

Key scientific questions to address climate crisis: Insights from the second climate change science conference

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The Second Climate Change Science Conference was successfully held in Fengxian, Shanghai, China, on October 31, 2024. Centered on the theme “Scientific Questions, Scientific Understanding, and Scientific Decision-Making”, the two-day event featured 15 sessions that addressed key challenges in climate change science and brought together leading scientists,

policymakers, and industry experts from over 250 institutions. The conference underscored that while technological breakthroughs are essential, advancing foundational science and fostering interdisciplinary collaboration are equally crucial for developing robust strategies to tackle the intensifying climate crisis. Based on these discussions, eight Key Scientific Questions



Figure 1. Key Scientific Questions in climate change science.

critical for combating the climate crisis were identified.

OVERVIEW OF CLIMATE CHANGE SCIENCE

Recent research suggests that critical Earth system boundaries may already have been crossed, with rising global temperatures driving extreme weather events and biodiversity loss at an alarming rate.¹ These extreme events not only endanger human lives but also disrupt food production, water availability, and public health, creating compounded risks for vulnerable populations. Biodiversity loss further exacerbates these risks as ecosystems face mounting pressure from habitat destruction, shifting climate zones, and pollution. For example, coral reefs, which sustain millions of marine species and support coastal livelihoods, are rapidly declining due to warming oceans and acidification. The record-breaking temperatures of 2023 underscore the

urgency of addressing these interconnected crises.² Without immediate and comprehensive action, these cascading impacts risk pushing the Earth system beyond thresholds from which recovery may no longer be possible.

Advances in Earth system science have significantly improved our ability to observe and model the intricate processes governing the climate system. Observational innovations, such as satellite-based monitoring of greenhouse gas concentrations, sea surface temperatures, and ice sheet dynamics, provide critical data for understanding climate variability. Meanwhile, climate models are evolving to incorporate dynamic components, such as improved representations of cloud-aerosol interactions, cryosphere processes, and regional feedback mechanisms, enabling more nuanced simulations of localized climate impacts. The synergy between observation and modeling forms the foundation for developing evidence-based strategies to address the

climate crisis effectively.

Mitigation and adaptation technologies offer complementary approaches to addressing the climate crisis,³ but their integration is essential for maximizing impact. Mitigation technologies, such as carbon capture, utilization, and storage (CCUS), alongside renewable energy systems, are vital for reducing greenhouse gas emissions and achieving carbon neutrality. Adaptation technologies, including early warning systems and resilient agricultural practices like drought-resistant crops, strengthen societal and ecological resilience to the unavoidable impacts of climate change. By aligning mitigation and adaptation strategies within a cohesive framework, it becomes possible to simultaneously reduce future risks and enhance current resilience, fostering a more sustainable and comprehensive response to climate change.

CHALLENGES FACING CLIMATE CHANGE SCIENCE

Despite significant advancements, climate science still encounters technical challenges that hinder accurate predictions. Inadequate observational data on remote regions, anthropogenic emissions, and carbon sources and sinks constrains our understanding of the climate system. Additionally, the nonlinear and complex nature of climate interactions challenges precise forecasting, as models often capture predictable signals weakly while exaggerating random variations.⁴ Furthermore, scaling up mitigation and adaptation technologies is costly, particularly in developing countries, where infrastructure and economic constraints often slow renewable energy deployment and other climate solutions.

Despite the efforts of numerous international organizations, institutional challenges such as inconsistent funding and policy implementation continue to slow global progress. This situation is exacerbated by limited resource sharing and uneven support for climate technology, which particularly burdens developing countries.⁵ Additionally, differences in national policies and the delicate balance of equitable responsibility sharing complicate coordinated action. Furthermore, socio-political factors, including levels of public awareness, economic priorities, and access to resources, shape the pursuit of fair and integrated climate strategies.

KEY SCIENTIFIC QUESTIONS IN CLIMATE CHANGE SCIENCE

Effectively addressing the climate crisis requires focused efforts on eight Key Scientific Questions (Figure 1):

1. Construction of Intelligent Sensing Networks and Digital Twin Systems for the Multi-sphere Earth System: How can we develop advanced intelligent sensing networks that integrate data from the atmosphere, hydrosphere, lithosphere, cryosphere, and biosphere to build comprehensive digital twin systems of the Earth, enabling detailed simulations and projections of climate dynamics?

2. Key Feedback Mechanisms and Sensitivity Assessment of the Global Climate System under Human Influence: How can we unravel the complex interactions and feedback mechanisms among the atmosphere, hydrosphere, cryosphere, and biosphere? How can we accurately quantify the climate system's response to increased greenhouse gas concentrations, leading to precise modeling of climate sensitivity and future scenarios?

3. Prediction of Tipping Points and Triggering Mechanisms of Irreversible Changes: How can we precisely identify and predict tipping points within the climate system? What are the triggering mechanisms behind irreversible changes such as ice sheet melting, permafrost thawing, and rainforest degradation? How can we identify critical time windows for intervention to avoid catastrophic consequences?

4. High-precision Prediction and Early Warning of Local Climate Change Trends and Extreme Weather Events: How can we develop high-resolution models to accurately predict climate change trends and changes in the frequency and intensity of extreme weather events at regional and local scales? What scientific approaches are needed to provide a solid basis for

formulating targeted disaster prevention and mitigation strategies?

5. Material Design and Process Optimization for Efficient Carbon Capture and Utilization: How can we develop novel materials with specialized surface properties to overcome physical and chemical bottlenecks such as CO₂ selective adsorption, mass transfer limitations, and high energy consumption? How can we improve CO₂ capture efficiency and reduce capture costs to make carbon capture and utilization more viable?

6. High-efficiency Conversion and Storage of Clean Energy: Through bandgap engineering and interface design, how can we overcome limitations in photogenerated carrier separation and transport? How can we address the stability issues of perovskite solar cells and construct fast ion conduction pathways in energy storage materials to achieve significant improvements in photoelectric conversion efficiency and energy storage density?

7. Novel Chemical Reaction Pathways for Near-zero Carbon Emissions in Industrial Processes: How can we develop new catalytic materials and reaction processes to achieve low-temperature, efficient conversion of hydrogen replacing carbon in steel reduction? How can we design chemical pathways that lower activation barriers in cement production, balance reaction kinetics with thermodynamics, and reduce energy use?

8. Integrated Optimization of Climate Change Adaptation Technologies and Policies with Evaluation of Economic and Social Benefits: How can we establish comprehensive big data and intelligent models to fully assess the economic and social impacts of climate change mitigation and adaptation technologies and policies across different regions and sectors? How can we quantify their cost-effectiveness, equity, and feasibility?

FUTURE OUTLOOK

Integrating emerging technologies, including artificial intelligence (AI), big data analytics, digital twins, and blockchain, is set to revolutionize climate change research. Innovations in hydrogen energy and nuclear fusion promise significant advances in clean energy. Developing urban adaptation technologies, such as smart cities and green infrastructure, will enhance urban resilience to climate impacts. Market mechanisms and incentive policies, such as carbon pricing and trading schemes, will encourage emission reductions from businesses and individuals. Public engagement through education and awareness campaigns will foster a culture of sustainability, strengthening societal resilience against climate change.

Addressing the eight Key Scientific Questions will require strengthening foundational research, fostering interdisciplinary collaboration, and integrating advancements in scientific understanding with mitigation and adaptation technologies to accelerate transformative solutions and drive impactful climate actions. The successful convening of the Second Climate Change Science Conference has set a clear path forward for the global scientific community, showing that through collective endeavor and scientific innovation, a sustainable and resilient future is increasingly within reach.

REFERENCES

1. Rockström J., Gupta J., Qin D., et al. (2023). Safe and just Earth system boundaries. *Nature* **619**:102–111. DOI:10.1038/s41586-023-06083-8
2. Jiang T., He X., Su B., et al. (2024). COP 28: challenge of coping with climate crisis. *The Innovation* **5**:100559. DOI:10.1016/j.xinn.2023.100559
3. Wang F., Harindintwali J.D., Yuan Z., et al. (2021). Technologies and perspectives for achieving carbon neutrality. *The Innovation* **2**:100180. DOI:10.1016/j.xinn.2021.100180
4. Weisheimer A., Baker L.H., Bröcker J., et al. (2024). The Signal-to-Noise paradox in climate forecasts: revisiting our understanding and identifying future priorities. *Bull. Amer. Meteorol. Soc.* **105**:E651–E659. DOI:10.1175/BAMS-D-24-0019.1
5. Wei T., Yang S., Moore J.C., et al. (2012). Developed and developing world responsibilities for historical climate change and CO₂ mitigation. *P. Natl. Acad. Sci. USA* **109**:12911–12915. DOI:10.1073/pnas.1203282109

DECLARATION OF INTERESTS

The authors declare no competing interests.