EDITORIAL PAPER

THE SENSITIVITY OF MID- AND HIGH-LATITUDE TERRESTRIAL ECOSYSTEMS TO CLIMATE CHANGE

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INTRODUCTION

Modern climate change has become one of the most significant scientific and societal challenges of the 21st century. Rising air temperatures, altered precipitation patterns, an increased frequency of extreme weather events, the degradation of cryosphere systems, and the acceleration of transformations in terrestrial ecosystems are now being observed across nearly all regions of the globe. These changes are particularly pronounced in the mid- and high latitudes of the Northern Hemisphere where, however, warming rates exceed the global average and natural and socioeconomic systems are highly sensitive to environmental change.

Northern Eurasia is a key region for understanding the mechanisms, consequences, and future trajectories of climate-driven transformations. Its diverse landscapes, including forests, tundra, steppes, wetlands, mountains, and permafrost, play a crucial role in global biogeochemical cycles, water resources, biodiversity conservation, and climate regulation. Moreover, these territories support major industrial, agricultural, transportation, and urban systems, the sustainability of which increasingly depends on the ability of societies to adapt to rapidly changing climatic conditions.

The Special Issue titled «The Sensitivity of Mid- and High-Latitude Terrestrial Ecosystems to Climate Change» was conceived as a platform for interdisciplinary discussions about how natural and human-modified systems respond to climate variability and long-term climate change. This issue integrates studies of paleoclimatic reconstructions, hydrological modeling, ecosystem dynamics, the impacts of climate on biodiversity and public health, land system transformations, and adaptation strategies. Together, the contributions demonstrate the importance of combining retrospective analyses, contemporary observations, numerical modeling, and scenario-based forecasting to better understand how terrestrial ecosystems function and how vulnerable they are under changing climatic conditions.

This Special Issue is closely linked to the implementation of the large, interdisciplinary scientific project titled «Global Climate Challenges in Russia: Retrospective Analysis, Forecast, and Adaptation Mechanisms», which is supported by the Ministry of Science and Higher Education of the Russian Federation. The project aims to evaluate the long-term dynamics and contemporary trends of natural and socioeconomic systems in the context of climate change, as well as possible future pathways, and to develop scientifically grounded adaptation strategies for societies and ecosystems. It integrates paleogeographic reconstructions, modern observational datasets, climate and hydrological modeling, remote sensing, and socioeconomic analysis to investigate climate impacts across diverse environmental zones in Russia, ranging from the Arctic to subtropical regions.

A major conceptual foundation of the project and this Special Issue is the understanding that contemporary climate trends cannot be fully interpreted without knowledge of past environmental variability. Instrumental observations only cover a relatively short period and do not encompass the full range of natural climate variability. Therefore, paleoclimatic archives, historical evidence, and long-term ecosystem reconstructions provide essential information for identifying analogues of future environmental states, evaluating the resilience of ecosystems and human communities, and improving the validation of climate models.

At the same time, modern climate change is no longer only a scientific problem. It directly affects water resources, food security, public health, biodiversity, energy systems, transportation infrastructure, and regional economic development. Climate adaptation is an increasingly urgent priority for national governments and regional administrations. Consequently, the studies in this issue address fundamental scientific questions and applied challenges related to sustainable development, environmental management, and climate adaptation.

The seven papers in this Special Issue demonstrate the variety of approaches and research directions that are currently influencing climate-related environmental studies in Northern Eurasia.

The paper by Medvedev, Stepanenko, and Ryazanova (2026) addresses a critical practical aspect of climate change research: how river runoff and hydrological systems respond to changing climatic conditions. In their paper entitled: «Simulation of the water regime of two large European Russian rivers under the conditions of modern climate in the TerM land surface model», they evaluate the TerM land surface model's ability to reproduce the hydrological regimes of the Vychegda and Oka rivers. Through their analysis of runoff dynamics, snow water equivalent, and spring flood characteristics, the authors demonstrate that physically based land surface models can accurately reproduce essential elements of the regional water balance under current climate conditions.

This study is significant because it highlights the opportunities and limitations of hydrological modeling in large river basins. Proposed model improvements, such as accounting for artificial irrigation, calibrating infiltration parameters, and refining river network characteristics, significantly improve simulation quality. These advances are crucial for future evaluations of water availability, flood risks, and hydrological responses to projected warming in European Russia and other temperate regions.

The hydrological sensitivity to climate change is addressed in the paper by Georgiadi et al. (2026) titled «Changes in annual river flow in the Volga–Kama and Angara–Yenisei reservoir basins under contemporary and scenario global warming». The paper examines observed and projected changes in annual runoff and water availability in some of the most important river systems in Russia. Using observational datasets and CMIP6 climate model ensembles, the authors demonstrate substantial regional differences in the hydrological responses to global warming. The study shows that annual runoff in the Angara–Yenisei reservoir basins will likely increase under future warming scenarios, while changes in the Volga–Kama basin may vary considerably in magnitude and direction. The paper's analysis of water availability per capita is particularly important because it links hydrological changes with demographic and socioeconomic dynamics.

The results emphasize the growing importance of integrating climate projections into long-term water management, hydropower planning, and regional adaptation strategies. Reservoir systems in Northern Eurasia are critical to energy production, navigation, and water supply; their future operation will depend heavily on evolving climatic conditions.

The paleoclimatic dimension of ecosystem sensitivity is explored in the paper by Razjigaeva et al. (2026) titled «The Late Holocene Climatic Events on the Southernmost Russian Far East Coast: Variability Drivers». Using high-resolution paleoecological and geochemical analyses of the Lotus Lake record, the study reconstructs hydroclimatic variability over the past 2460 years. The paper provides important insights into the interactions among monsoon circulation, solar activity, Pacific Ocean processes, and regional hydrological dynamics. The authors demonstrate that the environmental evolution of Lotus Lake was strongly influenced by fluctuations in the East Asian summer monsoon and large-scale atmosphere–ocean interactions in the northwestern Pacific.

One of the study's major strengths is its demonstration of the complex spatial heterogeneity of hydroclimatic changes in the Pacific sector of Northeast Asia. Reconstructed environmental shifts during the Medieval Climate Anomaly and the Little Ice Age suggest that regional ecosystem responses were controlled by multiple interacting climatic drivers, such as changes in atmospheric circulation regimes and modes of climatic variability, rather than by temperature changes alone. The paper also emphasizes the importance of high-resolution paleoclimatic reconstructions in understanding abrupt environmental transitions and identifying natural analogues of ongoing climate change.

The issue of the impact of climate change on biological systems and public health is addressed in the contribution by Popov and Popova (2026) titled «Modeling the Potential Distribution of the *Ixodes pavlovsky*i Tick and Its Changes under Current Climatic Conditions». The expansion of vector-borne diseases is one of the most serious ecological and public health consequences of contemporary climate change. Using the MaxEnt modeling approach, the authors reconstruct the climatic range of *Ixodes pavlovsky* for three periods spanning from 1961 to 2020. Their study shows that warming temperatures have already contributed to a significant expansion of suitable habitats for the species, especially in Siberia. Identifying annual mean temperature and precipitation seasonality as dominant controlling variables emphasizes the close relationship between climate and vector ecology.

Importantly, the paper goes beyond a purely biogeographical analysis by emphasizing the practical implications of shifting species ranges for epidemiological monitoring, veterinary management, and adaptation planning. The findings underscore the necessity of integrating ecological forecasting into public health strategies in the face of rapid environmental change.

Another dimension of the impacts of climate change is represented by the paper by Szwed (2026) titled «The Changing Climate of Kielce: Insights from Extended Meteorological Analyses». Using long-term meteorological observations from 1966 to 2023, the study reveals significant warming trends in the Świętokrzyskie region of central Poland. The results reveal increasing air temperatures and substantial transformations in snow cover, heat wave frequency, and precipitation variability. Of particular note is the documented decline in snow cover duration and thickness, which has important implications for regional hydrology, agriculture, ecosystems, and urban infrastructure.

This paper clearly illustrates how regional climate studies can provide information that can be directly applied to adaptation planning. The observed increase in compound climate extremes, including simultaneous heat waves and droughts, demonstrates the growing vulnerability of regional socio-ecological systems. Therefore, the study contributes to the broader understanding of how global climate change manifests at local and regional scales.

The socio-economic and policy dimensions of climate change are explored in the paper by Klimenko et al. (2026) titled «History versus Aspirations: Carbon Neutrality Postponed by Several Decades». The study addresses a central question of contemporary climate policy: Can major developing economies achieve their declared carbon-neutrality targets within the proposed timeframes? By analyzing energy systems, land use, decarbonization trajectories, and carbon capture capacities in nine major developing economies, the authors conclude that current decarbonization rates and carbon capture technology deployment may be insufficient to achieve carbon neutrality within the declared timeframes. The paper emphasizes the substantial inertia in energy, industrial, and agricultural systems and discusses the growing importance of adaptation measures alongside mitigation efforts in future climate policy.

The study raises important questions about the feasibility of current climate strategies, the technological and economic challenges of rapid decarbonization, and the role of adaptation planning in the context of ongoing climate change. This discussion contributes to the broader international debate on the interaction between mitigation and adaptation approaches in climate policy.

Finally, the paper by Matasov et al. «Historical Land Systems of Russia: Trends, Biases, and Gaps in the Literature» (2026) provides an important meta-analysis of land system science research in Russia. Through a systematic review of 210 peer-reviewed studies, the authors identify significant geographical and thematic imbalances in historical land use research. The paper reveals that despite their major significance for global environmental change research,

large regions of Siberia, the Arctic, and the Russian Far East remain poorly studied. The paper also highlights the methodological limitations associated with the insufficient integration of historical datasets, remote sensing, and multi-scalar analysis.

This contribution is especially valuable because it addresses the scientific infrastructure of climate-related research itself. By identifying gaps in data accessibility, international visibility, and methodological integration, the paper outlines priorities for the future development of land system science in Russia and northern Eurasia. The paper emphasizes the importance of interdisciplinary approaches combining environmental history, remote sensing, geography, ecology, and socio-economic analysis.

Taken together, the papers in this Special Issue reveal several common themes.

First, climate change in Northern Eurasia affects multiple systems simultaneously, including hydrological, biological, cryospheric, and socio-economic systems. Understanding these interactions requires interdisciplinary approaches that can integrate observations, modeling, paleodata, and applied assessments.

Second, regional responses to climate change are highly heterogeneous. Even within relatively similar climatic zones, ecosystem and hydrological responses may differ substantially depending on local environmental conditions, circulation patterns, land use, and socioeconomic factors.

Third, long-term perspectives are essential. Paleoclimatic reconstructions and historical analyses provide critical insights into ecosystem resilience, rates of environmental transformation, and the mechanisms driving climatic variability.

Fourth, adaptation emerges as a central challenge throughout the issue. Studies demonstrate that climate change is already influencing water resources, public health, biodiversity, energy systems, and land use. Effective adaptation therefore requires integrated scientific knowledge that bridges the natural and social sciences.

The Special Issue highlights the growing importance of advanced methodologies in climate research. Numerical modeling, remote sensing, paleoecological analysis, species distribution modeling, and large climate model ensembles are forming an increasingly important basis for quantitative assessments of ecosystem sensitivity and future environmental risks. At the same time, the contributions remind us that models and projections must be continuously validated against observational and historical evidence.

The editors hope this collection of papers will encourage further interdisciplinary collaboration among climatologists, geographers, ecologists, hydrologists, and social scientists. Addressing modern climate challenges requires improved scientific understanding and effective communication between science, policy, and society.

As climate change accelerates, Northern Eurasia will continue to play a critical role in the global climate system and in international discussions on adaptation, mitigation, biodiversity conservation, and sustainable development. The vast terrestrial ecosystems, water resources, cryosphere, and socio-economic systems of the region provide major vulnerabilities and significant opportunities for developing adaptive responses to environmental transformation.

We sincerely thank all the authors for their valuable contributions to this special issue and the reviewers for their thoughtful comments and constructive recommendations. We are also grateful to the editorial team for their support in preparing this issue.

We hope the studies presented here stimulate further research on the sensitivity, resilience, and adaptive capacity of terrestrial ecosystems under changing climatic conditions. We also hope they contribute to developing scientifically grounded strategies for sustainable environmental management in Northern Eurasia and beyond. ■

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