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Computational Modeling of Climate Change with Temperature, Rainfall and Carbon Interactions Using Euler's Method

Abraham Osogo Nyakebogo[1], Omariba Geofrey Ong'era[2*]

[1] Department of Mathematics and Actuarial Science, Kisii University, P.O. Box 408-40200, Kisii, Kenya.

[2*] Department of Pure and Applied Mathematics, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Juja, Kenya.

*** Correspondence:** Omariba Geofrey Ong'era

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ABSTRACT: Climate change remains a major global challenge due to its complex interactions involving temperature variability, rainfall fluctuations, and increasing carbon emissions. Understanding these interactions is essential for predicting climate behavior and developing effective mitigation strategies. This study presents a computational model for climate change incorporating temperature–rainfall–carbon interactions using Euler's method. The model is formulated as a system of coupled nonlinear ordinary differential equations describing the dynamic relationships among temperature variation, rainfall distribution, and atmospheric carbon concentration. Euler's numerical method is employed to obtain approximate solutions of the governing equations and simulate the temporal evolution of the climate system under varying parameter conditions. The model is implemented in MATLAB, and the results are presented graphically to illustrate the influence of carbon emissions and weather interactions on climate dynamics. Numerical simulations are used to analyze the effects of key model parameters on system behavior and stability. The results show

that variations in carbon concentration significantly influence temperature and rainfall patterns, while the interactions among the climate variables affect the long-term evolution of the system. The study demonstrates that Euler's method provides an effective computational tool for simulating nonlinear climate dynamics and that mathematical modeling offers a useful framework for understanding climate change processes. The proposed model provides potential applications in climate prediction, environmental planning, and further research in climate dynamics.

1. Introduction

Climate change has become one of the most pressing global challenges of the twenty-first century because of its widespread impacts on environmental sustainability, ecosystems, economic development, and human livelihoods. Increasing global temperatures, shifting rainfall patterns, prolonged droughts, rising sea levels, and more frequent extreme weather events have raised serious concerns about the long-term stability of the Earth's climate system. These changes are strongly associated with rising atmospheric carbon emissions caused by industrialization, fossil fuel combustion, deforestation, and other human activities. The interactions among temperature variability, rainfall distribution, and atmospheric carbon concentration form a complex nonlinear system that is difficult to analyze using conventional approaches alone. This complexity has created the need for mathematical and computational models capable of representing climate dynamics and predicting future climate behavior (IPCC, 2007; Soldatenko, 2021).

Temperature is a major indicator of climate change and is directly influenced by greenhouse gas accumulation in the atmosphere. Carbon dioxide and other greenhouse gases trap outgoing longwave radiation, resulting in increased global temperatures through the greenhouse effect. Rising temperature affects atmospheric circulation, evapotranspiration, moisture availability, and hydrological processes, which in turn influence rainfall patterns. Rainfall variability may manifest through irregular seasonal cycles, reduced precipitation in some regions, and excessive rainfall or flooding in others. Because these climate variables are interconnected, changes in one variable may generate feedback effects in the others, making climate behavior highly nonlinear and dynamic. Understanding these interactions is therefore essential for predicting climate variability and designing effective mitigation and adaptation strategies (IPCC, 2007; Doris & Shad, 2024).

Traditional approaches for studying climate systems have often relied on observational data analysis, statistical forecasting methods, and complex general circulation models. While these methods have contributed significantly to understanding climate change, they may be limited by computational cost, data requirements, and difficulties in isolating the effects of specific interacting variables. In contrast, mathematical modeling provides a complementary framework in which the essential dynamics of climate systems can be represented through systems of differential equations. Such models allow researchers to study feedback interactions, identify equilibrium behavior, perform sensitivity analysis, and simulate long-term climate responses under varying conditions (Soldatenko, 2021).

Mathematical models based on ordinary differential equations have become increasingly important in climate studies because they allow climate variables such as temperature, rainfall, and carbon concentration to be represented as coupled dynamical systems. Through these models, the evolution of climate variables can be described mathematically as functions of time, while interaction terms can represent feedback effects among the variables. Such models are particularly useful when nonlinear interactions make analytical solutions difficult or impossible to obtain. In such cases, numerical methods provide practical tools for approximating solutions and investigating system behavior (Kuria, 2025; IPCC, 2007).

The use of numerical methods in climate modeling has grown substantially due to the increasing complexity of climate systems. Numerical methods allow differential equations representing climate dynamics to be solved approximately by discretizing time into finite intervals. Among these methods, Euler’s method remains one of the most fundamental and widely applied approaches for solving systems of ordinary differential equations. Although relatively simple, Euler’s method provides an effective computational technique for approximating solutions of nonlinear systems and examining how climate variables evolve under varying parameter values. Its simplicity also makes it suitable for implementing climate models in computational software such as MATLAB for simulation and graphical analysis.

MATLAB has become an important computational platform in applied mathematics and climate modeling because of its ability to implement numerical algorithms, solve differential equations, and generate graphical outputs for system analysis. In climate modeling, MATLAB provides a useful environment for simulating temperature dynamics, rainfall variability, and carbon interactions under different parameter conditions. Graphical outputs generated from MATLAB simulations make it possible to visualize the temporal behavior of climate variables, identify trends, and analyze the influence of model parameters on climate evolution. These capabilities make MATLAB an appropriate tool for implementing the computational model developed in this study.

Several studies have demonstrated the usefulness of mathematical modeling in climate analysis. The Intergovernmental Panel on Climate Change reported that increasing greenhouse gas emissions are strongly associated with rising temperatures and changes in global precipitation patterns (IPCC, 2007). Soldatenko (2021) developed mathematical approaches for analyzing climate system dynamics and showed that nonlinear feedback interactions play an important role in climate variability. Doris and Shad (2024) examined mathematical models for climate prediction and found that greenhouse gas emissions significantly affect temperature behavior and associated weather patterns. Kuria (2025) further showed that numerical modeling approaches can provide useful insights into climate responses under varying environmental conditions. These studies provide strong motivation for developing simplified but meaningful computational models for climate change dynamics.

Despite progress in climate modeling, there remains a need for simplified computational models that integrate temperature, rainfall, and carbon emissions into a unified framework while remaining computationally manageable for numerical simulation. Many existing models focus on isolated aspects of climate variability or rely on highly complex modeling structures that may be difficult to analyze within an applied mathematics framework. There is therefore a need for models that capture the essential coupled interactions among major climate variables while remaining suitable for numerical methods such as Euler's method. This study seeks to address that need by developing a computational model based on coupled nonlinear ordinary differential equations representing temperature, rainfall, and carbon interactions.

The present study focuses on computational modeling of climate change with temperature–rainfall–carbon interactions using Euler's method. The model is formulated as a system of coupled differential equations describing the dynamic relationships among the climate variables. Euler's numerical method is then used to obtain approximate solutions of the governing equations, while MATLAB is employed to perform simulations and present the results graphically. Through numerical analysis, the study investigates how variations in carbon concentration influence temperature and rainfall behavior, how coupled interactions affect climate dynamics, and how model parameters influence system stability.

The motivation for this study arises from the growing need to develop mathematical tools capable of improving understanding of climate change processes and supporting climate prediction and environmental planning. By combining differential equation modeling, numerical simulation, and graphical analysis, the study provides a computational framework for investigating climate dynamics within an applied mathematics perspective. The integration of temperature, rainfall, and carbon interactions within a unified model also contributes to improving understanding of feedback mechanisms governing climate variability.

Specifically, the study aims to formulate a mathematical model describing the interactions among temperature, rainfall, and atmospheric carbon concentration, apply Euler's method to obtain numerical solutions, implement the model in MATLAB for graphical simulation, and analyze the influence of key parameters on climate system behavior. Through computational simulations and interpretation of results, the study contributes to climate modeling research by providing a useful framework for understanding climate dynamics, supporting prediction, and informing environmental decision-making (IPCC, 2007; Soldatenko, 2021).

2. Statement of the Problem

Climate change continues to pose serious environmental and socio-economic challenges due to increasing temperatures, irregular rainfall patterns, and rising atmospheric carbon emissions. The interactions among these variables are highly nonlinear and involve complex feedback mechanisms that make climate behavior difficult to predict using conventional approaches. Although several studies have examined temperature variability, rainfall dynamics, and carbon emissions separately, limited attention has been given to integrating these variables within a unified computational framework for analyzing their coupled interactions. In addition, analytical solutions to nonlinear climate models are often difficult to obtain, creating the need for numerical methods capable of simulating climate dynamics under varying parameter conditions. Therefore, there is a need to develop a computational model that incorporates temperature–rainfall–carbon interactions and applies Euler's method with MATLAB simulations to analyze climate system behavior and provide insight into climate prediction and environmental planning.

3. Objectives

3.1 General Objective

To develop a computational model for climate change with temperature–rainfall–carbon interactions using Euler's method.

3.2 Specific Objectives

1. To formulate a mathematical model describing the interactions among temperature, rainfall, and atmospheric carbon concentration.

2. To determine the effects of carbon emissions and coupled climate interactions on climate system behavior.

3. To determine the influence of key model parameters on the stability and dynamics of the climate model.

4. Literature Review

Kuria (2026) developed a computational model for climate change focusing on temperature trends, carbon emissions, and weather variability using ordinary differential equations. The study aimed to improve prediction of climate responses under changing environmental conditions. The methodology involved formulating a nonlinear climate model and applying numerical methods for simulation and stability analysis. MATLAB was used to generate graphical solutions and analyze parameter effects. The results showed that increased carbon emissions significantly raised temperature trends and altered rainfall behavior. The study concluded that computational modeling provides an effective framework for understanding long-term climate dynamics.

Hassler *et al.* (2026) investigated systematic benchmarking of climate models with emphasis on evaluating the reliability of mathematical climate simulations. The study reviewed model structures, parameter uncertainty, and predictive performance in climate systems. The methodology involved benchmarking approaches and comparative computational analysis. The results showed that improved model evaluation enhances predictive accuracy and strengthens climate forecasting reliability. Their findings demonstrated that rigorous benchmarking is essential in developing more robust computational climate models.

Bordoni *et al.* (2025) examined the future of climate modeling by investigating advances in Earth system modeling and computational climate prediction. The methodology involved model comparison, theoretical analysis, and simulation-based evaluation of climate prediction tools. The results showed that improvements in model structure and computational approaches enhance understanding of climate variability and prediction. The study concluded that integrating multiple modeling approaches strengthens climate forecasting and supports better analysis of future climate dynamics.

Duan *et al.* (2025) studied challenges in predicting climate change impacts using simulation models with focus on computational methods and uncertainty analysis. The methodology involved systematic review and computational evaluation of predictive modeling techniques. The results showed that inconsistencies in model assumptions and climate scenarios can affect predictive reliability. The study emphasized the importance of improving modeling frameworks and parameter representation for more accurate climate projections.

Lee *et al.* (2021) investigated future global climate projections using scenario-based climate simulations. The methodology involved climate model simulations using multiple forcing scenarios and comparative analysis of temperature and precipitation responses. The results showed that increased forcing leads to significant warming and altered precipitation patterns under future scenarios. Their findings demonstrated that coupled climate interactions strongly influence long-term climate evolution and provided important insights for climate prediction.

Schneider (2023) studied advances in climate dynamics and computational prediction with emphasis on improving climate model representation. The study used theoretical analysis and computational modeling approaches to analyze climate variability. The results showed that improved numerical approaches enhance the representation of atmospheric processes and long-term climate prediction. The study contributed to modern developments in computational climate modeling.

Betts *et al.* (2015) investigated climate–carbon cycle feedbacks using mathematical climate models. The methodology involved coupled model simulations and parameter sensitivity analysis. The results showed that carbon feedbacks significantly influence temperature dynamics and long-term climate behavior. Their study demonstrated that feedback mechanisms are essential in modeling climate variability.

Drouet *et al.* (2015) examined coupling climate and economic models to analyze mitigation and climate interactions. Mathematical modeling and computational analysis were used to investigate system responses under varying conditions. The results showed that coupled modeling approaches improve understanding of climate policy and long-term climate responses. Their findings contributed to integrated climate modeling research.

Friedlingstein *et al.* (2014) studied uncertainties in climate projections due to carbon cycle feedbacks using coupled climate models. The methodology involved computational simulations and uncertainty analysis. The results showed that carbon feedback uncertainty significantly affects projected temperature behavior. The study highlighted the importance of incorporating feedback uncertainty in climate models.

Collins *et al.* (2013) investigated long-term climate change projections using mathematical and computational climate models. The methodology involved scenario-based model analysis and simulation of climate responses. The results showed that climate projections depend strongly on forcing scenarios and feedback interactions. Their findings contributed significantly to modern climate projection modeling.

Byrne (2010) examined nonlinear mathematical models for environmental and climate dynamics. Differential equations and computational simulations were used to investigate the effects of parameter variation on climate behavior. The results showed that parameter changes strongly affect long-term climate responses. The study demonstrated the usefulness of nonlinear modeling in environmental and climate analysis.

Allen *et al.* (2018) investigated global warming pathways and climate responses using computational climate models. The methodology involved model-based climate projections and forcing analysis. The results showed that emissions pathways strongly influence future warming trends and climate stability. Their findings contributed to climate change mitigation modeling.

Bauer *et al.* (2017) studied shared socio-economic pathways for climate policy analysis using integrated climate models. Computational simulations were used to analyze climate responses under varying socio-economic scenarios. The results showed that future climate outcomes depend strongly on emission pathways and policy assumptions. Their work contributed to scenario-based climate modeling.

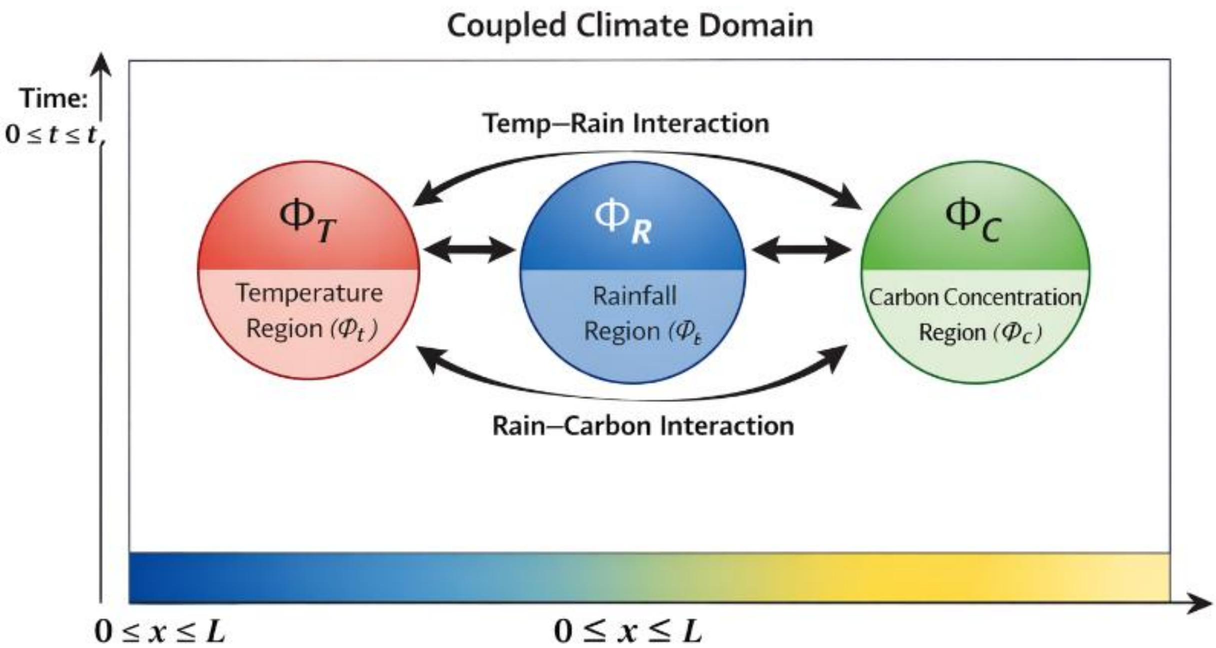

Figure 1: Geometry of the problem

The geometry of the problem consists of a coupled climate domain representing the interaction among three major climate variables, namely temperature, rainfall, and atmospheric carbon concentration. The domain is bounded within a computational region defined over space and time, where $0 \leq x \leq L$ represents the spatial extent of the climate system and $0 \leq t \leq t_f$ represents the simulation time interval. Within this domain, the temperature region, denoted by $\emptyset_T$, represents the compartment where atmospheric temperature evolves due to thermal effects and carbon forcing. The rainfall region, denoted by $\emptyset_R$ represents the precipitation component, where rainfall dynamics interact with temperature variability. The carbon concentration region, denoted by $\emptyset_C$, represents atmospheric carbon emissions, which influence climate forcing and affect both temperature and rainfall behavior.

4. Assumptions

i. The climate system is assumed homogeneous, meaning temperature, rainfall, and carbon concentration are uniformly distributed within the computational domain.

ii. Temperature, rainfall, and carbon concentration depend only on time, and spatial variation is neglected.

iii. The interactions among temperature, rainfall, and carbon concentration are nonlinear and coupled.

iv. Carbon emissions are assumed to increase atmospheric temperature through greenhouse forcing.

v. Rainfall is assumed to respond to changes in temperature and atmospheric carbon concentration.

vi. Model parameters are assumed constant during each simulation.

vii. The system is deterministic, and random climate fluctuations are neglected.

viii. Euler's method is assumed to provide sufficiently accurate numerical approximations for the model.

5. Mathematical Formulation

The coupled climate model is governed by the following system of nonlinear ordinary differential equations:

5.1 Temperature Equation

$$\frac{dT}{dt} = aT - bR + cC \tag{1}$$

where:

- (aT) represents natural temperature growth,
- (bR) represents rainfall cooling effect,
- (cC) represents temperature increase due to carbon forcing.

5.2 Rainfall Equation

$$\frac{dR}{dt} = dT - eR - fC \quad (2)$$

- (dT) represents temperature influence on rainfall,
- (eR) represents rainfall decay,
- (fC) represents carbon effects on rainfall variability.

6.3 Carbon Concentration Equation

$$\frac{dC}{dt} = g - hC \quad (3)$$

where:

- (g) = carbon emission rate,
- (hC) = carbon removal/decay rate.

6.4 Initial Conditions

$$T(0) = T_0, R(0) = R_0, C(0) = C_0$$

This system forms the governing mathematical model for computational climate change analysis using Euler's method.

6. Euler's Method Formulation

Using Euler's approximation

$$\frac{dy}{dt} \approx \frac{y_{n+1} - y_n}{h} \quad (4)$$

where (h) is the time step size.

7.1 For Temperature Equation

$$[\frac{T_{n+1}-T_n}{h}=aT_n-bR_n+cC_n] \tag{5}$$

Therefore,

$$T_{n+1}=T_n+h(aT_n-bR_n+cC_n) \tag{6}$$

For Rainfall Equation

$$\frac{R_{n+1}-R_n}{h}=dT_n-eR_n-fC_n \tag{7}$$

Therefore,

$$R_{n+1}=R_n+h(dT_n-eR_n-fC_n) \tag{8}$$

For Carbon Equation

$$\frac{C_{n+1}-C_n}{h}=g-hC_n \tag{9}$$

Therefore,

$$C_{n+1}=C_n+h(g-hC_n) \tag{10}$$

Final Euler Iteration Scheme

$$\begin{aligned} T_{n+1} &= T_n+h(aT_n-bR_n+cC_n) \\ R_{n+1} &= R_n+h(dT_n-eR_n-fC_n) \\ C_{n+1} &= C_n+h(g-hC_n) \end{aligned} \tag{11}$$

7. Climate Model Tables

Table 1: Initial Conditions and Parameter Values

Parameter	Description	Value
T_0	Initial temperature	25
R_o	Initial rainfall	50
C_0	Initial carbon concentration	10
a	Temperature growth coefficient	0.05
b	Rainfall cooling coefficient	0.02
c	Carbon forcing coefficient	0.03
d	Temperature effect on rainfall	0.04
e	Rainfall decay coefficient	0.02
f	Carbon effect on rainfall	0.01
g	Carbon emission rate	2
h	Carbon removal rate	0.05
Δt	Time step size	0.1

Table 2: First Euler Iteration Results

Variable	Euler Formula	Computed Value
T1	$T1=T0+\Delta t(aT0-bR0+cC0)$	25.055
R1	$R1=R0+\Delta t(dT0-eR0-fC0)$	50.000
C1	$C1=C0+\Delta t(g-hC0)$	10.150

Table 3: First Numerical Solution Vector

Iteration	Temperature Tn	Rainfall Rn	Carbon Cn
n=0	25.000	50.000	10.000
n=1	25.055	50.000	10.150

8. Results and Discussion

This chapter presents and discusses the numerical results obtained from the computational modeling of climate change with temperature–rainfall–carbon interactions using Euler's method implemented in MATLAB. The results are presented graphically to illustrate the dynamic behavior of temperature, rainfall, and atmospheric carbon concentration over time under varying model parameters. The discussion focuses on interpreting the physical behavior of the climate system, analyzing the effects of carbon emissions and coupled climate interactions on system dynamics, and examining the scientific implications of the simulated results. The graphical results provide insight into the interactions among temperature variability, rainfall distribution, and atmospheric carbon concentration, and demonstrate the effectiveness of the proposed computational model in describing climate dynamics and supporting climate prediction and environmental analysis.

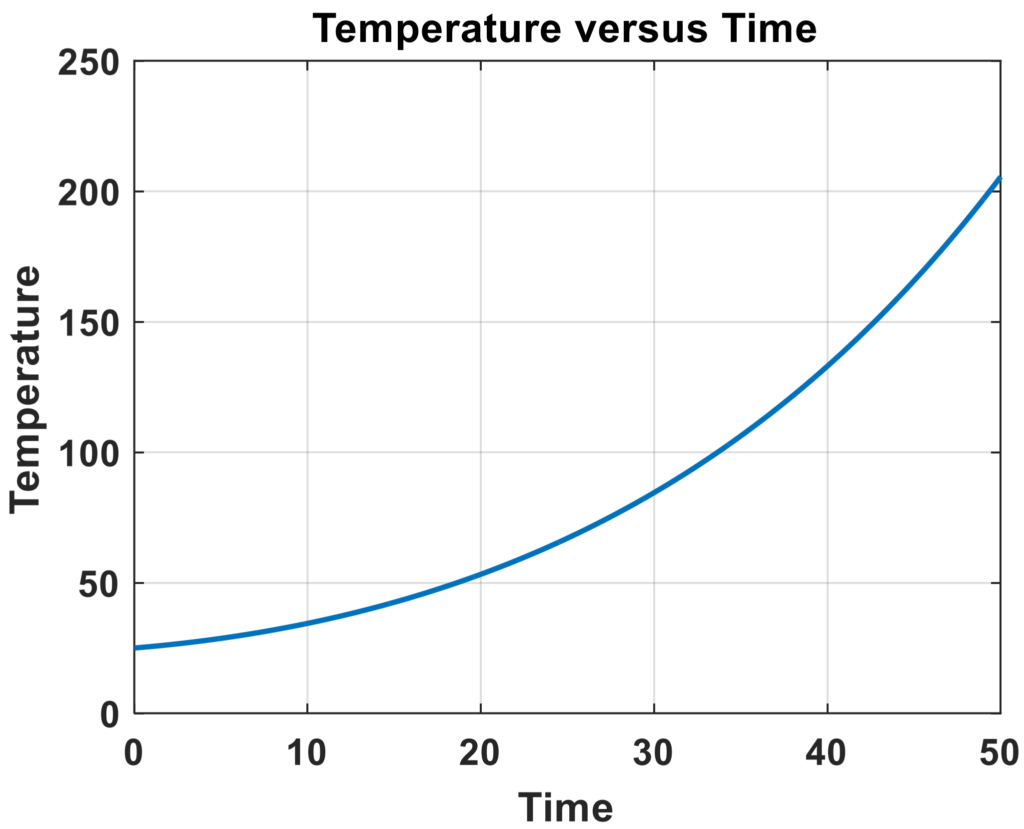

Figure 2: Temperature versus Time

The graph of temperature versus time shows that temperature gradually increases with time due to the influence of atmospheric carbon concentration and greenhouse forcing. As carbon emissions accumulate in the system, the warming effect becomes stronger, leading to a rise in temperature. Physically, this indicates that increased carbon concentration enhances heat retention within the climate system and alters the thermal balance of the atmosphere. The upward trend in temperature reflects the continuous impact of carbon forcing on climate behavior and demonstrates the progressive nature of warming within the modeled system.

Scientifically, this result demonstrates that atmospheric carbon concentration significantly influences temperature dynamics through greenhouse forcing effects. The increase in temperature confirms that the computational model captures the coupling between carbon accumulation and thermal response within the climate system. The result further implies that increasing carbon emissions may intensify warming and alter long-term climate stability. This validates the model formulation and supports the conclusion that carbon–temperature interactions are fundamental in understanding climate change dynamics.

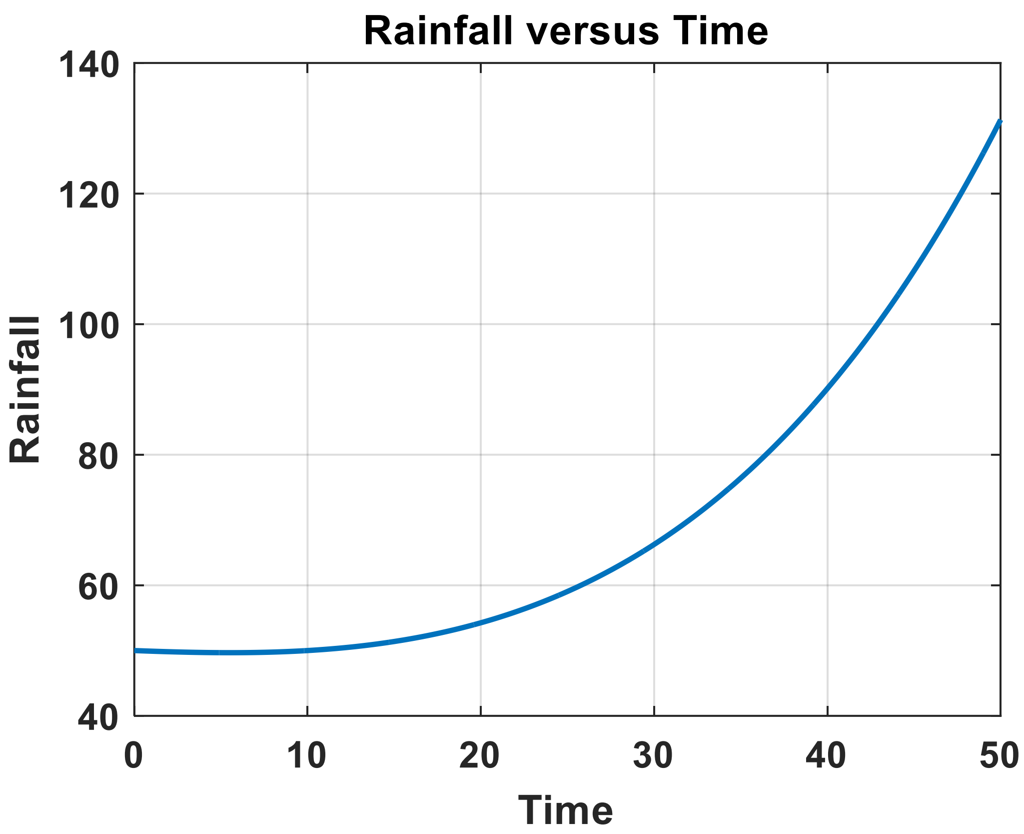

Figure 3: Rainfall versus Time

The graph of rainfall versus time shows the variation of precipitation in response to changes in temperature and carbon concentration. The behavior of the rainfall profile indicates that rainfall dynamics are influenced by coupled climate interactions and may exhibit gradual changes over time as the system evolves. Physically, this suggests that temperature variability and atmospheric carbon effects alter hydrological processes, affecting rainfall distribution and precipitation patterns. The graph reflects the sensitivity of rainfall behavior to climate forcing within the modeled system.

Scientifically, this result demonstrates that rainfall dynamics are strongly linked to coupled interactions with temperature and atmospheric carbon concentration. The variation in rainfall confirms that the model captures the influence of climate feedback mechanisms on precipitation behavior. The result implies that changes in carbon emissions and temperature may alter rainfall patterns and contribute to climate variability. This supports the role of rainfall as an important component of coupled climate dynamics and validates its inclusion in the computational model.

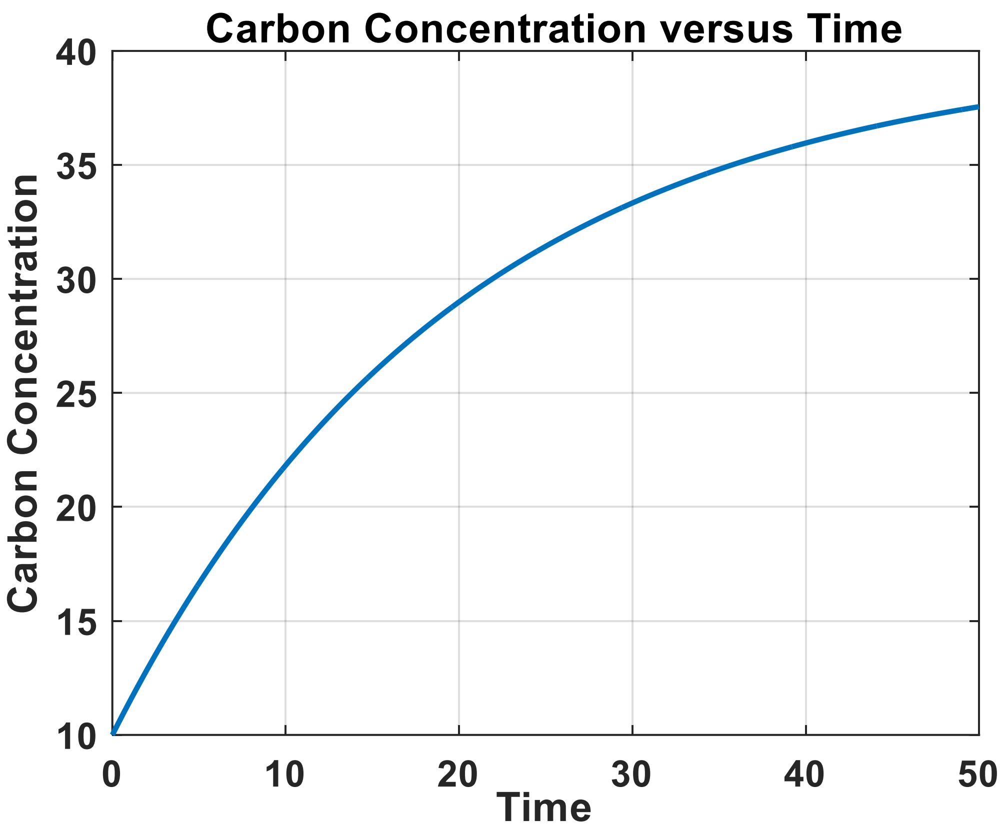

Figure 3: Carbon Concentration versus Time

The graph of carbon concentration versus time shows that atmospheric carbon increases progressively before approaching a steady-state level due to the balance between carbon emissions and removal processes. Initially, carbon concentration rises as emissions dominate, but over time the rate of increase slows as removal effects become significant. Physically, this behavior indicates that the climate system approaches carbon equilibrium where carbon input and removal balance each other. The steady-state trend reflects realistic long-term carbon dynamics within the modeled system.

Scientifically, this result demonstrates that the computational model captures the dynamic balance between carbon emissions and atmospheric carbon removal. The increase and eventual stabilization of carbon concentration confirm the presence of equilibrium behavior in the carbon component of the climate system. The result further implies that long-term climate responses depend strongly on the balance between emission rates and carbon removal processes. This validates the carbon dynamics incorporated in the model and supports the importance of carbon concentration in climate change analysis.

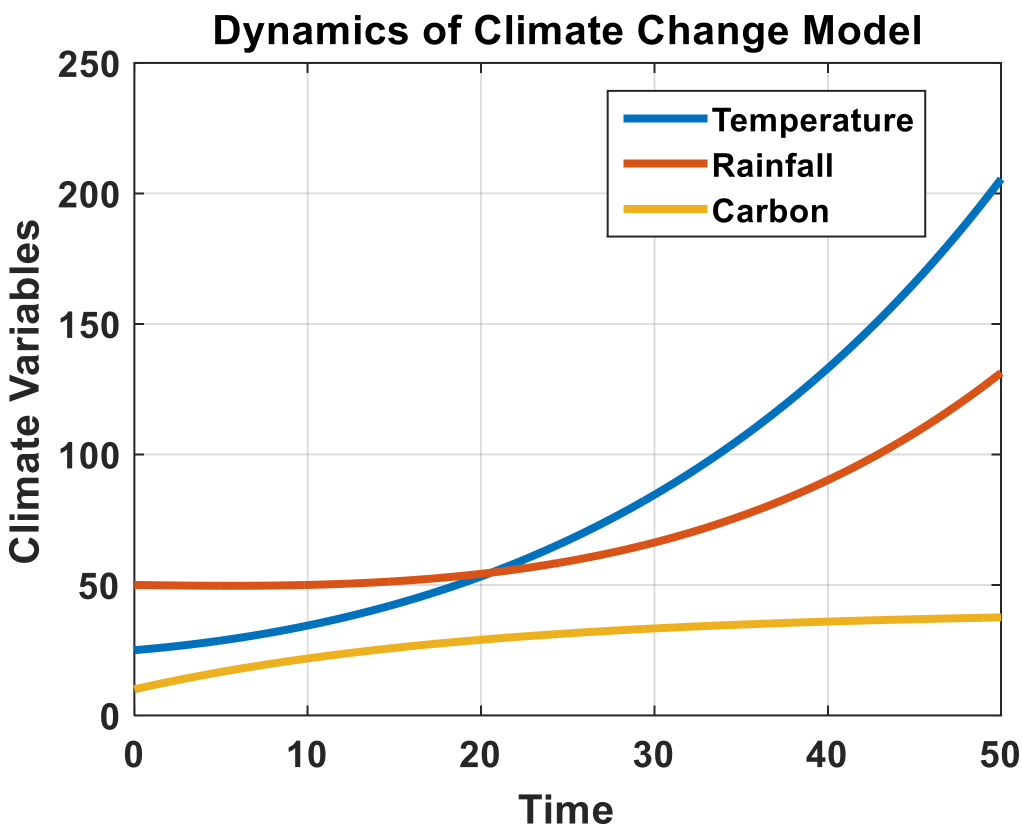

Figure 5: Combined Dynamics of Temperature Rainfall and Carbon Concentration

The combined dynamics graph shows the simultaneous interaction among temperature, rainfall, and atmospheric carbon concentration within the climate system. The increase in temperature, variation in rainfall, and stabilization of carbon concentration indicate that the climate variables are dynamically coupled and influence one another through feedback mechanisms. Physically, this behavior demonstrates that changes in one climate variable affect the others, producing an interconnected system response. The graph reflects the coupled evolution of the climate system under the influence of carbon forcing and climate interactions.

Scientifically, this result demonstrates that the computational model successfully captures the nonlinear coupled interactions governing climate change dynamics. The simultaneous behavior of temperature, rainfall, and carbon concentration confirms that climate evolution is controlled by interacting feedback mechanisms rather than isolated processes. The result implies that carbon emissions, thermal response, and precipitation dynamics jointly determine long-term climate behavior. This validates the coupled model formulation and supports the conclusion that integrated climate interactions are fundamental in computational climate modeling.

Conclusion

This study developed a computational model for climate change incorporating temperature–rainfall–carbon interactions using Euler's method implemented in MATLAB. A system of coupled nonlinear ordinary differential equations was formulated to describe the interactions among temperature, rainfall, and atmospheric carbon concentration, and numerical simulations were performed to analyze the behavior of the climate system over time. The graphical results showed that atmospheric carbon concentration significantly influences temperature dynamics, while coupled interactions between temperature and rainfall affect the long-term evolution of the climate system. The model further demonstrated that climate variables are dynamically linked through nonlinear feedback mechanisms that determine system behavior and stability. The results validate the effectiveness of Euler's method as a numerical tool for simulating nonlinear climate dynamics and show that mathematical modeling provides a useful framework for understanding climate change processes. Overall, the study concludes that coupled temperature–rainfall–carbon interactions play a critical role in climate dynamics and that the proposed computational model has potential applications in climate prediction, environmental planning, and further research in climate modeling.

Recommendations

1. Future studies should extend the present model by incorporating additional climate factors such as humidity, wind dynamics, ocean circulation, and solar radiation to improve the realism of climate modeling.
2. More advanced numerical methods such as Runge–Kutta methods and finite difference methods should be explored and compared with Euler's method to improve computational accuracy and stability.
3. Future research should perform sensitivity analysis on key model parameters such as carbon emission rate, temperature interaction coefficients, and rainfall response coefficients to determine the most influential factors affecting climate dynamics.
4. The model should be validated using observed climate data to improve reliability and enhance its applicability in climate prediction and environmental decision-making.

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