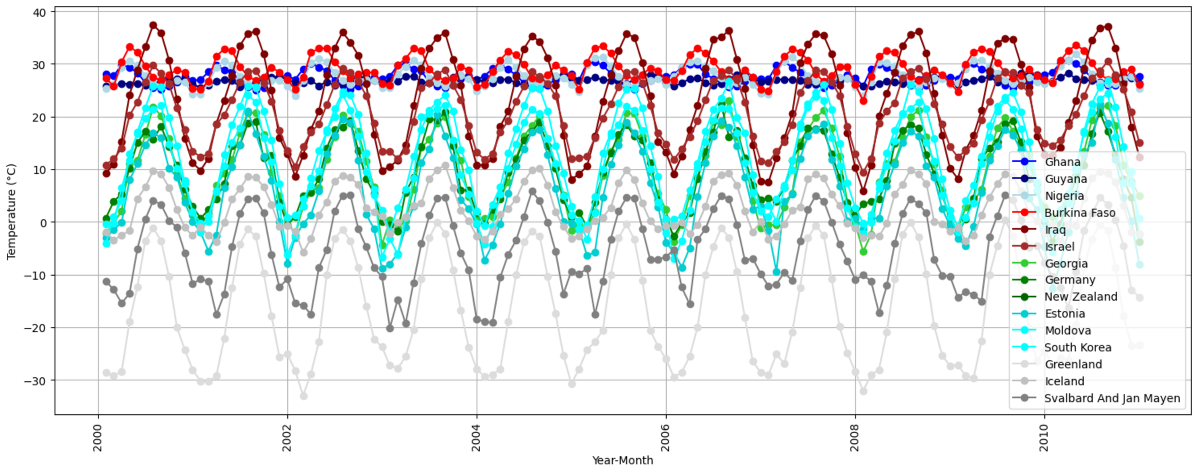


Fig. 6. Temperature in different countries

It is clearly seen that the graphs of countries that are located in the same climate zone have significant similarities. Therefore, to predict future temperature changes, it is advisable to select a machine learning method for each climate zone separately.

Figure 7 shows temperature patterns of each climate zone. Average temperatures from 2000 to 2010 of all countries of the same climate zone were used for plotting. It is advisable to use this data to train the model.

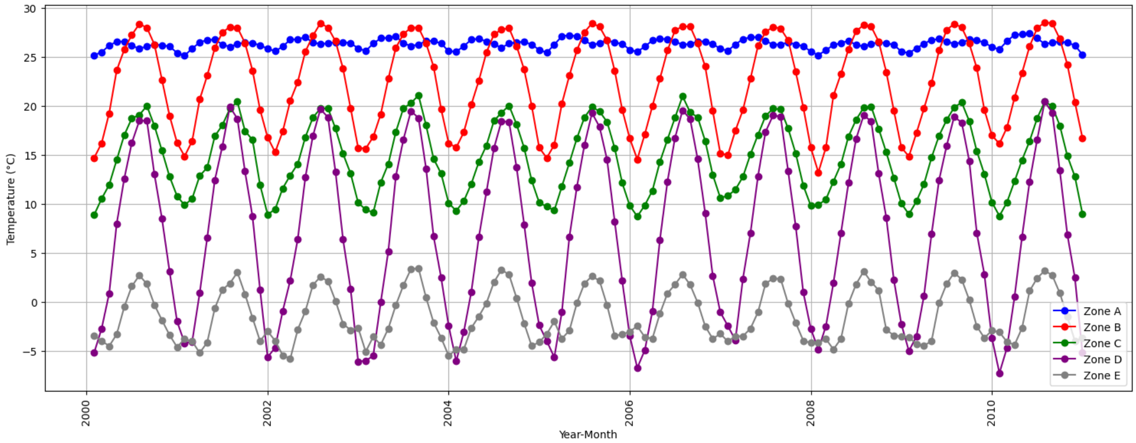


Fig. 7. Temperature in different climate zones

Average minimum and maximum values for the period from 1743 to 2013 for each climate zone presented in Table 2.

Table 2

Statistical temperature data for each climate zone

Climate zone	Average minimum (°C)	Average maximum (°C)	Average temperature (°C)
A	17,7	29,5	25,4
B	2,1	33,8	20,4
C	–2,4	22,6	12,6
D	–12,9	20,9	5,75
E	–19,8	11,9	–3,8

The concept of an information system

It is advisable to develop an information system for temperature forecasting in the form of a web application. Thus, access to the system via the Internet will be provided to any user through a browser. The data entered by the user (e. g. country from the proposed list and year for which a forecast should be made) is transmitted to the server.

After processing the received data, the system selects a model for forecasting and requests the necessary information from the database. The obtained values of expected temperatures are displayed via the User Interface (UI) in numerical and graphical representations. Figure 8 shows architecture of the information system.

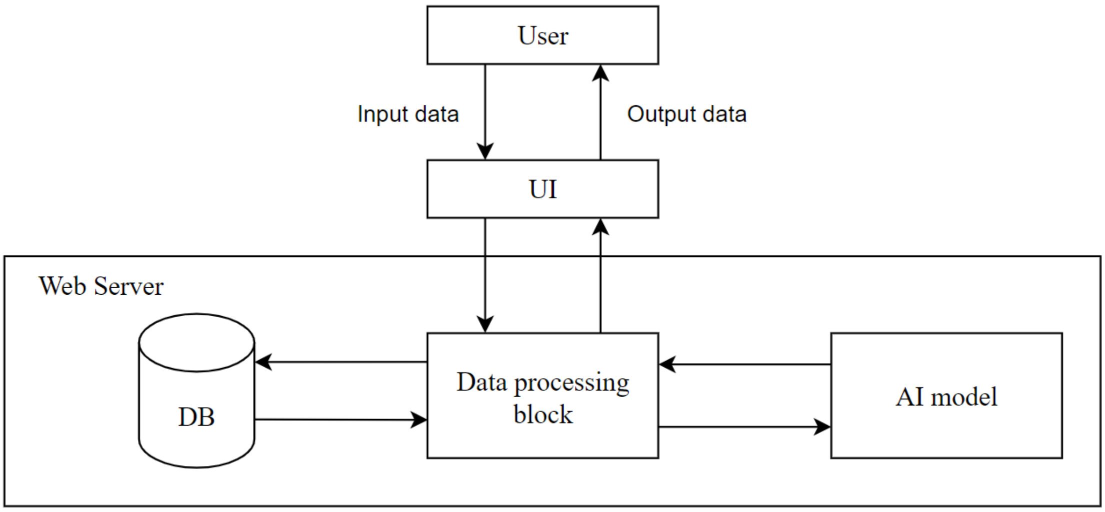


Fig. 8. Architecture of the information system

Conclusions

In summary, land temperature prediction plays a crucial role in addressing various aspects of sustainable development, from climate action and food security to water management, biodiversity conservation, economic growth, and public health. By leveraging accurate forecasts, policymakers and stakeholders can make informed decisions and implement targeted interventions to advance the SDGs and create a more sustainable future.

Based on a comparison of temperature graphs (Figure 6), it can be concluded that the temperature regimes of countries located in the same climate zone are similar to each other. At the same time, the temperature regime of countries from other climate zones differs significantly. Thus, we consider it expedient to conduct research to determine the most suitable methods for temperature forecasting.

The concept of an information system has been proposed that will be able to carry out a more accurate temperature forecast for a specific area by selecting the most profitable ML models based on the climate patterns of different regions. Further researches in this area will help find more accurate and cheaper approaches to predicting climate indicators, which will significantly contribute to the development of AI and ML, as well as achieving the SDGs.

References

1. Luterbacher, J., Newfield, T.P., Xoplaki, E., Nowatzki, E., Luther, N., Zhang M., Khelif, N. Past pandemics and climate variability across the Mediterranean. *Euro-Mediterr J Environ Integr* 5, 46. 2020. URL: https://doi.org/10.1007/s41207-020-00197-5 (Last accessed April 18, 2024)

2. Wang, Z., Luo, R., Lu, Q., Zhang, X., Miao, D., Hu, Y., Dai, K., Li, H., Luo, Z., Fang, L., Liu, E., Liu, W. The Impact of Weather and Air Pollution on Viral Infection and Disease Outcome Among Pediatric Pneumonia Patients in Chongqing, China, from 2009 to 2018: A Prospective Observational Study. *Clinical Infectious Diseases* (Online. University of Chicago. Press), 73(2), e513–e522. 2020. URL: https://doi.org/10.1093/cid/ciaa997 (Last accessed April 14, 2024)

3. UNCC Learn. Resource Guide for Advanced Learning on predicting and projecting climate change. URL: https://www.uncclearn.org/wp-content/uploads/library/resource_guide_predicting_and_projecting_climate_change.pdf (Last accessed April 8, 2024)

4. NASA Earth Observatory. Vegetation & land surface temperature. URL: https://earthobservatory.nasa.gov/global-maps/MOD_NDVI_M/MOD_LSTD_M (Last accessed April 10, 2024)

5. THE 17 GOALS. Sustainable Development. URL: https://sdgs.un.org/goals (Last accessed April 11, 2024)

6. United Nations. Transforming our world: the 2030 Agenda for Sustainable Development. [Online]. URL: https://sdgs.un.org/2030agenda (Last accessed March 29, 2024)

7. History of numerical weather prediction. Met Office. URL: https://www.metoffice.gov.uk/weather/learn-about/how-forecasts-are-made/computer-models/history-of-numerical-weather-prediction (Last accessed April 7, 2024)

8. Gong, B., Langguth, M., Ji, Y., Mozaffari, A., Stadtler, S., Mache, K., Schultz, M. Temperature forecasting by deep learning methods. *Geoscientific Model Development*, 15 (23), pp. 8931–8956. 2022. URL: https://doi.org/10.5194/gmd-15-8931-2022 (Last accessed April 15, 2024)

9. Behzadi, F., Wasti, A., Rahat S. H., Tracy, J. N., Ray, P. A. Analysis of the climate change signal in Mexico City given disagreeing data sources and scattered projections. *Journal of Hydrology: Regional Studies.* Vol. 27. 2020. URL: https://doi.org/10.1016/j.ejrh.2019.100662 (Last accessed April 14, 2024)

10. Mansourmoghaddam, M., Rousta, I., Zamani, M. et al. Investigating and predicting Land Surface Temperature (LST) based on remotely sensed data during 1987–2030 (A case study of Reykjavik city, Iceland). *Urban Ecosyst* 26, pp. 337–359. 2023. URL: https://doi.org/10.1007/s11252-023-01337-9 (Last accessed April 14, 2024)

11. Aghelpour, P., Mohammadi, B., Biazar, S. M. Long-term monthly average temperature forecasting in some climate types of Iran, using the models SARIMA, SVR, and SVR-FA. *Theoretical and Applied Climatology*, 138(3–4), pp. 1471–1480. 2019. URL: https://doi.org/10.1007/s00704-019-02905-w (Last accessed April 11, 2024)

12. Chin, S., Lloyd, V. Predicting climate change using an autoregressive long short-term memory model. *Frontiers in Environmental Science*, 12. 2024. URL: https://doi.org/10.3389/fenvs.2024.1301343 (Last accessed April 8, 2024)

13. Saja Kh. Abu Safiah, Samy S. Abu-Naser. Climate Change temperature Prediction Using Just Neural Network. *International Journal of Academic Engineering Research (IJAER)*. ISSN: 2643-9085. Vol. 7 Issue 9, pp: 35–45. 2023. URL: https://philarchive.org/archive/ABUCCT (Last accessed April 10, 2024)

14. Shams, M. Y., Tarek, Z., Elshewey, A. M., Hany, M., Darwish, A., Hassanien, A. E. A Machine Learning-Based model for predicting temperature under the effects of climate change. *In Studies in big data*, pp. 61–81. 2023. URL: https://doi.org/10.1007/978-3-031-22456-04 (Last accessed April 14, 2024)

15. Climate. World Meteorological Organization. 2024. URL: https://wmo.int/topics/climate (Last accessed April 11, 2024)

16. Climate zones. Met Office. URL: https://www.metoffice.gov.uk/weather/climate/climate-explained/climate-zones (Last accessed April 12, 2024)

17. Köppen Climate Classification System. URL: https://education.nationalgeographic.org/resource/koppen-climate-classification-system/ (Last accessed April 13, 2024)

18. Beck, H. E., McVicar, T. R., Vergopolan, N., Berg, A., Lutsko, N. J., Dufour, A., Zeng, Z., Jiang, X., Van Dijk, A. I. J. M., Miralles, D. G. High-resolution (1 km) Köppen-Geiger maps for 1901–2099 based on constrained CMIP6 projections. *Scientific Data*, 10(1). 2023. URL: https://doi.org/10.1038/s41597-023-02549-6 (Last accessed April 9, 2024)

19. Köppen-Geiger Explorer. URL: https://koppen.earth/ (Last accessed April 14, 2024)

20. List of countries by climate zone and average yearly temperatures. URL: https://weatherandclimate.com/countries#google_vignette (Last accessed April 14, 2024)

21. Kaggle. Globallandtemperature. URL: https://www.kaggle.com/datasets/sambapython/ globallandtemperature (Last accessed April 7, 2024)

Olga PAVLOVA **Ольга ПАВЛОВА**	PhD, Associated professor of Computer Engineering & Information Systems Department, Khmelnytskyi National University, Khmelnytskyi, Ukraine, e-mail: olya1607pavlova@gmail.com https://orcid.org/0000-0001-7019-0354 Scopus Author ID: 57218181382 https://scholar.google.com.ua/citations?user=sQfkv30AAAAJ&hl=uk&authuser=1	доктор філософії, доцент кафедри комп'ютерної інженерії та інформаційних систем, Хмельницький національний університет, Хмельницький, Україна.
Vitalii ALEKSEIKO **Віталій АЛЕКСЕЙКО**	Master degree student of Computer Engineering & Information Systems Department, Khmelnytskyi National University, Khmelnytskyi, Ukraine, e-mail: vitalii.alekseiko@gmail.com https://orcid.org/0000-0003-1562-9154 https://scholar.google.com/citations?user=tVNesMAAAAAJ&hl=en	магістрант спеціальності «Комп'ютерна інженерія», Хмельницький національний університет, Хмельницький, Україна.