Ukrainian Journal of Remote Sensing

journal homepage: www.ujrs.org.ua

https://doi.org/10.36023/ujrs.2024.11.3.268

УДК 528.8:551.5:528.4:551.58

Utilizing remotely sensed data for atmospheric precipitation analysis in Ukraine

A. A. Apostolov, T. A. Orlenko*, L. O. Yelistratova

State Institution "Scientific Centre for Aerospace Research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine", Olesia Honchara Str., 55-b, Kyiv, 01054, Ukraine

Up-to-date, the world, including Ukraine, faces one of the biggest environmental problems: climate change. Studying changes in meteorological indicators is an essential task that receives significant attention. Changes in atmospheric precipitation in Ukraine from 2000 to 2023 were analyzed. The study is based on satellite data to establish trends in precipitation changes.

Nowadays, in the era of big data, selecting the best-performing dataset can be challenging. Current cloud-based technologies, such as Google Earth Engine (GEE), which store both petabytes of data and computational power for processing, offer researchers new opportunities to use and explore available datasets. The GEE service and NOAA satellite data were used to assess the spatiotemporal patterns of precipitation changes in the 21st century. Advanced cloud-based processing techniques for remotely sensed data offer extensive access to a wide range of geospatial products. These include detailed earth surface characteristics and the spatial distribution of climate indicators collected over extended periods.

Additionally, these technologies enable efficient processing and analysis of large-scale datasets, facilitating rapid assessment and monitoring of extensive geographical areas. This capability is crucial for applications in environmental monitoring and climate change studies. Average long-term values of precipitation amounts over 24 years were calculated monthly for the entire year. The research revealed specific trends in seasonal changes in precipitation characteristics during the study period, and the obtained results correspond to the current state of climatic conditions in Ukraine.

Keywords: precipitation, remote sensing, data, long-term analysis, GEE.

Introduction

Space-based remote sensing of the Earth is now widely used worldwide. The diversity of space surveys developed for remote sensing, and their total number, is steadily increasing. The detailed information they provide is used to solve numerous economic and scientific tasks by monitoring the state of the natural environment. Long-term satellite data from remote sensing of the Earth are also crucial for conducting climatological studies, allowing for the studying of the Earth as a complete ecological system. Remote sensing today encompasses a wide variety of methods for obtaining images across almost all wavelength ranges of the electromagnetic spectrum (from ultraviolet to infrared) and the radio spectrum (Apostolov et al., 2021). These methods offer a broad range of imagery, from meteorological geostationary satellite images covering almost the entire hemisphere to detailed aerial surveys of several hundred square meters.

One of the frequently discussed climatological issues at various levels is the change in climatic conditions. It should be noted that despite existing contradictions in views, there are undeniable trends that reflect the direction and indicators of changes in various factors, as revealed by long-term observational data (Lyalko et al., 2020; Khodorovskyi et al., 2023). Knowledge of the precipitation regime, including agriculture, energy, and transportation, is crucial for human life. The seasonal distribution and inter-annual variability of atmospheric precipitation determine the state of natural ecosystems and influence human economic activities in specific regions. Ukraine is among the countries where regional warming is expanding the area with insufficient moisture supply (Fooladi et al., 2023; Koman, 2020). The relevance of this study lies in the need for operational monitoring of atmospheric precipitation, which satellite data can effectively provide.

The main goal is to study the possibility of utilizing remotely sensed data on atmospheric precipitation in Ukraine assessment.

Study area

Ukraine and many Central and Eastern European countries were determined as regions under a high risk of climate change impact. During the last 20 years, air temperature has rapidly increased, posing a high concern about water resource relocation and availability (IPCC, 2021). Precipitation is one of the most essential characteristics of weather and climate conditions.

Depending on the type of atmospheric processes and features of the underlying surface, precipitation on

*E-mail: tetianaorlenko96@gmail.com
ORCID: https://orcid.org/0000-0002-4933-7750

Ukraine's territory is unevenly distributed in time and space. In Ukraine, a continental annual kind of precipitation is observed in which the amount of precipitation in the warm period exceeds that in the cold period (Ivanov et al., 2009; Santos et al., 2016). First of all, the formation of climatic conditions in the territory of Ukraine is influenced by solar radiation, the nature of the subsoil surface, and atmospheric circulation. A specific territorial individuality characterizes these factors' interaction, intensity, and effects.

Expected changes in precipitation in Ukraine vary depending on the season, while by the middle of the 21st century, seasonal changes may be complex to distinguish from the existing annual variability. Under all scenarios of greenhouse gas concentrations, most models until the 2080s indicate the probability of a significant decrease in summer precipitation in the south and southeast of Ukraine and an increase in winter precipitation in the north of Ukraine. However, the almost complete absence of changes in precipitation during these seasons is also possible.

The data indicate a greater probability of decreased precipitation in the coastal regions and an increase in the north of Ukraine. Despite the wide range of possible future changes in average precipitation, extreme precipitation events in all seasons are expected to become more intense, leading to increased surface runoff and flooding under all greenhouse gases increasing concentration scenarios. An increase in the number of wettest days per year by 10% to 25% by the end of the century is possible under all greenhouse gas concentration scenarios (Wilson et al., 2021; Lyalko et al., 2023). Natural phenomena have occurred in Ukraine during the last thirty years, primarily related to the precipitation regime. The underestimation of some aspects in the formation of this climatic index of moisture leads to the fact that it still needs to be sufficiently studied today (Khokhlov et al., 2020; Diadin, Vystavna, 2020; Boychenko et al., 2016).

As a result of global warming, the climate in Ukraine is changing dramatically (Zamfirova, Khokhlov, 2020). Therefore, each new study in this direction will provide an opportunity to predict the future state of the climate system to ensure our country's sustainable socio-economic development. Precipitation monitoring is needed to understand present and predict future climate and precipitation regime changes using remotely sensed data.

Methodology

Remotely sensed data, including GPM (Global Precipitation Measurement) and Meteosat, monitors precipitation in Ukraine. GPM provides global precipitation data via active radar, allowing us to estimate the amount and intensity of rain and snow. However, for real-time monitoring, we rely on Meteosat data, which operates in the visible and infrared bands, tracking cloudiness and precipitation. The Sentinel-1 satellite (SAR) also provides information on soil moisture, indirectly affecting precipitation estimates. The estimation algorithms use radar and radiometric data calibration techniques such as TMPA (Tropical Rainfall Measuring Mission Multi-Satellite Precipitation Analysis) to fuse information from multiple satellites. The CHIRPS system (Climate Hazards Group InfraRed Precipitation with Station Data) is an essential tool that combines satellite data with ground measurements. However, it's important to note that the CHIRPS system does not cover all of our territory of Ukraine.

Most satellite precipitation products could better capture extreme events with high temporal resolution (Kogan, Guo, 2011; Kogan et al., 2011). Thus, there is a need for a precipitation measurement product that reliably detects the intensity of heavy precipitation with high spatiotemporal resolution and a more extended recording period; available precipitation measurement products are listed in Table. 1.

Table 1. Overview of available operational satellite precipitation estimation products with their coverage and spatio-temporal resolution
(Sadeghi et al., 2021; Schneider et al., 2013)

Product	Name	Spatial resolution	Spatial coverage	Time difference	Temporary coverage
CHIRPS	Climate Hazards group Infrared Precipitation with Stations	0,05°	50°S–50°N	Daily	1981 – up-to-date
CMAP	Climate Prediction Center (CPC) Merged Analysis of Precipitation	2,5°	90°S–90°N	Monthly	1979 – up-to-date
CMORPH	CPC morphing technique	0,25°	60°S–60°N	Daliy	1998 – up-to-date
GPCP	Global Precipitation Climatology Project (GPCP)	0,5 °	90°S–90°N	Monthly	1979 – up-to-date
GPCP-1DD	Global Precipitation Climatology Project (GPCP) 1-Degree Daily (1DD) Combination	1°	90°S–90°N	Daily	1996 – 2015
IMERG	Integrated Multi-satellite Retrievals for GPM	0,1°	60°S–60°N	30-minutes	2014 – up-to-date
MSWEP	Multi-Source Weighted Ensemble Precipitation (MSWEP)	0,1°	90°S–90°N	3-hours	1979 – 2017
PERSIANN	Precipitation Estimation from Remotely Sensed Information using Artifcial Neural Networks	0,25°	60°S–60°N	1-hour	2000 – up-to-date

Product	Name	Spatial resolution	Spatial coverage	Time difference	Temporary coverage
PERSIANN-CCS	PERSIANN-Cloud Classifcation System	0,04 °	60°S–60°N	1-hour	2003 – up-to-date
PERSIANN-CDR	PERSIANN–Climate Data Record	0,25°	60°S–60°N	Daliy	1983 – 2022
PERSIANN-CCS-CDR	PERSIANN-Cloud Classifcation SystemClimate Data Record	0,04°	60°S–60°N	3-hours	1983 – up-to-date
TMPA 3B42	TRMM Multi-satellite Precipitation Analysis	0,25°	50°S–50°N	3-hours	1998 – up-to-date

The most reliable method we used in our study is the PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) model, which uses neural networks to forecast and estimate precipitation.

Since precipitation varies spatially and temporally, it is essential to use measurement products that reliably detect precipitation intensity with high spatiotemporal resolution and a more extended observation period. Analysis of available products revealed that for the entire territory of Ukraine, the most reliable data source is the PERSIANN-CDR climate data record (Ashouri et al., 2015), which utilizes artificial neural networks and NOAA constellation satellites. These sources provide daily estimates of precipitation amounts. The study assessed precipitation levels for each region of Ukraine using shapefiles to define their boundaries. Our analysis of the Ukrainian regions, which square from approximately 12,000 km² to 30,000 km² on average, led us to conclude that the PERSIANN-CDR library is an excellent tool for spatial analysis of total precipitation distribution (Paluba et al., 2024; Rincón-Avalos et al., 2022; Sorooshian et al., 2014).

In the contemporary era of big data, selecting optimal datasets poses a significant challenge. Modern cloud-based platforms, such as Google Earth Engine (GEE), provide extensive data storage capabilities and robust computational power, giving researchers unprecedented data utilization and exploration opportunities. The Google Earth Engine platform, leveraged for our study, enables the access and processing of satellite datasets through JavaScript in the cloud interface, eliminating the necessity of downloading data to local devices (Fig. 1).

Working with GEE requires basic programming skills, as it is based on JavaScript. The main principles of GEE are defining variables, functions, and expressions, which can be represented by "var variable". New variables must start with a minuscule but may contain numbers and majuscules. Earth observation data can be searched via the upper panel, which resembles Google, and called via their ID (Phan et al., 2020; Rincon-Avalos et al., 2022).

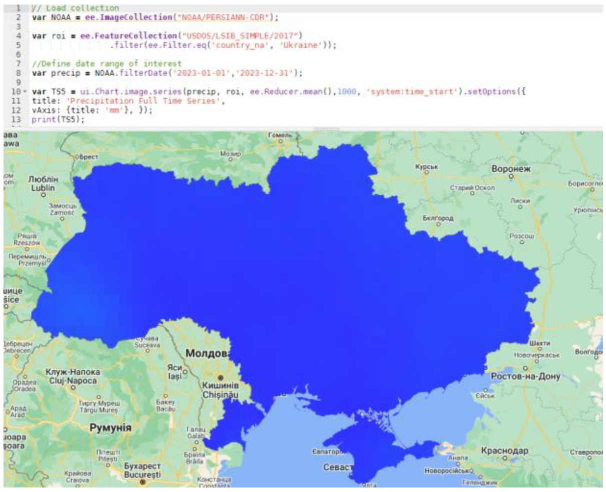

Figure 1. GEE interface for receiving and spatial analysis of precipitation on the territory of Ukraine

The methodology for estimating the spatial distribution of precipitation in Ukraine from 2000 to 2023 involves the following steps:

Open the Google Earth Engine Code Editor and upload the shapefile for Ukraine.

Import data from the NOAA library (PERSIANN-CDR: Precipitation estimation from remotely sensed information using artificial neural networks - Climate Data Record) to analyze precipitation distribution.

Select the period from 2000 to 2023 for data analysis within the PERSIANN-CDR dataset.

Generate a graph showing the distribution of annual precipitation across Ukraine.

Calculate the average yearly precipitation for Ukraine from 2000 to 2023.

Export the precipitation data as CSV files for numerical data and TIFF files for raster data.

Precipitation datasets available in half-hourly, hourly, and three-hourly temporal resolution were aggregated to year composites in GEE.

Results and discussion

Several key aspects are considered when deriving data from the PERSIANN-CDR database. PERSIANN-CDR satellite data usually have a much lower spatial resolution than data from weather stations. This can lead to underestimating precipitation in small areas or mountainous regions.

Data from weather stations arrive in real-time, while satellite data may be delayed. This is important when analyzing rainfall to monitor weather events such as downpours or floods. Data from weather stations are more accurate in a given area because they are measured on-site.

Satellite data may contain some errors, which is essential to consider when using it. Satellite data can help obtain information about precipitation over large areas or regions with no weather stations. However, they may need to be more informative for detailed analysis in specific locations.

In practice, the optimal approach combines data from both sources to obtain a more accurate and complete picture of rainfall in a given area.

The amount and seasonal variation of atmospheric precipitation across Ukraine are influenced by factors such as the movement of air masses, the nature of the underlying surface (particularly the topography), and the distribution of high and low atmospheric pressure areas. Moist air masses primarily enter Ukraine from the Atlantic Ocean, traveling from the west and northwest toward the east and southeast.

Precipitation decreases progressively from the northwest and north, where the average annual rate reaches 600-700 mm, to the east, where it ranges from 450-500 mm. Further, it decreases to around 350 mm annually in the south and southeast. The highest average annual precipitation occurs in the mountains: 1000-1500 mm in the Carpathians and up to 1200 mm in the Crimean Mountains (Climate of Ukraine, 2003).

The rise in global temperature of the surface layer of the atmosphere and its consequences have led to a set of adverse processes, which are expressed in a decrease in the bioproductivity of ecosystems, a reduction in fertility, and the level of soil moisture.

A particularly damaging process is the redistribution of precipitation throughout the year, in which the amount significantly increased in the autumn period and decreased in the hottest months.

Ukraine belongs to territories vulnerable to climatic and anthropogenic changes. In this, cloud geodata processing technologies are beneficial, including Google Earth Engine, which allows you to quickly process large data sets for large areas and quickly obtain the results of calculating the distribution of characteristics of the earth's surface.

Figure 2 illustrates the amount of precipitation over a multi-year period. There is no clear long-term trend in precipitation; instead, it exhibits an oscillating pattern with alternating peaks and declines. From 2000 to 2023, the highest total annual precipitation in Ukraine, according to satellite data, was recorded in 2001, 2004, 2005, 2010, 2016, 2017, and 2021. The lowest amounts were observed in 2011 and 2019.

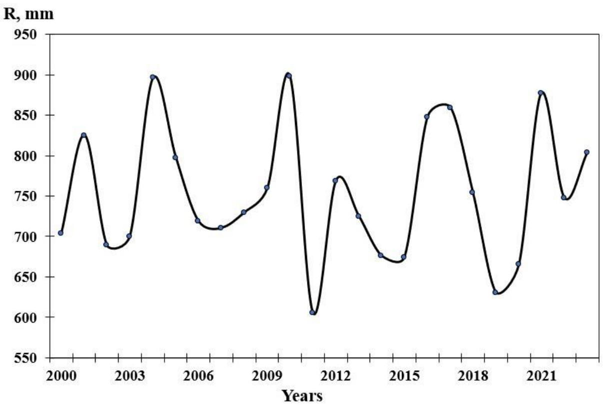

Figure 2. Observed total annual precipitation values for the territory of Ukraine from 2000-2023 based on data from the PERSIANN-CDR library

Globally, precipitation does not consistently increase with rising temperatures due to global warming. There is no uniform pattern of increased precipitation with higher temperatures. However, it should be noted that with rising temperatures, there has been an increase in spontaneous precipitation events in the modern climate of the 21st century (Apostolov et al., 2021). In Ukraine, no significant long-term changes in precipitation have been observed. Figure 3 demonstrates the spatial distribution amount of precipitation on the territory of Ukraine.

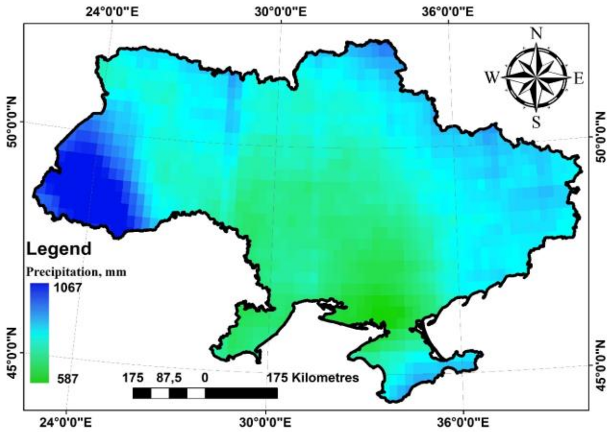

Figure 3. Average values of precipitation for the territory of Ukraine for the period 2000–2023 using data from the PERSIANN-CDR library

The amount of precipitation was calculated for different zones in Ukraine, as delineated by physical and geographical zoning (Shyshchenko, Marynich, 2003). The average annual precipitation values for each zone are as follows:

- Mixed (Coniferous-Broad-Leaved) Forests: 711–875 mm, with an averaging of 768 mm.
- Broad-Leaved Forests: 707-973 mm, averaging of 787 mm.
- Forest-Steppe Zone: 658-856 mm, averaging of 733 mm.
- Steppe Zone: 587-814 mm, with an average of 716 mm.
- Carpathians: 776-1067 mm, with an average of 963 mm.
- Crimean Mountains: 733-835 mm, with an average of 792 mm.

In mountainous regions, precipitation increases with elevation, with these areas experiencing the highest values of precipitation in the country. Additionally, satellite data reveals some meridional components in the distribution of atmospheric precipitation.

Conclusion

The current state of Earth's remote sensing technologies allows for the operational assessment of a wide range of scientific issues, including the study of changes in climatic parameters across the entire country. Our study assesses precipitation datasets in Ukraine, utilizing annual precipitation data from 2000 to 2023. The analysis was conducted using precipitation datasets available in GEE. Overall, NOAA PERSIANN-CDR was the most reliable dataset for Ukraine. Certain regions have increased rainfall, while others may face decreased rainfall. The amount of precipitation in Ukraine is unevenly distributed across the territory. The western part of the country usually has higher rainfall, while the eastern regions are more prone to aridity. This research was conducted as part of the scientific and research work titled "Assessing the Impact of Climate Change on the Environment and Socio-Economic Sustainability in Ukraine, and Developing Recommendations to Mitigate Negative Effects Based on Aerospace Survey Data and Field Studies."

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ЗАСТОСУВАННЯ ДАНИХ ДИСТАНЦІЙНОГО ЗОНДУВАННЯ ЗЕМЛІ ДЛЯ АНАЛІЗУ АТМОСФЕРНИХ ОПАДІВ В УКРАЇНІ

Апостолов О. А., Орленко Т. А., Єлістратова Л. О.

ДУ "Науковий центр аерокосмічних досліджень Землі ІГН НАН України", вул. Олеся Гончара, 55-Б, Київ, 01054, Україна

Нині світ, зокрема Україна, стикається з однією з найбільших екологічних проблем – кліматичними змінами. Вивчення змін метеорологічних показників є актуальним завданням, якому приділяється значна увага. Проаналізовано зміни кількості атмосферних опадів в Україні у період з 2000 по 2023 рік. Дослідження базується на використанні супутникових даних для встановлення тенденцій зміни опадів. На сьогодні вибір найефективнішого набору даних для виконання дослідження на території України є складним та актуальним завданням.

Сучасні хмарні технології, такі як Google Earth Engine (GEE), що зберігають як петабайти даних, так і обчислювальну потужність для обробки, пропонують дослідникам нові можливості для використання та дослідження доступних наборів даних. Використовувався сервіс Google Earth Engine та дані супутника NOAA для оцінювання просторово-часових закономірностей змін кількості опадів у XXI столітті. Удосконалені технології обробки даних дистанційного зондування на основі хмари пропонують широкий доступ до широкого спектру геопросторових продуктів. Вони містять детальні характеристики земної поверхні та просторовий розподіл кліматичних показників, зібраних протягом тривалих періодів. Крім того, ці технології забезпечують ефективне оброблення та аналіз великомасштабних наборів даних, полегшуючи швидке оцінювання та моніторинг значних географічних територій. Ця можливість має вирішальне значення для застосування в моніторингу навколишнього середовища та дослідженнях зміни клімату.

У роботі визначалися середні багаторічні значення кількості опадів за 24 роки по місяцях, загалом за рік, холодний та теплий періоди. Проведене дослідження виявило певні тенденції в сезонних змінах характеристик опадів за період дослідження, отримані висновки відповідають сучасному стану кліматичних умов на території України.

Ключові слова: опади, дистанційне зондування Землі, довгостроковий аналіз, GEE.

Рукопис статті отримано: 05.09.2024
Надходження остаточної версії: 16.09.2024
Публікація статті: 30.09.2024