

Frequent occurrence of extreme weather and out-of-balance climate systems

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INTRODUCTION

Under the background of the "La Nina" event lasting for three years, the summer of 2022 experienced large-scale persistent heat wave and various heating-induced natural disasters. The 2023 summer was still extremely hot. Monthly reports from the World Meteorological Organization (WMO) indicated record-breaking global average temperatures for June, July, and

August, making the period from June to August 2023 the hottest summer on record¹ (see Figure 1A). In September, the global average temperature once again broke the record, even reaching 16.38°C, approximately 1.75°C warmer than the pre-industrial average for 1850–1900, as reported by the European Union-funded Copernicus Climate Change Service (C3S) implemented by ECMWF. Observations show that, as of 2 October 2023, the

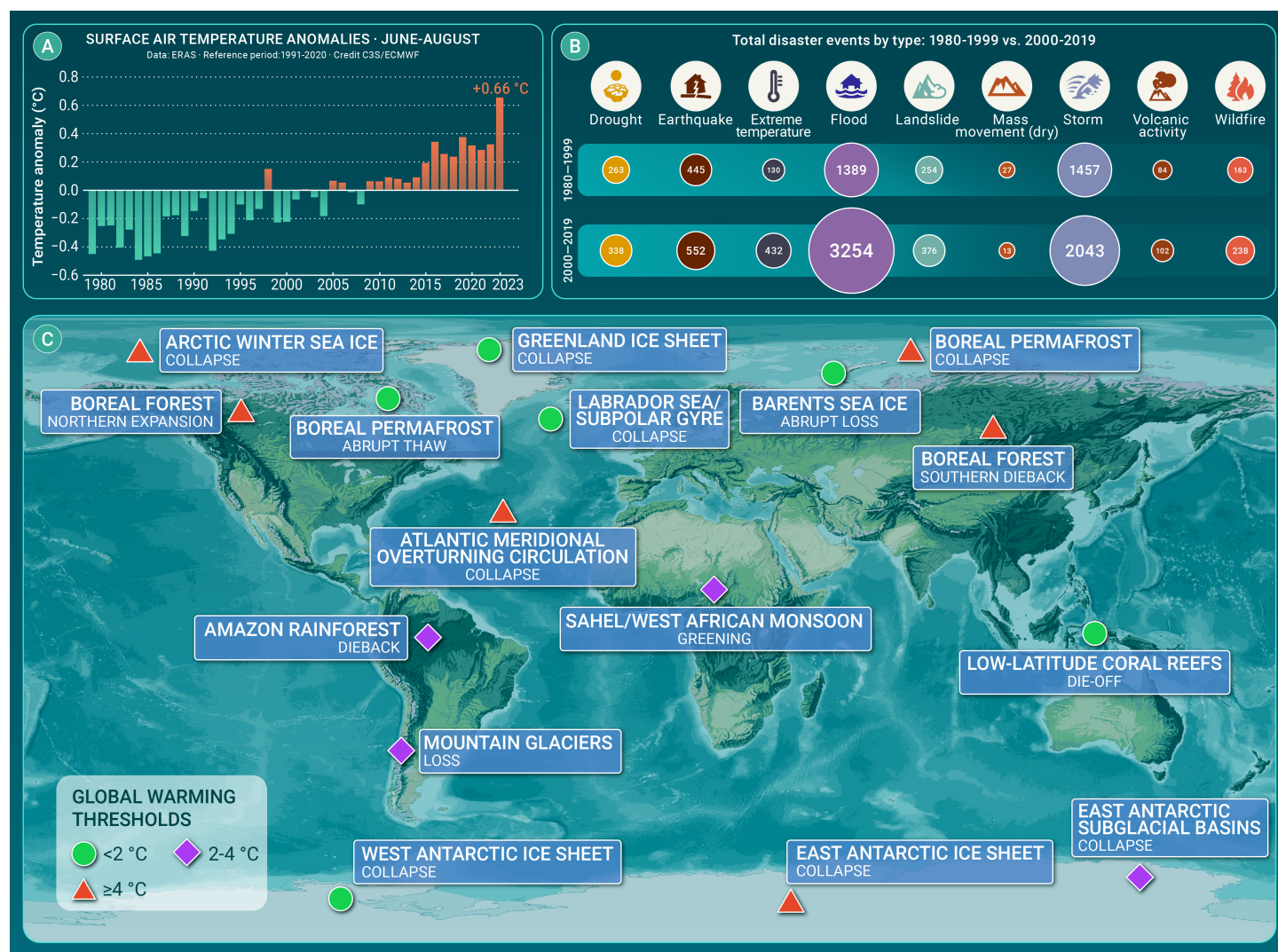


Figure 1. Extreme weather and its related disaster events (A) Surface air temperature anomalies of June–August from 1980 to 2023 (Bonn and Geneva, 6 September 2023 (ECMWF and WMO) – Earth just had its hottest three months on record, according to the European Union-funded Copernicus Climate Change Service implemented by ECMWF). (B) In 2000–2019, natural disasters related to weather and climate increased significantly relative to 1980–1999. (C) Locations of climate tipping elements in cryosphere (blue), biosphere (green) and ocean/atmosphere (orange), and global warming levels for their tipping points to be likely triggered.

number of days when the global average temperature increase range was 1.5 °C above the 1850–1900 preindustrial average temperature threshold has reached 86 days. Moreover, the temperature increment even exceeded 1.8 °C in some records, significantly surpassing the previous record of most warming days in 2016. On 30 November, WMO released a "Provisional State of the Global Climate 2023" on the opening day of the COP28

United Nations climate change conference, considering 2023 will be the hottest year in history on record.

Then, what does the global-scale persistent high temperature and the accompanied extreme precipitation, drought and floods mean in the context of the changes in global weather and climate? This is a serious issue that needs to be discussed and pursued.

EXTREME WEATHER AND CLIMATE EVENTS AND FREQUENT DISASTERS

On 12 December 2015, nearly 200 parties to the United Nations Framework Convention on Climate Change unanimously adopted the "Paris Agreement" at the Paris Climate Change Conference. One of the important binding targets set in the agreement is to limit the global average temperature rise to 2 °C above the pre-industrial level, and strive to control it within 1.5 °C. The world should achieve the peak of greenhouse gas emissions soon and net zero emissions in the second half of this century.

According to the report released by the United Nations Office for Disaster Risk Reduction (UNDRR) in October 2020, climate-related disasters have increased significantly since the 21st century (Figure 1B).² Relative to 1980–1999, flood disasters increased from 1,389 to 3,254 in 2000–2019, and storms from 1,457 to 2,043. Moreover, the number kept rising after 2020, getting to a new high of 176 in 2022. Particularly, the global sustained high temperature events in 2022 caused the death toll of 16,416, which ranked first in the death toll due to all types of natural disasters.³

Global meteorological disasters resulting from heavy precipitation occur frequently, exemplified by the floods in California stemming from intense precipitation between 31 December 2022 and 25 March 2023, for which the U.S. President Biden and California Governor Newsom both declared California into a state of emergency successively in January 2023. Against the background of high temperature and drought, forest fires in Canada raged from spring to autumn 2023. As of September, the fire area has exceeded 170,000 km², more than 6 times the average in the past decade. Moreover, the rain-deprived Libya in North Africa was hit by an unprecedented Medican Daniel killing more than 10,000 people and leaving another 10,000 missing. This is the second heaviest casualty disaster by meteorological disasters in past 15 years since the severe tropical storm Nargis landed in Myanmar on 2 May 2008 and led to more than 140,000 deaths.

China's situation was harsh as well in 2023. In June 2023, extensive heat wave and drought occurred in northern China, where the high temperature days rose to the highest in the same period since 1961 as the result of four intense heating processes. At the end of July, however, there was a reversal of drought and flood. The subtropical marine system in the northwest Pacific Ocean was distinctly active. Thus, from 29 July to 1 August, extremely severe precipitation caught the Beijing-Tianjin-Hebei region. The rainfall intensity of this process exceeded that of many extreme rainstorm processes in North China in recent 30 years, making serious disasters and losses.

For frequent extreme weather and climate events, the Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC AR6) has given a clear conclusion, i.e., there is no doubt that the human activities have contributed to the warming of the atmosphere, oceans and land. The atmosphere, ocean, cryosphere and biosphere have undergone extensive and rapid changes. It is believed that the observed extreme weather events such as heat waves, severe precipitation, droughts and tropical cyclones, especially the impact evidence of human activities, have been intensified since the IPCC AR5. Although not all extreme weather and climate events can be attributed to climate change or human activities, it is clear that these evolution trends are closely correlated to climate change. With the continuous climate warming, how to take more active actions to protect the earth's environment and avoid systematic disasters is indeed a significant issue needing to be seriously considered and responded.

CLIMATIC TIPPING POINTS AND OUT-OF-BALANCE SYSTEMS

Extreme meteorological events tend to occur one after another, and their backgrounds and causes are obviously the key issues to be concerned. The further questions are: What does it mean if the so-called extreme events occur frequently? Can we use "frequent" for them? When quantitative analysis confirms that extreme meteorological events have shown the tendency of occurring frequently, what we worry about is whether the earth environment on which human beings depend has changed systematically, or whether the living space we rely on has entered an unfavorable "new normal".

William D. Nordhaus, winner of the 2018 Nobel Prize in Economics,

proposed in *Climate Casino* that a normal economy or ecosystem can vary from a good equilibrium to a bad equilibrium. When the system surpasses a tipping point under various pressures, some rapid and catastrophic changes would occur. Does the frequency of extreme meteorological events mean that the earth's climate system is heading for another bad equilibrium point? This involves the climate tipping point proposed by IPCC at the beginning of this century.⁴ The climate tipping point defined by IPCC is the critical value or threshold for global or regional climate to change from one stable state to another. Beyond this threshold, the system will undergo sudden and irreversible changes and cannot return to its original stable state. The climate system is composed of multiple subsystems interacting nonlinearly, and there may be multiple critical points at different scales. The tipping points that most climate systems may pass through are called "tipping elements" and, in extreme cases, the whole climate system may become a tipping point. In September 2022, Armstrong McKa et al. published an article in *Science*, analyzing the risk degrees of the current 16 climate tipping-point events in the world. They believed that even if global warming is less than 2 °C, five tipping elements still exist in the danger zone, including Greenland ice sheet, West Antarctic ice sheet, low-latitude coral reefs, permafrost in the Northern Hemisphere, and sea ice in the Barents Sea. If the 2 °C warming is surpassed, more tipping elements will be triggered (Figure 1C).⁵

For this summer's extreme heat wave across North America, Europe and China, scientists of the World Weather Attribution Program have carried out an assessment, aiming at confirming to what extent the climate change caused by human activities has altered the likelihood and intensity of extreme high temperature in these regions in July 2023. One conclusion is that without human-induced climate change, high temperature event would have been rarely seen. In China, it might have occurred about once every 250 years, while the United States/Mexico region and Southern Europe, would not have had any such events. Meanwhile, the assessment also mentions another view that heat wave is one of the most deadly natural disasters because thousands of people die from heat-related diseases every year.

In summary, the frequent occurrence of extreme weather and climate events and the possible breakthrough of multiple climate tipping points mean that the earth system is likely to face urgent risks, and will slip into a bad equilibrium state. The entire earth's ecosystem will encounter uncontrollable and irreversible systemic changes. This is a problem that human society cannot avoid and needs special attention and urgent solution. In terms of the relevant issue of tipping point, climate scientists are still conducting in-depth and systematic investigations, hoping to obtain more reliable evidences. Obviously, what we are facing is not only the harm of extreme weather and climate events, but also the risk that the risk of current extreme events are becoming a new normal.

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DECLARATION OF INTERESTS

The author declares no competing interests.