

An Integrated Data Science Framework for Climate Risk Assessment and Sustainable Intervention

OPEN ACCESS

Volume: 13

Special Issue: 3

Month: February

Year: 2026

P-ISSN: 2321-788X

E-ISSN: 2582-0397

Citation:

Kannan, A., and J. Jayanthi. "An Integrated Data Science Framework for Climate Risk Assessment and Sustainable Intervention." *Shanlax International Journal of Arts, Science and Humanities*, vol. 13, no. 3, 2026, pp. 210–14.

DOI:

<https://doi.org/10.34293/sijash.v13iS3-i1-Feb.10281>

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Abstract

Environmental calamity of great proportion, climate change represents a critical threat to ecosystems and societies around the globe. However, it is imperative to formulate mitigation strategies and solutions promptly, and this is heavily dependent on the improvement of detection, attribution, and prediction techniques derived from the analysis of climate change. Apart from assessing the quantification of anthropogenic climate change, this paper aims to examine the rising role of data science in informing impact assessment and specific interventions in climate-sensitive industries. First, this paper examines the conventional and novel techniques for understanding the climate, particularly through the application of machine learning techniques using data obtained from Earth systems. Next, this paper overviews how statistical analysis of multi-domain data sets, such as crop yields and migration, and sophisticated climate modelling helps scientists understand the effects of climate change. On this basis, we focus on the role of data-driven solution paradigms in enabling smart actions for addressing the issue of climate change. This includes the suppression of global warming through control of solar radiation, reduction of emissions through optimized renewable infrastructure, and mapping of risk. However, we examine the ethical issues surrounding some of the solutions to this problem and the barriers to implementation. In this paper, we focus on the role of ongoing data collection in addressing the issue of climate change through interdisciplinarity, in spite of the fact that there are good tools for detection, attribution, and response to this issue through data science.

Keywords: Climate Change, Data Science, Climate Modelling, Machine Learning, Big Data Analytics, Renewable Energy Optimization, Earth Observation

Introduction

Climate change has emerged as a defining global issue of our time. Global warming, extreme weather events, sea-level rise, and loss of biodiversity have been increasingly associated with anthropogenic increases in greenhouse gas emissions. Scientific consensus indicates that human activities, particularly fossil fuel combustion, deforestation, and industrial activities, have substantially altered the Earth's climate system.

To understand and mitigate climate change, it is critical to accurately detect changes, attribute causes, and predict future scenarios. Traditional science approaches to understanding climate

change have been remarkable; however, with the exponential growth of climate-related information, the field of data science has become indispensable.

This paper aims to explore the role of data science in understanding and mitigating climate change.

Climate Data Sources and Earth System Observations

Climate science draws on a wide range of data sources gathered over a wide range of spatial and temporal scales. Some of the sources include:

Satellite Observations

Earth observation satellites offer continuous global monitoring of atmospheric temperature, greenhouse gas concentrations, sea ice extent, ocean heat content, and vegetation. Remote sensing technologies enable scientists to monitor large-scale climate trends and anomalies at very high spatial resolutions.

Ground-Based Monitoring Systems

Weather stations, ocean buoys, and ground sensors measure temperature, precipitation rates, wind speed, and composition. Long-term historical records obtained from ground-based monitoring systems are critical for trend analysis.

Reanalysis and Climate Model Data

Reanalysis combines data from ground-based monitoring systems and physical models of the climate system to produce global climate data sets. General Circulation Models (GCMs) simulate the interactions between the atmosphere, oceans, land surfaces, and ice to project future climate scenarios under different emission scenarios.

The integration of these data sources provides a ‘big data’ environment characterized by high volume, velocity, and variety—an appropriate setting for data science.

Data Science Techniques in Climate Change Research

Statistical Climate Trend Analysis

Various statistical techniques, for example, time series, regression, and extreme value theory, have been utilized to examine long-term rising trends in the Earth’s temperature. This helps to differentiate between anthropogenic and natural changes.

Machine Learning for Climate Prediction

Various machine learning techniques have been applied to improve the accuracy of climate prediction. Some of the techniques applied include:

- Deep learning techniques for precipitation prediction
- Neural network techniques for cyclone prediction
- Random forest techniques for drought prediction
- Support vector machines for temperature anomaly prediction

These techniques improve pattern detection in the dataset.

Big Data Analytics and High-Performance Computing

Global climate change involves huge volumes of data, with some of this data having been collected over decades. High-performance computing infrastructures have been applied to enable:

- Real-time processing of climate change data
 - Ensemble techniques for simulating climate change
 - Downscaling of global climate change models to regional levels
- Big data analytics techniques have been applied to enable the extraction of valuable information from the complex climate change phenomenon.

Detection and Attribution of Climate Change

Detection of climate change refers to the statistical detection of changes in climate variables. On the other hand, attribution of climate change refers to the determination of the reasons for the changes.

Signal Detection

Using sophisticated statistical tools, changes in the climate are compared with computer-generated natural variability.

Causal Inference Models

Using data science techniques, the role of greenhouse gases in the detection of changes in the climate can be quantified. Causal inference techniques have been combined with statistical validation techniques.

Extreme Event Attribution

Using data science techniques, the possibilities of extreme weather events happening in the future due to human activities can be determined.

Multi-Domain Impact Assessment

Climate change affects different domains simultaneously. Data fusion of different domains helps in better understanding of the risks involved.

Agriculture

Combining climate projections with agricultural data helps in predicting food security risks.

Migration and Socioeconomic Impacts

Combining data using statistical models helps in predicting migration patterns based on climate stressors such as droughts and sea level rise.

Public Health

Changes in temperature and precipitation patterns due to climate change affect public health, and predictive analytics helps in predicting diseases that are affected by climate change.

Data-Enabled Climate Solutions

Renewable Energy Optimization

Data analytics helps in optimizing the placement of solar panels and windmills to increase their efficiency.

High-Resolution Climate Risk Mapping

Geospatial data analysis helps in creating climate risk maps that can be used at the local level.

Solar Radiation Management (SRM)

Solar radiation management, a technique to mitigate global warming, involves reflecting a fraction of solar radiation to prevent global warming. It requires extensive climate modeling and predictive simulations, but it is a geoengineering technique that needs to be addressed in a broader framework of ethical concerns.

Ethical and Practical Challenges

Ethical Concerns

- Unequal regional consequences of geoengineering
- Issues of intergenerational justice
- Issues of governance with regard to climate change

Data Limitations

- Gaps in the coverage of observational data
- Biases in the data
- Uncertainties associated with the data

Implementation Challenges

- High costs associated with the infrastructure
- Resistance from the political class
- Lack of international cooperation

Climate change is a multifaceted challenge requiring cooperation among experts from different fields.

Interdisciplinary Collaboration and Future Directions

Climate change is a multifaceted challenge requiring cooperation among experts from different fields. The fields include:

- Climate change experts
- Data experts
- Engineers
- Economists
- Policymakers

Future directions include:

- Improved climate data integration systems
- AI-assisted earth system modeling
- Ethical considerations with regard to climate change intervention technologies
- Community-based participatory data systems

Further investment in climate change data systems is crucial.

Conclusion

Data science has proven to be a valuable asset in the fight against climate change, helping to detect, attribute, predict, and design solutions to the problem of climate change. Data science, through the use of various data sets and advanced analytical techniques, helps scientists better understand the complex nature of Earth's climate system. However, it is worth noting that while technical capabilities are a great start, addressing the ethical, governance, and implementation hurdles is equally important to avert drastic changes to the environment and foster sustainable development.

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