



## Original Article

## The evolution of climate science: past, present, and future

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### Abstract

This article reviews the evolution of the climate science, including its history, current status and development trends expected. Having the interdisciplinary nature dedicated to studying the climate system, including its components, processes, and interactions, climate science is relatively a new field of science but with its foundational concepts laid in the 19th century. Its development into a distinct and mature field took place primarily in the 20th century, especially in response to the growing recognition of human impacts on the climate. It encompasses the examination of long-term patterns and changes in temperature, precipitation, and other atmospheric conditions to understand and predict the behavior of Earth's climate. This field of science integrates knowledge from various disciplines, including but not limited to, meteorology, oceanography, geology, physics, chemistry, biology, and environmental science, to provide a comprehensive understanding of the climate system and its impacts. It aims to improve our comprehension of climate variability and change, and enhance predictive capabilities. Today, climate science is a vital area of research, evolving from rudimentary observations to empirical extrapolations or speculative predictions, further to a sophisticated understanding of Earth's climate systems. It enables informing policies and strategies for addressing climate change, particularly for managing and mitigating the effects of climate change. With ongoing advancements in technology and methodology, particularly in achievements in artificial intelligence, climate science is poised to continue its critical role in addressing the challenges of climate change. As we move forward, interdisciplinary collaboration, improved observational capabilities, more accurate predictions, effective communication, and more powerful mitigation measures will be essential in guiding global efforts to mitigate and adapt to the impacts of a changing climate.

**Key words:** climate science; history; status; future trend; global warming; climate change and crisis

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**Article Info:** Received: 6 September, 2024 / Revised: 13 October 2024 / Accepted: 26 October 2024 / Published Online: 18 November 2024. [www.naturalisscientias.com](http://www.naturalisscientias.com)

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**Citation:** YZ Tang. 2024. The evolution of climate science: past, present, and future. *Naturalis Scientias*, 1 (3): 218-227. DOI: <https://doi.org/10.62252/NSS.2024.1016>.

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## 1 Introduction

Climate science is relatively a new field of science having the interdisciplinary nature dedicated to studying the climate system, including its components, processes, and interactions. While having roots that extend back centuries, it has developed significantly as a distinct field primarily in the 20th and 21st centuries with its foundational concepts laid in the 19th century. Its development into a distinct and mature field took place primarily in the 20th century, especially in response to the growing recognition of human impacts on the climate. It encompasses the examination of long-term patterns and changes in temperature, precipitation, and other atmospheric conditions to understand and predict the behavior of Earth's climate.

This field of science integrates knowledge from various disciplines, including but not limited to, meteorology, oceanography, geology, physics, chemistry, biology, and environmental science, to provide a comprehensive understanding of the climate system and its impacts. It aims to improve our comprehension of climate variability and change, and enhance predictive capabilities. Today, climate science is a vital area of research, informing policies and strategies for addressing climate change, particularly for managing and mitigating the effects of climate change.

Overall, climate science has undergone a profound transformation over the past century, evolving from rudimentary observations to empirical extrapolations or speculative predictions, further to a sophisticated understanding of Earth's climate systems. This evolution reflects advancements in technology, methodology, and scientific inquiry. Understanding the past developments and current status of climate science is crucial for addressing future challenges related to climate change.

## 2 Early foundations

The roots of climate science can be traced back to the late 18th and early 19th centuries, during the Enlightenment, when scientists began systematically studying the Earth's atmosphere. One of the early milestones was Joseph Fourier's recognition in the 1820s of the greenhouse effect, a process by which the Earth's atmosphere traps heat, making the planet warmer than it would be without an atmosphere. Fourier's work laid the foundation for future investigations into how atmospheric gases affect the Earth's temperature. His paper was published in the *Memoirs of the Royal Academy of Sciences*, where he suggested the idea that there would be higher temperatures on Earth due to the "greenhouse effect", compared to what would be expected if there were no atmosphere<sup>1</sup>.

In the mid-19th century, John Tyndall, an Irish physicist, identified specific gases, such as water vapor, carbon dioxide (CO<sub>2</sub>), and methane, as significant contributors to the greenhouse effect, by trapping heat in the atmosphere similar to the glass of a greenhouse built for planting<sup>2</sup>. His experiments demonstrated that these gases absorb infrared radiation, leading to the warming of the atmosphere. Svante Arrhenius, a Swedish scientist, took this research further in 1896 by quantifying the relationship between CO<sub>2</sub> concentrations and global temperatures, providing an early model for understanding anthropogenic climate change<sup>3</sup>.

However, by that time much of the scientific work related to climate was based on empirical observations. Both Tyndall and Arrhenius used empirical data to understand the behavior of gases in the atmosphere and to estimate their impact on Earth's temperature. Arrhenius made calculations based on the known properties of carbon dioxide and its effect on the Earth's energy balance to predict the impact of increased CO<sub>2</sub> levels on global temperatures. He was the first to suggest that human activities, such as burning fossil fuels, could lead to global warming - a theory that has since been validated by extensive research.

Predictions in the 19th century were less sophisticated compared to modern climate science due to the limited availability of data and computational tools. However, they were still significant. Arrhenius, for example, used his understanding of the greenhouse effect to predict that doubling the concentration of CO<sub>2</sub> in the atmosphere could lead to a significant increase in Earth's temperature. While these predictions were based on empirical data, they involved a level of theoretical extrapolation and mathematical modeling.

Nowadays, it is generally understood that the greenhouse effect is a natural process that warms Earth's surface. It occurs when certain gases in Earth's atmosphere trap heat, preventing it from escaping into space. These gases are known as greenhouse gases (GHGs) and include carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), water vapor (H<sub>2</sub>O), and nitrous oxide (N<sub>2</sub>O).

Here is a brief description on how the greenhouse effect works:

- **Solar radiation:** The Sun emits energy in the form of solar radiation. When this radiation reaches Earth, some of it is absorbed by the surface, warming it.
- **Infrared radiation:** The Earth's surface, now warmed, emits energy back towards the atmosphere as infrared radiation (heat).
- **Absorption by greenhouse gases:** Greenhouse gases in the atmosphere absorb some of this infrared radiation. Instead of letting it escape into space, these gases re-radiate the heat in all directions, including back towards the Earth's surface.
- **Heat retention:** This process effectively traps heat within the atmosphere, warming the lower atmosphere and the Earth's surface.
- **Balance:** In a stable climate, the amount of energy coming from the Sun is balanced by the amount of energy leaving the Earth. However, increased concentrations of greenhouse gases enhance this effect, leading to more heat being trapped on the earth and thus contributing to global warming.

Figure 1 is an illustration on how the greenhouse effect works.

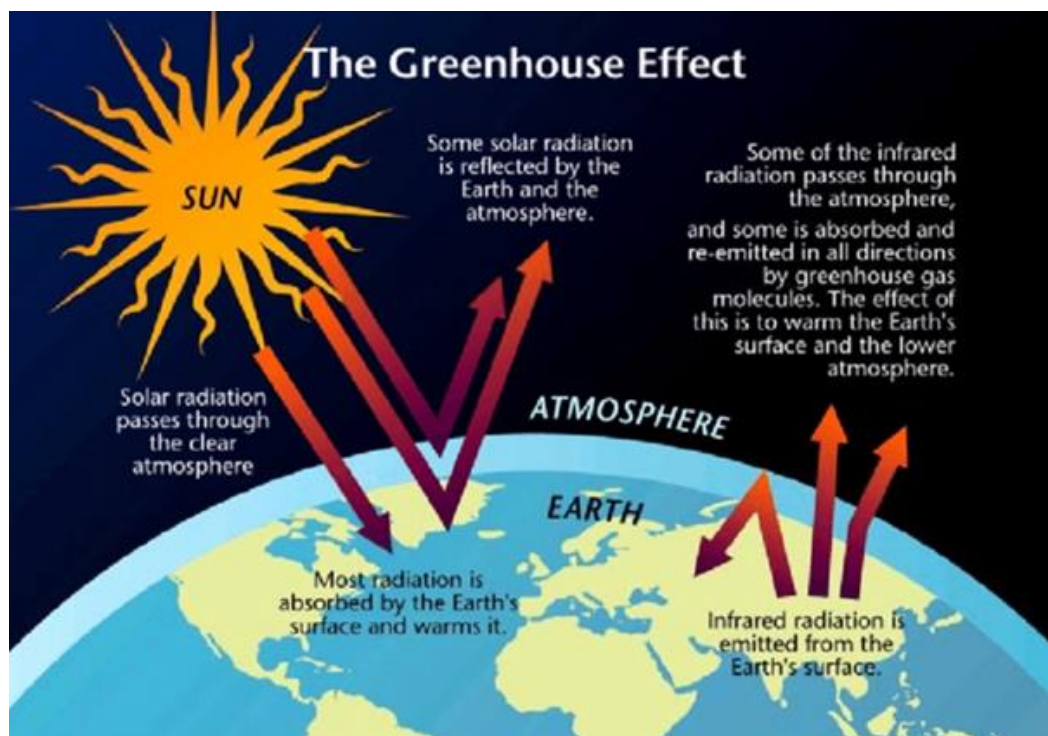


Figure 1. Illustration of the greenhouse effect<sup>4</sup>

### 3 The rise of modern climate science

The 20th century marked rapid expansion in climate science, driven by advancements in technology and computing enabling more sophisticated observations and models, thus an increased understanding of atmospheric dynamics. The development of global temperature records, starting in the early 20th century, allowed scientists to identify trends and anomalies in the Earth's climate. The 1950s and 1960s saw the emergence of atmospheric CO<sub>2</sub> monitoring, most notably through the Keeling Curve<sup>5</sup>, which provided clear evidence of rising CO<sub>2</sub> levels due to human activities (Figure 2).

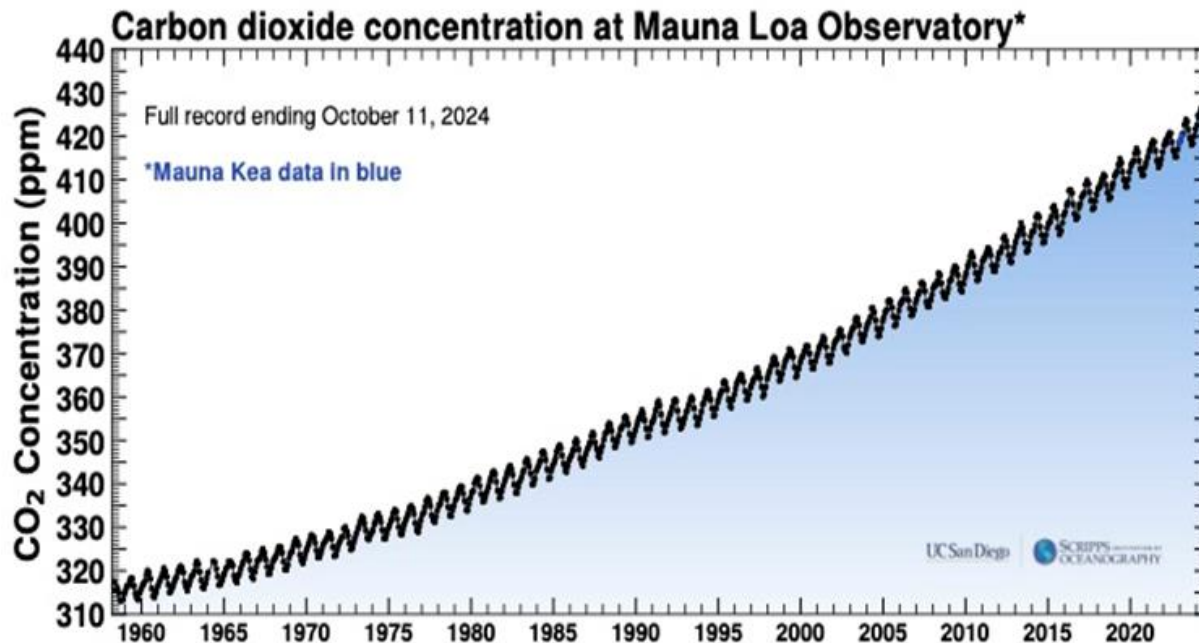


Figure 2. Increase in carbon dioxide level in the atmosphere<sup>6</sup>

The development of numerical weather prediction models in the 1950s allowed scientists to simulate climate conditions, understand the complexities of the Earth's climate system and predict future scenarios. This period also witnessed the establishment of key institutions and programs, such as the Intergovernmental Panel on Climate Change (IPCC), founded in 1988 to assess scientific knowledge and inform policy<sup>7</sup>. It provided a forum for scientists to assess and communicate the risks associated with climate change. The IPCC's assessment reports have since become the cornerstone of global climate policy discussions.

Satellite technology, which became prominent in the 1970s, revolutionized climate observation by providing comprehensive data on atmospheric temperatures, sea levels, and ice cover. This technology has been instrumental in monitoring changes in Earth's climate system and validating climate models<sup>8</sup>.

In summary, modern climate science focuses on the following four major aspects, using interdisciplinary approaches:

- **Components and processes:** Climate science investigates the various elements of the climate system—such as the atmosphere, oceans, land surfaces, and ice masses—and how they interact. This includes studying atmospheric dynamics, ocean currents, heat exchanges, and feedback mechanisms that influence climate patterns.
- **Historical and modern data:** It involves analyzing historical climate data to identify trends and variability, as well as using modern observational tools like satellites, weather stations, and climate models to gather current and predictive information.
- **Climate models:** Scientists use computer models to simulate and predict climate behavior under different scenarios. These models help in understanding how changes in greenhouse gas concentrations, land use, and other factors can affect future climate conditions.
- **Impacts and adaptation:** Climate science also explores the impacts of climate change on ecosystems, human societies, and economies. This includes studying phenomena like extreme weather events, sea-level rise, and changes in biodiversity, as well as developing strategies for adaptation and mitigation.

## 4 Current status of climate science and the climate

Today, climate science is a robust field characterized by advanced computational models, extensive datasets, and a high level of scientific consensus on climate change. The key findings of recent assessments, such as the IPCC's Sixth Assessment Report (AR6), highlight several critical aspects of current climate understanding:

- **Global warming trends:** Average global temperatures have risen significantly, with 2020 being one of the hottest years on record. The past decade has been the warmest in the historical record<sup>7</sup>.
- **Attribution of climate change:** There is a high level of confidence that human activities, particularly the burning of fossil fuels and deforestation, are the primary drivers of recent global warming. The IPCC AR6 report states that it is "unequivocal" that human influence has warmed the atmosphere, oceans, and land<sup>7</sup>.
- **Impact projections:** Future projections indicate more frequent and severe heat waves, rising sea levels, and increased intensity of extreme weather events. These impacts are expected to have profound effects on ecosystems, human health, and economies<sup>7</sup>.
- **Mitigation and adaptation:** There is an ongoing focus on strategies to mitigate climate change by reducing greenhouse gas emissions and adapting to its unavoidable impacts. Efforts include transitioning to renewable energy sources, enhancing energy efficiency, and developing adaptive infrastructure<sup>9</sup>.

The Intergovernmental Panel on Climate Change (IPCC) reports provide a comprehensive and scientifically rigorous assessment of the current state of the Earth's climate and the challenges posed by global warming. The IPCC's AR6 Synthesis Report (SYR) as a comprehensive and authoritative document integrates the findings from the three Working Groups of the Sixth Assessment Report. It provides a clear, scientifically grounded overview of the current state of the climate, the risks and impacts associated with climate change, and the necessary pathways to address these challenges<sup>10</sup>.

### 4.1 Current status of our climate and global warming

**Warming trends:** The Earth's surface temperature has increased by approximately 1.1 °C above pre-industrial levels (1850-1900) due to human activities, primarily the burning of fossil fuels and deforestation as shown in Figure 3.

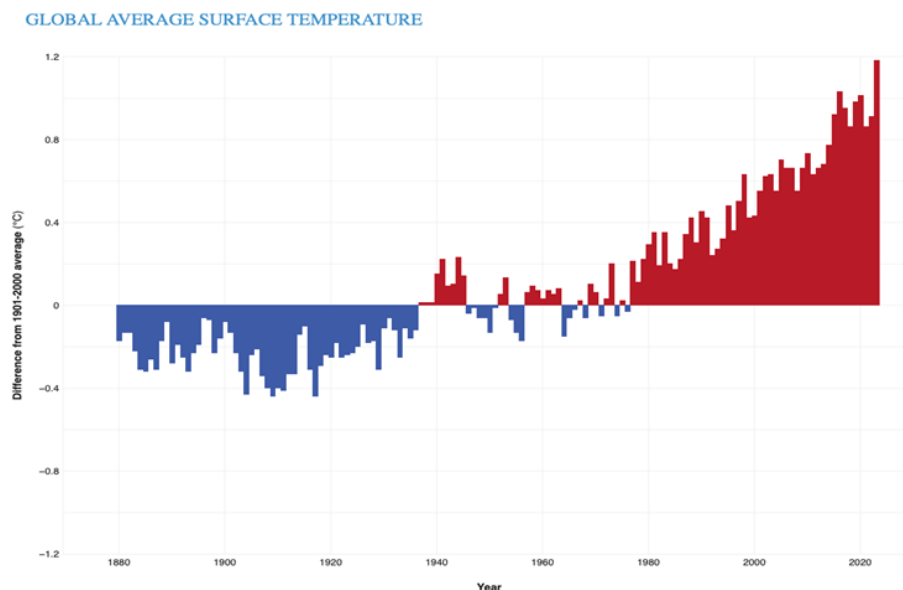


Figure 3. Warming trend of the Earth's surface<sup>11</sup>

The last few decades have been the warmest on record, with each of the past four decades successively warmer than any decade that preceded it since 1850.

It is reaffirmed that human activities, particularly the burning of fossil fuels and deforestation, are unequivocally responsible for the observed warming of the climate system.

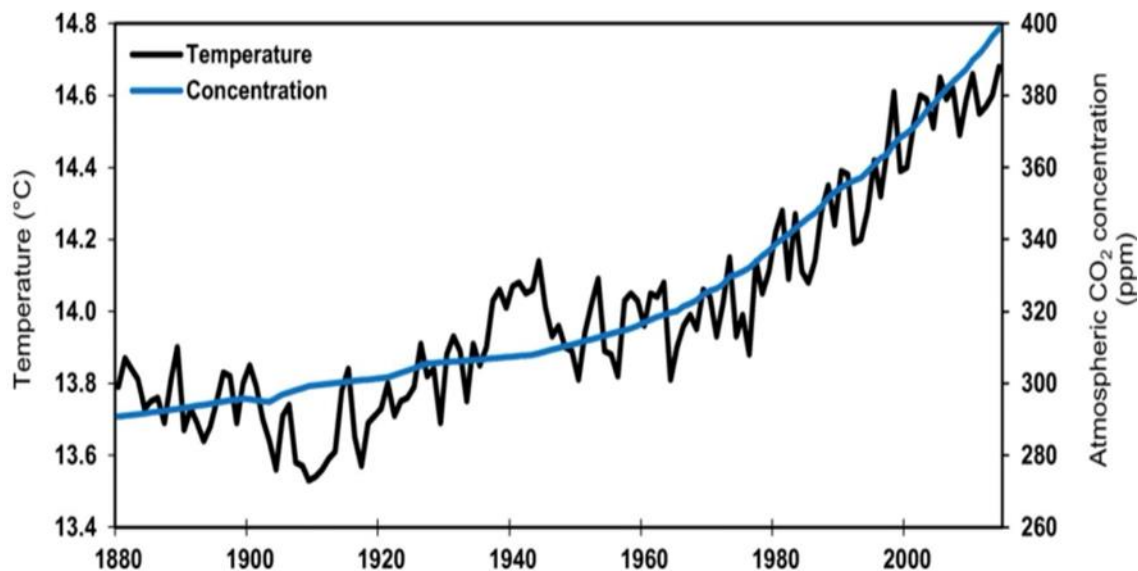
It is emphasized that the scale of recent changes across the climate system is unprecedented over many centuries to millennia.

**Greenhouse gas concentrations:** Concentrations of greenhouse gases (GHGs) such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) are at unprecedented levels in at least the last 800,000 years.

CO<sub>2</sub> levels have increased by about 50% since the pre-industrial era.

Clearly the rising global temperature is correlated well with the increase in CO<sub>2</sub> concentration as shown in Figure 4.

It is urgently needed for immediate and deep reductions in greenhouse gas (GHG) emissions to avoid the most severe impacts of climate change.



Average global temperature and atmospheric CO<sub>2</sub> concentration, 1880-2014. Source: the authors based on data from the Earth Policy Institute (2017)

**Figure 4.** Correlation between carbon dioxide concentration and global warming<sup>12</sup>

**Impacts on the climate system:** Climate change is already affecting every region on Earth, with impacts becoming more frequent, severe and widespread.

These include more frequent and intense heat waves, storms, and extreme precipitation events, as well as other extreme weather phenomena.

Glaciers and ice sheets are melting, contributing to rising sea levels, which threaten coastal communities and ecosystems.

Ocean temperatures are rising, leading to increased ocean acidification and deoxygenation, affecting marine life.



The impacts are disproportionately affecting vulnerable populations, particularly in low-income countries and marginalized communities.

**Irreversible Changes:** Some aspects of climate change, such as sea level rise and the loss of polar ice, are irreversible over centuries to millennia.

Continued warming will exacerbate these impacts, leading to long-lasting consequences for ecosystems and human societies.

Even if we stopped emitting GHGs today, certain impacts would continue to unfold.

The window of opportunity to limit global warming to 1.5 °C above pre-industrial levels is rapidly closing, and current global efforts are insufficient to meet this target. temperature.

#### 4.2 Current status of our climate and global warming

**Mitigation of emissions:** To limit global warming to 1.5 °C or 2 °C above pre-industrial levels, as outlined in the Paris Agreement, the world needs to achieve significant reductions in GHG emissions. Current policies and pledges are not sufficient to meet these targets, leading to concerns about exceeding these thresholds.

**Adaptation to impacts:** Even with significant mitigation efforts, some degree of climate change is inevitable. Communities worldwide must adapt to the impacts of climate change, such as rising sea levels, increased frequency of extreme weather events, and shifts in agricultural productivity. However, adaptation is challenging, especially for vulnerable populations with limited resources.

**Economic and social disruption:** Climate change poses significant risks to economies, infrastructure, and human health. Extreme weather events can disrupt food and water supplies, displace populations, and exacerbate poverty and inequality. The economic costs of inaction are expected to be far higher than the costs of taking preventive measures.

**Loss of biodiversity:** The changing climate is leading to shifts in ecosystems and the loss of biodiversity. Species that cannot adapt or migrate to new habitats face extinction, which can have cascading effects on ecosystems and human livelihoods.

**Political and social will:** Addressing climate change requires global cooperation and strong political will. However, climate action is often hindered by political divisions, economic interests, and public skepticism. Achieving the necessary scale of change requires not only technological advancements but also societal transformation.

#### 4.3 Potential solutions to address these challenges

**Transition to renewable energy:** A rapid transition from fossil fuels to renewable energy sources such as solar, wind, and hydropower is essential. This transition includes scaling up clean energy technologies, improving energy efficiency, and investing in energy storage solutions.

**Carbon pricing and regulation:** Implementing carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, can incentivize reductions in GHG emissions. Strong regulatory frameworks that limit emissions from key sectors like energy, transportation, and industry are also crucial.

**Nature-based solutions:** Protecting and restoring natural ecosystems, such as forests, wetlands, and mangroves, can enhance carbon sequestration, reduce climate risks, and support biodiversity. Sustainable land management practices and reforestation efforts are vital components of these solutions.

**Climate adaptation and resilience:** Investing in infrastructure that can withstand extreme weather, improving water management systems, and developing early warning systems for natural disasters are key adaptation strategies. Building resilience also involves supporting vulnerable communities and integrating climate risks into urban planning.



**Technological innovation:** Advancements in technology, including carbon capture, utilization and storage (CCUS), renewable energy innovations, and climate-resilient agricultural practices, can play a significant role in mitigating and adapting to climate change. Research and development in these areas need to be accelerated.

**Global cooperation and governance:** International collaboration is critical for addressing climate change. Strengthening global agreements, such as the Paris Agreement, and ensuring that countries meet their commitments is essential. Enhanced support for developing countries, including financial and technical assistance, is also necessary.

**Public awareness and education:** Raising public awareness about climate change and its impacts can drive behavioral changes and build support for climate policies. Education and community engagement are key to fostering a culture of sustainability and empowering individuals to take action.

In conclusion, the IPCC reports paint a clear picture of the urgent need for action to address the global climate crisis. While the challenges are immense, the solutions are within reach if we act decisively and collectively. A combination of technological innovation, policy measures, nature-based solutions, and global cooperation can help mitigate the worst impacts of climate change and build a more sustainable and resilient future.

## 5 Future trends in climate science

Today, climate science is a robust field characterized by advanced computational models, extensive datasets, and a Looking ahead, several trends are likely to shape the future of climate science:

**Enhanced climate models:** Advances in computing power and data assimilation techniques will continue to improve the accuracy of climate models. The integration of artificial intelligence and machine learning is expected to enhance predictive capabilities and allow for more detailed regional forecasts<sup>13</sup>.

**Improved observational networks:** Expansion of satellite and ground-based observational networks will provide more granular data on climate variables. This will improve our understanding of regional climate dynamics and enhance early warning systems for extreme weather events<sup>14</sup>.

**Interdisciplinary research:** Future climate science will increasingly rely on interdisciplinary approaches, integrating insights from fields such as ecology, economics, and social sciences. This holistic perspective will be crucial for developing comprehensive strategies to address climate impacts and inform policy decisions<sup>15</sup>.

**Public engagement and policy:** Effective communication of climate science to the public and policymakers will be vital in driving action. Enhanced transparency and engagement efforts will help bridge the gap between scientific research and policy implementation<sup>16</sup>.

### Climate change adaptation and mitigation technologies and engineering.

**Artificial intelligence:** In addition to enhance climate models mentioned above, AI is revolutionizing climate science by also enhancing our ability to predict and respond to climate change. It enables more accurate and localized predictions, improves the management of big data, and supports the development of effective mitigation and adaptation strategies. However, the integration of AI into climate science also requires careful consideration of ethical, environmental, and interdisciplinary challenges. Overall, AI holds significant promise in advancing our understanding and response to the global climate crisis.

## 6 Discussion

Evolution and advancement of any subject of science takes its natural course and is often accelerated by the realities and particularly by urgent challenges confronted by mankind. Climate science is no exception. Into the 20th and 21st centuries, impacts of climate change to human society became more and more obvious and serious, and this subject has attracted more and more public attention which helped to build political will in response to the increasing pressure from the society and internationally. Thus, studies on the climate are getting flourishing, and new innovations and advanced technologies have brought more breakthrough discoveries. Access to increased fundings



and resources, interdisciplinary collaboration, global cooperation, international initiatives, and open-source knowledge sharing, all contributed to the rapid development of climate science in the recent decades. As the application of AI becomes widespread, the advancement of this field will definitely accelerate, and become more precise and accurate.

## 7 Conclusions

The evolution of climate science reflects a journey from early theoretical insights to a sophisticated understanding of Earth's climate system. With ongoing advancements in technology and methodology, climate science is poised to continue its critical role in addressing the challenges of climate change. As we move forward, interdisciplinary collaboration, improved observational capabilities, more accurate predictions, effective communication, and more powerful mitigation measures will be essential in guiding and facilitating global efforts to mitigate and adapt to the impacts of a changing climate. The urgency for action to address the global climate crisis is also obvious. It is expected that AI would play an increasing role in climate science.

**Acknowledgements:** Special thanks to the editor and reviewers of Naturalis Scientias for their comments and suggestions.

## 8 References

1. Fourier J. 1827. Mémoire sur les températures du globe terrestre et des espaces planétaires. *Mémoires de l'Académie. Royale des Sciences de l'Institut de France*, 7: 569-604.
2. Tyndall J. 1861. On the absorption and radiation of heat by gases and vapours, and on the physical connexion of radiation, absorption, and conduction. *Philosophical Transactions of the Royal Society of London*, 151: 1-36.
3. Arrhenius S. 1896. On the influence of carbonic acid in the air upon the temperature of the ground. *Philosophical Magazine*, 41: 237-276.
4. Schuler J. Researchgate.net. 2024, [https://www.researchgate.net/figure/The-Greenhouse-Effect\\_fig1\\_237730165](https://www.researchgate.net/figure/The-Greenhouse-Effect_fig1_237730165). Retrieved October 19, 2024.
5. Keeling CD, Piper SC, Bacastow RB, Wahlen M, Whorf TP, Heimann M and Meijer HA. 2005. Atmospheric CO<sub>2</sub> and <sup>13</sup>C<sub>CO2</sub> exchange with the terrestrial biosphere and oceans from 1978 to 2000: observations and carbon cycle implications. In: Ehleringer JR, Cerling TE and Dearing MD (eds). *A History of Atmospheric CO<sub>2</sub> and its effects on Plants, Animals, and Ecosystems*, New York: Springer Verlag, 83-113.
6. Scripps Institution of Oceanography at UC San Diego. 2024. The Keeling Curve of UCSanDiego. [https://bluemoon.ucsd.edu/co2\\_400/mlo\\_full\\_record.pdf](https://bluemoon.ucsd.edu/co2_400/mlo_full_record.pdf). Retrieved October 19, 2024.
7. Intergovernmental Panel on Climate Change. 2021. *Climate Change 2021: The Physical Science Basis*. <https://www.ipcc.ch/report/ar6/wg1/>. Retrieved October 19, 2024.
8. NASA. 2020. *NASA Earth Science: Climate Observations*. <https://earthdata.nasa.gov/>. Retrieved October 19, 2024.
9. United Nations Framework Convention on Climate Change. 2022. *Climate Action and the 2030 Agenda for Sustainable Development*. <https://unfccc.int/>. Retrieved October 19, 2024.
10. Pirani A, Matthews R and Chen L (eds). Intergovernmental Panel on Climate Change. 2023. *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II, and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*. IPCC, Geneva, Switzerland.
11. NOAA's National Centers for Environmental Information. 2024. Climate.gov. <https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature>. Retrieved October 19, 2024.
12. El-Montasser G and Salha OB. 2019. A new methodology for assessing the energy use-environmental degradation nexus. *Environmental Monitoring and Assessment* 191 (9): 587.
13. Hawkins E. 2021. The role of artificial intelligence in climate science. *Nature Climate Change*, 11 (5): 356-362.
14. World Meteorological Organization. 2023. *State of the Global Climate 2023*. <https://library.wmo.int/viewer/68835/?offset=#page=1&viewer=picture&o=bookmark&n=0&q=>. Retrieved October 19, 2024.



15. Pachauri RK. 2014. *Climate Change 2014: Synthesis Report*. Intergovernmental Panel on Climate Change. <https://www.ipcc.ch/report/ar5/syr/>. Retrieved October 19, 2024.
16. Moser SC and Dilling L. 2004. Making climate hot: communicating climate change in the public sphere. *Environment*, 46 (10): 32-46.

**Data availability**

The data that support the findings of this study is available from the author upon reasonable request.

**Declaration of competing interest**

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Use of AI tools declaration**

The author declares that he has not used Artificial Intelligence (AI) tools in the creation of this article.

