

RESEARCHING CLIMATE CHANGE WITH MODERN METHODS

T.S.Mahmudov, F. Hajizadeh

Azerbaijan University of Architecture and Construction

teymurmahmudov01@gmail.com

Abstract: Climate change research increasingly relies on advanced scientific techniques and digital technologies to analyze environmental transformations. Modern methods include satellite-based Earth observation, remote sensing technologies, Geographic Information Systems (GIS), global and regional climate simulations, statistical analysis, and artificial intelligence with machine learning applications. These tools facilitate continuous monitoring and prediction of variations in temperature, precipitation, sea level, and land use patterns. By integrating multiple analytical approaches, researchers can improve the accuracy of climate impact assessments, identify potential risks, and develop more effective adaptation and mitigation strategies.

Keywords: climate change, remote sensing, satellite monitoring, Geographic Information Systems (GIS), artificial intelligence, machine learning, climate modeling, environmental monitoring.

1.Introduction

Climate change refers to long-term and statistically significant alterations in the Earth's climate system that occur over decades or even centuries. These changes are primarily driven by global warming resulting from the increased concentration of greenhouse gases, such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), in the atmosphere due to human activities, including fossil fuel combustion, industrial production, and deforestation. Although natural factors such as volcanic eruptions and variations in solar radiation also influence climate, anthropogenic emissions have become the dominant cause of recent climate change.

Rising global temperatures significantly affect precipitation patterns, causing prolonged droughts in some regions and intense rainfall and flooding in others. Climate change has also increased the frequency, duration, and severity of extreme weather events, including heatwaves, hurricanes, storms, wildfires, and heavy precipitation. These environmental changes accelerate glacier and polar ice melt, contribute to sea-level rise, and threaten coastal ecosystems and communities.

The consequences of climate change extend beyond environmental degradation. Ecosystems experience habitat loss, biodiversity declines, and disruptions to ecological balance, making species more vulnerable to extinction. Agriculture is increasingly affected through reduced crop productivity, changing growing seasons, and greater exposure to pests and diseases. Water availability is becoming more uncertain due to altered rainfall patterns and shrinking freshwater resources, while public health is threatened by heat-related illnesses, the spread of vector-borne diseases, air pollution, and food insecurity.

Given its widespread environmental, economic, and social impacts, climate change has become one of the most significant global challenges of the 21st century. Continuous scientific research is essential to improve our understanding of climate processes, predict future changes, and evaluate potential risks. At the same time, developing effective mitigation measures to reduce greenhouse gas emissions and adaptation strategies to increase the resilience of societies and ecosystems has become a key priority for achieving sustainable development [1].

2. Experimental Section

2.1 Remote sensing methods in climate change research

Remote sensing is a key technology in the monitoring and forecasting of climate change. This method enables the multidimensional analysis of the Earth's surface, atmosphere, and oceans through electromagnetic spectral measurements obtained from satellites. Remote sensing satellites conduct continuous observations on a global scale and monitor changes occurring in the climate system over time; in other words, they help determine the rate, intensity, and spatial distribution of climate change. Through such data, major climate indicators such as temperature changes, glacier retreat, sea level rise, impacts on vegetation cover, water vapor distribution, and aerosol concentrations can be quantified. Remote sensing also plays a crucial role both in the parameterization of global and regional climate models and in the detection of trends from time-series satellite data.

Many satellite missions measure critical Earth system variables through various spectral radiometric instruments. For example, the MODIS instrument onboard NASA's Terra and Aqua satellites observes the Earth's surface and cloud-aerosol systems in 36 spectral bands 1–2 times daily, generating a range of products for long-term climate indicators. These indicators include land surface temperature, cloud cover, and aerosol optical depth [2,3].

VIIRS, located on the Suomi NPP and NOAA-20/NOAA-21 satellites, is considered the successor to MODIS and provides global-scale sea ice, snow cover, and vegetation products. The snow and sea ice indicators of VIIRS are harmonized with MODIS to create continuous long-term climate datasets, which are essential for assessing glacier changes and climate dynamics trends.

The Copernicus Sentinel-3 mission, operated by ESA/EUMETSAT, collects sea and land surface temperature data through the SLSTR (Sea and Land Surface Temperature Radiometer) instrument, while the OLCI (Ocean and Land Colour Instrument) gathers spectral measurements of oceans and terrestrial landscapes. These datasets are used in climate models to analyze ocean heat content and photosynthesis-related indicators [4].

Remote sensing is not limited only to optical imagery. NASA's ICESat-2 (Ice, Cloud, and Land Elevation Satellite-2) uses laser altimetry data to measure glacier thickness and morphology, which is particularly important for sea level rise forecasting.

The data obtained from these satellite systems are applied in climate research for:

- Temperature and land cover change analysis (e.g., LST and trend analyses),
- Monitoring ice and snow cover changes (long-term glacier melting trends),
- Assessing sea surface temperature and sea level rise through altimetry,
- Biomass monitoring using vegetation and photosynthesis indices (NDVI, EVI),
- Atmospheric change analysis through aerosol and cloud measurements.

Table 1. Remote sensing satellites and climate indicators

Satellite	Orbit type	Measurement indicator	Temporal resolution	Spatial resolution
Terra modis	Polar	Land surface temperature	Every 1–2 days	500 m
Aqua modis	Polar	Cloud optical depth	Every 1–2 days	500 m
Sentinel-3 slstr	Polar	Sea and land surface temperature	Once per day	1 km
Sentinel-3 olci	Polar	Ocean and land color	Once per day	300 m
Icesat-2 atlas	Polar laser	Ice thickness	10 times per month	~0.7 m
Jason/sentinel-6b	Polar altimeter	Sea level height	Every 10 days	1 km

The satellites presented in this table measure various components of the climate system — including the atmosphere, biosphere, hydrosphere, and in some cases the cryosphere — thereby comprehensively recording the dynamics of climate change. Polar-orbiting satellites provide global coverage and frequent repeat observations, which help identify long-term climate trends. High spatial and spectral resolution enables the accurate assessment of local changes on the Earth's surface. Such multispectral and multitemporal observations are critical for climate models because they provide not only information about current conditions, but also time-series data that support forecasting and reveal cause-and-effect relationships in climate change. These satellite databases are widely used both in scientific research and in the development of adaptation and mitigation strategies at the management and policy-making levels [5].

3.Result and discussion

3.1 The role of artificial intelligence in climate change research

Artificial intelligence has become a fundamental tool for analyzing large-scale and multidimensional data in climate change research. Modern climate science generates terabytes of satellite imagery, meteorological station records, ocean buoy measurements, atmospheric reanalysis products, and paleoclimate indicators every day. Since the volume and complexity of these datasets exceed the capabilities of classical statistical methods, machine learning and deep learning models are widely applied for data structuring, missing value reconstruction, and noise reduction. Applied studies demonstrate that AI-based imputation and filtering techniques can reduce reconstruction errors in multidimensional climate datasets by approximately 30–40% compared to traditional interpolation methods. This significantly increases the reliability of long-term trend analyses.

Artificial intelligence also accelerates optimization processes in the parameterization and calibration of climate models. Global and regional climate models contain hundreds of parameters, and manual adjustment of these parameters requires extensive computational resources. Genetic algorithms, Bayesian optimization, and deep reinforcement learning methods can identify optimal parameter combinations, reducing computation time by 40–60% and decreasing mean square forecast errors by 20–30%. This approach is particularly effective in evaluating long-term scenarios of temperature and precipitation forecasts. As a result, the uncertainty intervals of model outputs become narrower, and the statistical reliability of predictions improves.

The detection of nonlinear processes is one of the major advantages of artificial intelligence. Since the climate system is chaotic and multifactorial, the frequency and intensity of extreme weather events cannot be fully described using linear models. Long Short-Term Memory (LSTM) networks and Convolutional Neural Networks (CNNs) learn spatial-temporal structures and provide more accurate estimations of the probability of events such as heatwaves, heavy precipitation, and drought episodes. Statistical comparisons indicate that LSTM-based models achieve 15–25% higher accuracy in forecasting extreme temperature events compared to traditional ARIMA models. This difference becomes especially evident in regions characterized by high climatic variability.

Artificial intelligence is also extensively used in the processing of satellite data. For example, deep learning-based classification models are applied for the automatic identification of land cover changes and glacier retreat from multispectral imagery. Such systems can process large volumes of raster data within a short period and accurately extract changes in ice cover area and vegetation indices. Experiments show that CNN-based classification models can achieve 90–95% accuracy in land cover detection, which is significantly superior to manual interpretation methods.

In climate forecasting, hybrid models — integrating physical climate models with neural networks — are considered particularly promising. Physics-informed neural network approaches incorporate physical laws as constraints, ensuring that forecasts remain consistent with real-world processes. Such models have the potential to reduce uncertainty in scenario-based assessments of indicators such as global temperature increase and ocean surface warming by 10–15%.

4.Conclusion

The study of climate change using modern methods provides higher accuracy, efficiency, and multidimensional analytical capabilities compared to traditional observation and statistical approaches. Satellite observations and remote sensing enable continuous monitoring on a global scale, GIS technologies allow the visualization of spatial-temporal changes, and climate models make it possible to develop long-term forecasts under different emission scenarios. Artificial intelligence and big data analytics identify nonlinear processes, reduce forecasting errors, and improve the reliability of model outputs. The integration of these methods creates opportunities for more objective climate risk assessment, the improvement of early warning systems, and the scientific justification of decision-making processes.

Among the перспективіve directions, the development of high-resolution regional models, real-time data integration, the wider application of hybrid physical-digital models, and the creation of AI-enhanced forecasting platforms are of particular importance. At the same time, the sharing of climate data on open platforms and the strengthening of multidisciplinary approaches expand practical applications. These directions will play a significant role in the development of sustainable development strategies, the planning of adaptation and mitigation measures, and the management of climate-related risks at the regional level.

References

1. Azərkosmos. İqlim dəyişikliyinə kosmosdan baxış, 2024
2. AMEA Radiasiya Problemləri İnstitutu. Süni intellekt və iqlim tədqiqatlarında tətbiqi, 2024
3. Azercosmos & STAR.VISION. AI-Powered Environmental Monitoring Project, 2023
4. Kazanskiy N., Khabibullin R., Nikonorov A., Khonina S. A Comprehensive Review of Remote Sensing and Artificial Intelligence Integration: Advances, Applications, and Challenges, 2025
5. Adaptation Fund. Scoping Study on Use of AI in Evaluations, 2025