The differences of global extreme climate events changes before and after 1.5℃ overshoot

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1. INTRODUTION

According to the IPCC AR6 , the average temperature rise in 2011-2020 was 1.09 ℃ (0.95-1.20 ℃) than the pre-industrial period (1850-1900) , from 2001 to 2020, it will be 0.99 ℃ warmer than before industrialization. The climate is rapidly warming, human activities have already led to an increase in the frequency and intensity of many meteorological and climate extreme events across every region of the globe, including heatwaves, heavy rainfall, droughts, and tropical storms. If urgent global action is not taken, extreme events such as high temperatures, droughts, floods, and the compound extreme events they cause may become the norm in the future.Compared to a 2℃ temperature increase, limiting the temperature increase to 1.5 ℃ can reduce the increase in extreme high-temperature events by 35% to 46% in terms of intensity, frequency, and duration. Therefore, controlling the temperature target within 1.5 ℃ is more beneficial to societal development than controlling it within 2 ℃.

2. DATA AND METHODS

- This study uses numerical simulations from CMIP6 under the SSP1-1.9 scenario. SSP1-1.9 represents a sustainable development pathway where global CO2 emissions are reduced to net-zero around 2050. It is the only future projection scenario in CMIP6 that aligns with the goals of the Paris Agreement and the only pathway that limits global warming to within 1.5° C by the end of the century. The simulation data includes daily average, maximum, minimum temperatures and precipitation, with a daily time resolution. The historical period covers 1850-2014, and the future period spans 2015-2100. In this study, the period from 1861-1900 is selected as the reference period for 1.5° C warming; the period from 1995-2014 serves as the contemporary average climate period. MME refers to the multi-model ensemble mean. The initial period when the global average temperature increase reaches 1.5° C is called the P1 phase, and the subsequent period when it returns to 1.5° C is termed the P2 phase..
- The study selected seven representative indices from the extreme index system defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) to examine the changing characteristics of global extreme climate events, including four temperature indices and three precipitation indices.
- Due to the varying impacts of climate change on different regions, this study refers to the definitions provided by Giorgi et al. and Francisco to divide the globe into 23 regions, allowing for a more intuitive presentation of the response of different regions to a 1.5° C warming.

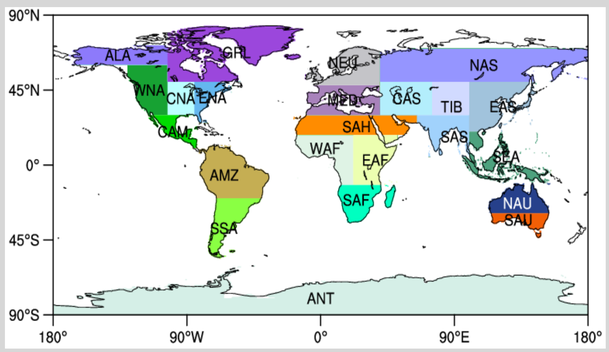


Fig. 1 Map of 23 subregions in the globe

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3. RESULTS

- Under the SSP1-1.9 scenario, the model mean reaches a 1.5° C temperature increase in 2034, returns to 1.5° C in 2055, with a duration of 21 years, and peaks at 1.57° C in 2038, with an overshoot intensity of less than 0.1° C, which can be classified as a low overshoot pathway as defined in the IPCC Special Report
- .Due to differences in climate sensitivity and other factors, there are also variations among the models. Although all models exhibit overshoot characteristics, the magnitude of warming differs. Among them, five models reach a 1.5° C temperature increase for the first time between 2017 and 2067. Only three models, CNRM-ESM2-1, EC-Earth3-Veg-LR, and MRI-ESM2-0, return to within the 1.5° C warming level by the end of the 21st century after overshooting, while the other five models never reach the 1.5° C warming level.

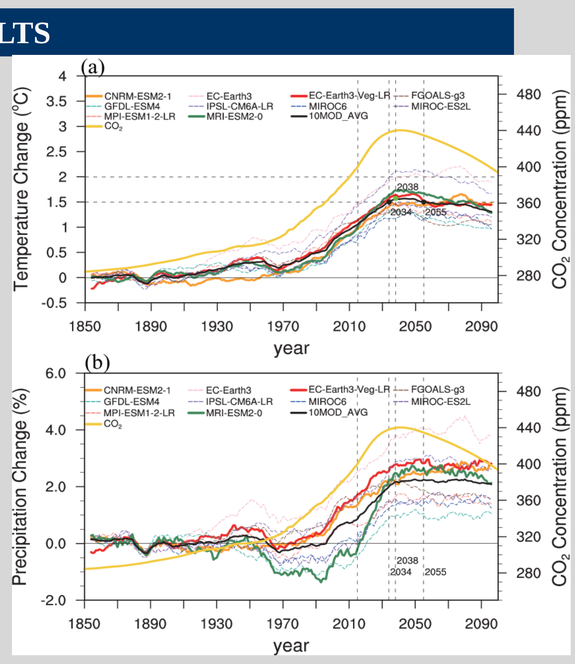


Fig 2 Temporal evolution of (a) global mean surface temperature (units: ℃) and (b) precipitation (units: %) from 10 CMIP6 models and their ensemble mean (relative to 1861–1900), in SSP1-1.9 pathway

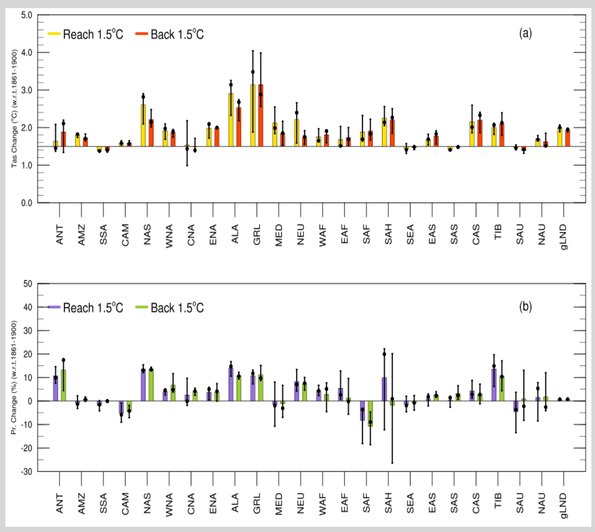


Fig.3 The changes in annual mean (a) temperature (units: ℃) and (b) precipitation (units: %) in 1.5℃(P1 phase) and return to 1.5℃(P2 phase) over the 23 subregions (relative to 1861–1900)

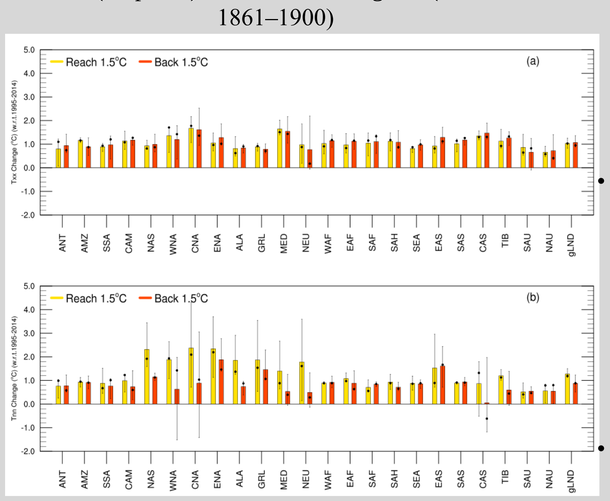


Fig 4. Projected changes in (a) TXx, (b) TNn in 1.5℃ and return to 1.5℃ over 23 subregions (units: ℃) (relative to 1995–2014) ）

- During the P1 phase, due to the higher warming amplitude over land compared to the ocean, the average temperature in most regions globally exceeds 1.5° C . Notably, the warming amplitudes in NAS, ALA, and GRL are significantly higher than in other regions, with ALA and exceeding 2.5° C , and GRL having the largest increase, reaching 3° C . The P2 phase are generally consistent with those during the P1 phase, with average temperature increases in 17 out of 23 global regions (74%) exceeding 1.5° C .
- During the P1 phase, 13 out of 23 global regions exhibit an increasing trend in average precipitation. Unlike the changes in average temperature, the variations in average precipitation across different regions globally during the P1 phase show more pronounced regional characteristics. Overall, there is an increase in precipitation in high-altitude and mid-to-high latitude regions, with higher increases than in low latitudes. During the P2 phase, precipitation changes continue to exhibit distinct regional characteristics, with 15 regions experiencing a greater increase in precipitation compared to the P1 phase.
- During both P1 and P2 phases, compared to the period from 1995 to 2014, the regional averages of TXx (maximum daily temperature) and TNn (minimum daily temperature) increased across all 23 regions. In the P1 phase, regions with significant increases in TXx, exceeding 1° C, included WNA, CAN, ENA, MED, SAF, SAH, and CAS. For TNn, increases of 1-2° C, which were greater than those for TXx, were observed in NAS, WNA, CAN, ENA, ALA, GRL, NEU, and EAS.
- In the P2 phase, TXx increases were higher than those in the P1 phase in 13 regions, with increases of more than 0.2° C in ENA, EAF, EAS, and SAS compared to the P1 phase. However, TNn decreased in 14 regions, with reductions of more than 1° C in NAS, WNA, CNA, ALA, and NEU during the P2 phase compared to the P1 phase.

- Spatially, the differences in TXx between the two periods are evident in most land regions, with a maximum difference exceeding ±1° C. The differences in TNn between the two periods are more pronounced in the Northern Hemisphere, with most values being negative and the maximum change exceeding -3° C.
- Overall, in regions such as the Qinghai-Tibet Plateau, eastern China, South Asia, East Africa, North America, and Antarctica, the frequency and intensity of high-temperature events in the P2 period are likely to be higher than those in the P1 period. However, in the western part of the mid-to-high latitudes of the Eurasian continent, North America, and northeastern China, the frequency and intensity of low-temperature events in the P2 period are likely to be higher than those in the P1 period..

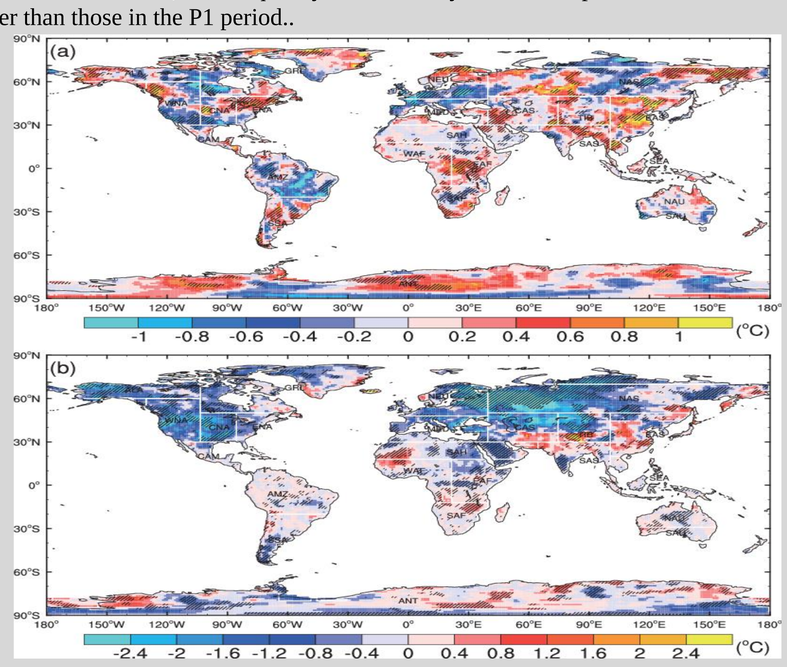


Fig. 5 The difference in (a) TXx changes and (b) TNn changes (relative to 1995–2014) between the periods of P1 and P2 (P2 minus P1). The hatched regions in (a) and (b) indicate the simulations agree on the sign of the changes

- Compared to the period 1995-2014, during the P1 phase, R20mm increased significantly in regions such as AMZ, ENA, SEA, EAS, and SAS, with slight increases in other regions but a decrease in SAF. During the P2 phase, R20mm continued to increase relative to 1995-2014 in most regions. When comparing the two phases, the regional average differences within each partition are relatively small. In the P1 phase, MME's RX5day increased in most regions. During the P2 phase, the increase in RX5day exceeded 5mm in SEA and SAS compared to the P1 phase.
- There were no significant changes in CDD across most of the globe during the P1 phase. However, increases in CDD were greater in CAM, MED, EAF, SAF, SAH, and SAU compared to other regions, while decreases were observed in ANT, EAS, TIB, and NAU. During the P2 phase, regions with increases and decreases in CDD relative to the current period each accounted for 50%. Specifically, SAS, CAS, and TIB will continue to experience increases of 2-4 days, indicating that drought conditions in these already arid regions will intensify. Conversely, CDD will decrease by approximately 2 days in EAS and SAH, suggesting that drought conditions in these regions may weaken after returning to a 1.5° C temperature increase.

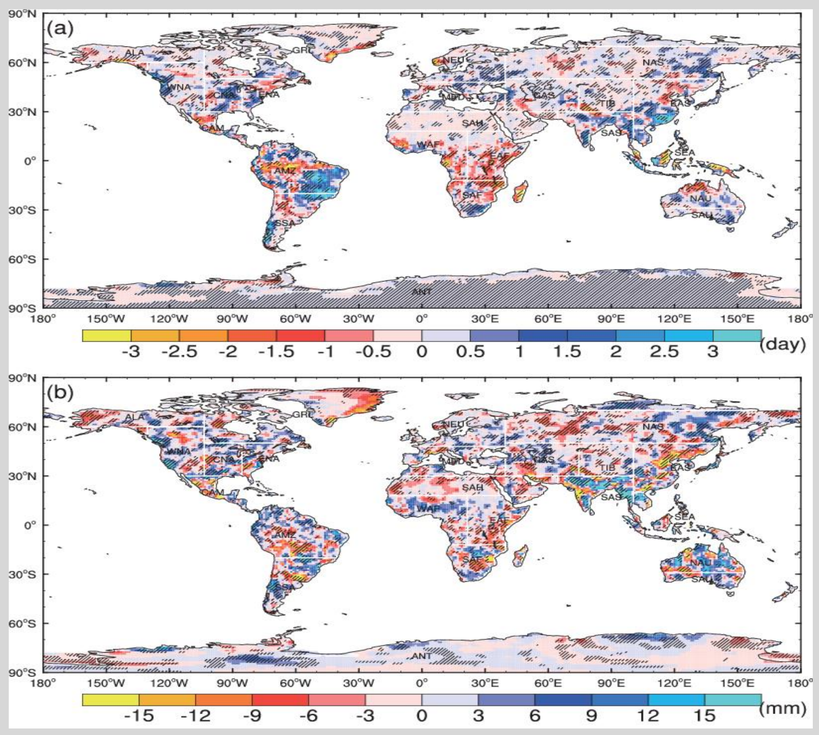


Fig. 6 The difference in (a) R20mm changes and (b) RX5day changes (relative to 1995–2014) between the periods of P1 and P2 (P2 minus P1). The hatched regions in (a) and (b) indicate the simulations agree on the sign of the changes

4. CONCLUSIONS AND DISCUSSION

- Based on global climate models CMIP6 under SSP1-1.9 scenario, the changes in mean temperature and precipitation, as well as seven extreme climate indices, over the 23 subregions at 1.5℃ level (P1 phase) and back to 1.5℃ level (P2 phase) were projected.
- Globally, the areas with multi-model consistent increases in both cold and hot events are larger than those with the decreases.
- The risk of extreme cold/hot events will increase over the western part of mid-high latitudes in Eurasia, North America and northeastern China/the Tibet Plateau, eastern China, South Asia, East Africa, North America and Antarctic.
- The spatial pattern of heavy precipitation differences is partially similar to that of annual mean precipitation: the values over southern China, South Asia, Southeast Asia, eastern and southwestern South America, North America, Australia, and central and eastern Europe will increase with good agreement, and the values over North China to northeastern China, southern edge of the Tibet Plateau, southern Africa, northern South America and northern Australia will decrease with good agreement.
- More consecutive dry days (CDDs) are projected in most regions, the large changes with good agreement can be found over Central Asia, South Asia, the Tibet Plateau, central and northern Russia, north of and the central Sahara in Africa, central Australia, parts of Antarctic.
- The results indicate that even if carbon emission peaks around 2035 and then begins to reduce immediately, temperature and precipitation extremes at certain regions will be even larger than those before overshooting, due to the difference regional climate responses to global warming. Then the impact will still last many years, with the influence increasing.
- Thus, the projected increases in extreme climate events on regional and local scale should be alerted.

5. ACKNOWLEDGEMENTS

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