Delayed slow ocean response to carbon dioxide removal causes asymmetric tropical rainfall change

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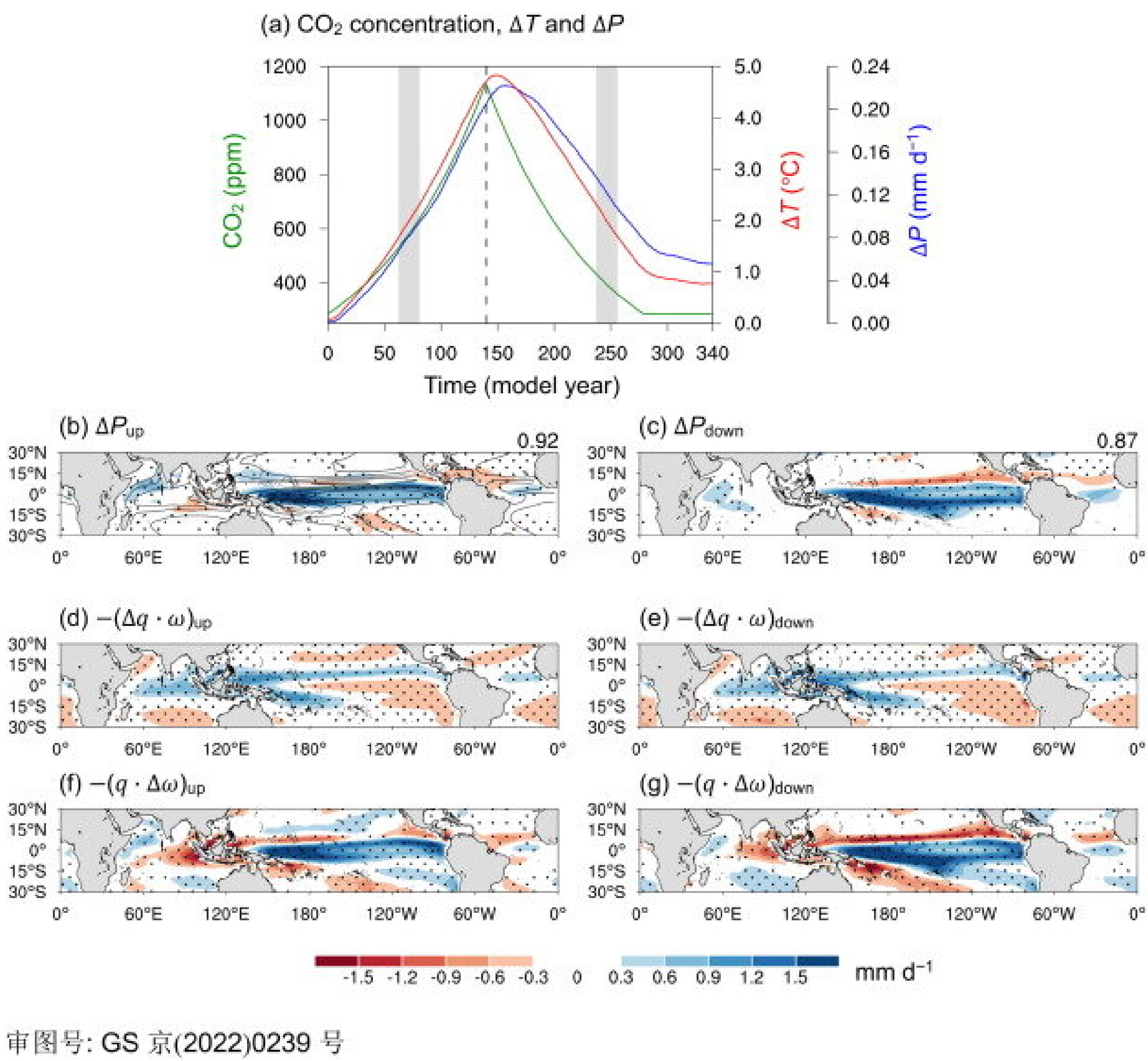


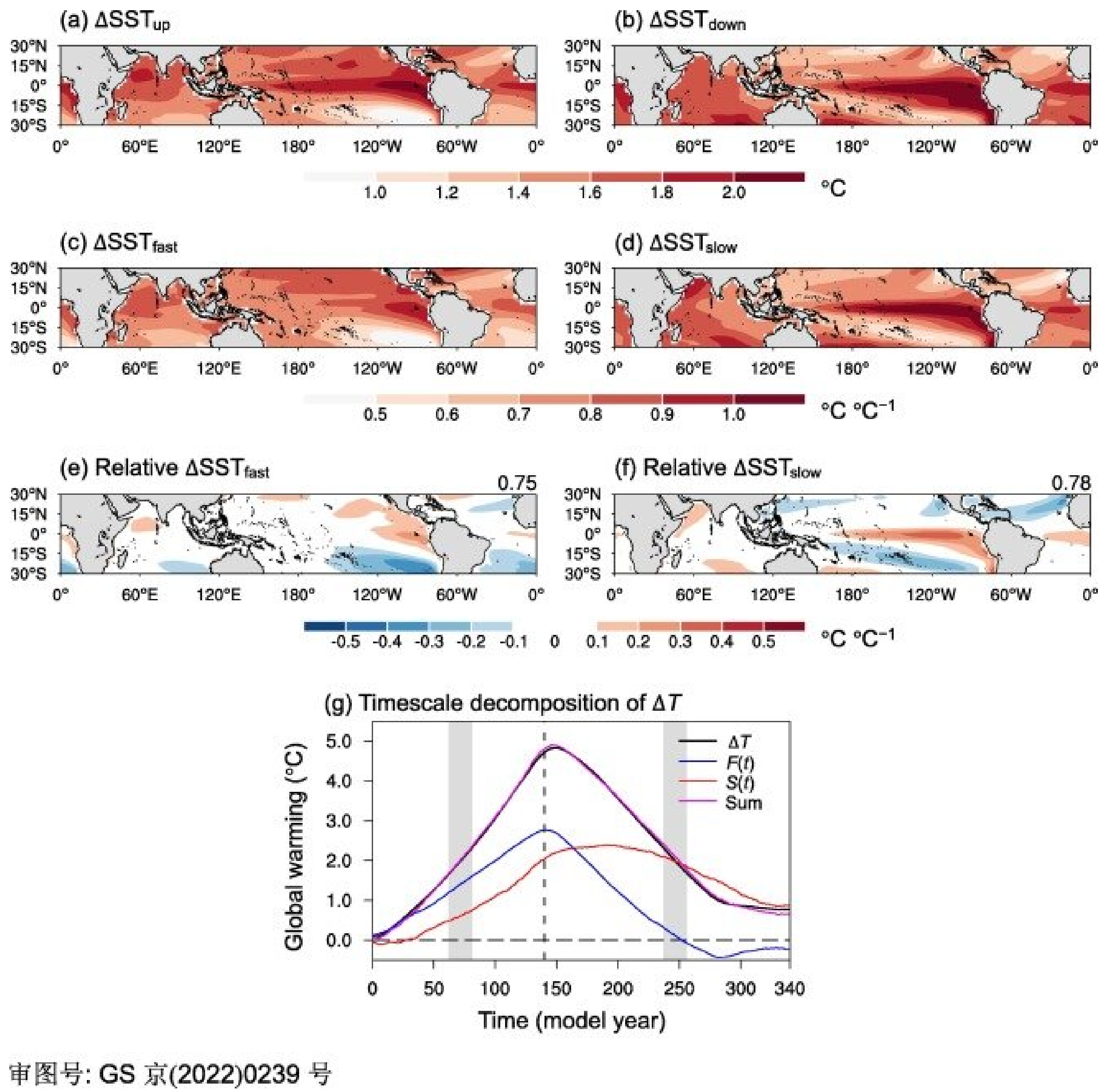
Evolution of global mean and patterns of change in surface temperature and rainfall during the CO_2 ramp-up and ramp-down periods. (a) The 21-year running mean of atmospheric CO_2 concentration (green) and the annual-mean changes in global mean surface temperature (red) and rainfall (blue) in the CO_2 ramp-up/ramp-down experiment. The dashed vertical line indicates year 140, when the CO_2 concentration peaks. The two gray bands covering years 62–81 and 237–256 denote the two representative time slices of 2 °C global mean warming during ramp-up and ramp-down. Changes in tropical rainfall (b, c) and the thermodynamic (d, e) and dynamic (f, g) components in the 2 °C warming time slices during CO_2 ramp-up (b, d, f) and ramp-down (c, e, g). The contours in (b) represent the climatology of tropical rainfall in piControl (interval: 2 mm d^{-1}). The spatial correlation coefficients between the sum of the thermodynamic and dynamic components and tropical rainfall changes are shown in the top-right corners of (b) and (c). Stippling in (b–g) indicates that at least five out of six models agree on the sign of the multi-model mean. Credit: Science China Press

Using fossil fuels causes large amounts of carbon dioxide (CO_2) to be emitted, which is one of the major greenhouse gases responsible for global warming. The climate changes under increasing CO_2 radiative forcing (called "CO_2 ramp-up") have been widely projected using numerical experiments. For a carbon-neutral world, more studies have begun to focus on the regional climate responses under decreasing CO_2 forcing from a high CO_2 concentration to the pre-industrial level (called "CO_2 ramp-down").

A new study, published in the journal *Science Bulletin*, shows that the changes in tropical rainfall—one of the most important indicators for global climate change—are asymmetric at the same warming level (such as 2°C) during CO_2 ramp-up and ramp-down. The spatial variation of tropical rainfall change is stronger during CO_2 ramp-down than ramp-up, increasing over the equatorial Pacific with a southward extension but decreasing over the Pacific intertropical convergence zone and the South

Pacific convergence zone. This study is based on an idealized CO_2 ramp-up/ramp-down scenario, in which the CO_2 continuously increases at 1% year^{-1} from the pre-industrial level to a quadrupled level during ramp-up, followed by ramp-down at the same rate of 1% year^{-1} to reach the pre-industrial level.

Using a moisture budget decomposition method, the researchers demonstrate that this asymmetric tropical rainfall change is mainly due to the tropical circulation change, which is further closely related to the local sea surface temperature (SST) change.



Pattern of tropical SST changes and the timescale decomposition. Changes in tropical SST in 2 °C warming time slices during CO_2 ramp-up (a) and -down (b). The normalized fast (c) and slow (d) changes in tropical SST. (e, f) As in (c, d) but with the tropical mean (shown in the top-right corner) removed. (g) The 21-year running mean contribution of the fast (Ft; blue) and slow (St; red) responses in the CO_2 ramp-up/ramp-down experiment. Their sum (purple) is shown to compare with the total global mean warming (black). Credit: Science China Press

"The multi-timescale processes could be tangled up during the CO_2 ramp-up/ramp-down scenario, forming a complex time-evolving pattern of tropical rainfall changes," explains the corresponding author, Dr. Ping Huang, a professor at the Institute of Atmospheric Physics, Chinese Academy of Sciences. "These time-dependent SST responses during the two periods are a hybrid of responses at different timescales."

The researchers apply a timescale decomposition method to the climate response, (developed in previous studies to understand the tangled evolutions of responses at different timescales) to separate the impacts of SST responses at different timescales on the tropical rainfall change. A fast SST response and a slow one based on processes at different timescales are defined to be evaluated in terms of their time-varying contributions and impacts under the CO_2 ramp-up/ramp-down scenario.

Results show that the impact of the fast SST response on the tropical rainfall change is much weaker than that of the slow SST response during CO_2 ramp-down, and its contribution is also much smaller. The slow SST response can induce a stronger tropical rainfall change due to an El Niño-like warming pattern over the equatorial eastern Pacific. A stronger subsurface warming during the CO_2 ramp-down period suppresses the ocean dynamical thermostat effect, leading to the El Niño-like warming pattern.

"Our results indicate that returning the global mean temperature increase to below a certain goal, such as 2°C, by removing CO_2, may fail to restore tropical convection distribution, with potentially devastating effects on climate worldwide," concludes the first author, Dr. Shijie Zhou, a postdoctoral researcher at the Institute of Atmospheric Physics, Chinese Academy of Sciences.

More information: Shijie Zhou et al, Varying contributions of fast and slow responses cause asymmetric tropical rainfall change between

CO_2 ramp-up and ramp-down, *Science Bulletin* (2022). DOI: 10.1016/j.scib.2022.07.010

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