Climate Response to Volcano-like Pulse Versus Sustained Stratospheric Aerosol Forcing

Lei Duan[1], Long Cao[2], Govindasamy Bala[3], and Ken Caldeira[4]

[1]Carnegie Institution for Science Stanford
[2]ZheJiang University
[3]Indian Institute of Science
[4]Carnegie Institution for Science

November 24, 2022

Abstract

Solar geoengineering has been suggested as a potential approach to counteract the anthropogenic global warming. Major volcanic eruptions have been used as natural analogues to large-scale deployments of stratospheric aerosol geoengineering, yet difference in climate responses to these forcings remains unclear. Among many factors characterizing the difference between the two, durations of the additional aerosol layer in the stratosphere differ substantially between volcanic eruptions and the SAI geoengineering. Sulfate aerosols from volcanic eruptions typically stay in the stratosphere for one to two years. Stratospheric aerosol geoengineering, however, if used to counteract anthropogenic warming, would need to be deployed quasi-continuously and thus the additional aerosols would stay in the stratosphere persistently. Using the NCAR CESM model, we compare the climate response to two highly idealized stratospheric aerosol forcings that have different durations: a short-term pulse representative of volcanic eruptions and a long-term sustained forcing representative of geoengineering. For the same amount of global mean cooling, the pulse case causes much larger reductions in surface temperature over land relative to the sustained case. This greater cooling over land leads to a larger decrease in the vertical motion of air over land in lower atmosphere, and reduces water vapor transport from the ocean to land. For similar amounts of global cooling, the decrease in land runoff caused by a short-term pulse aerosol forcing is about twice as large as that caused by a sustained aerosol forcing. Our results clearly demonstrate difference in the climate response to volcanic-like and geoengineering-like stratospheric aerosol forcings, and suggest that caution should be exercised when extrapolating results from volcanic eruptions to the SAI geoengineering deployments. However, observations and simulations of climate impacts from volcanic eruptions test many of the same physical mechanisms that would come into play in a stratospheric aerosol geoengineering scenario, and thus major volcanic eruptions remain as valuable analogues for solar geoengineering deployment.

CARNEGIE SCIENCE

Climate response to Pulse versus Sustained Stratospheric Aerosol Forcing

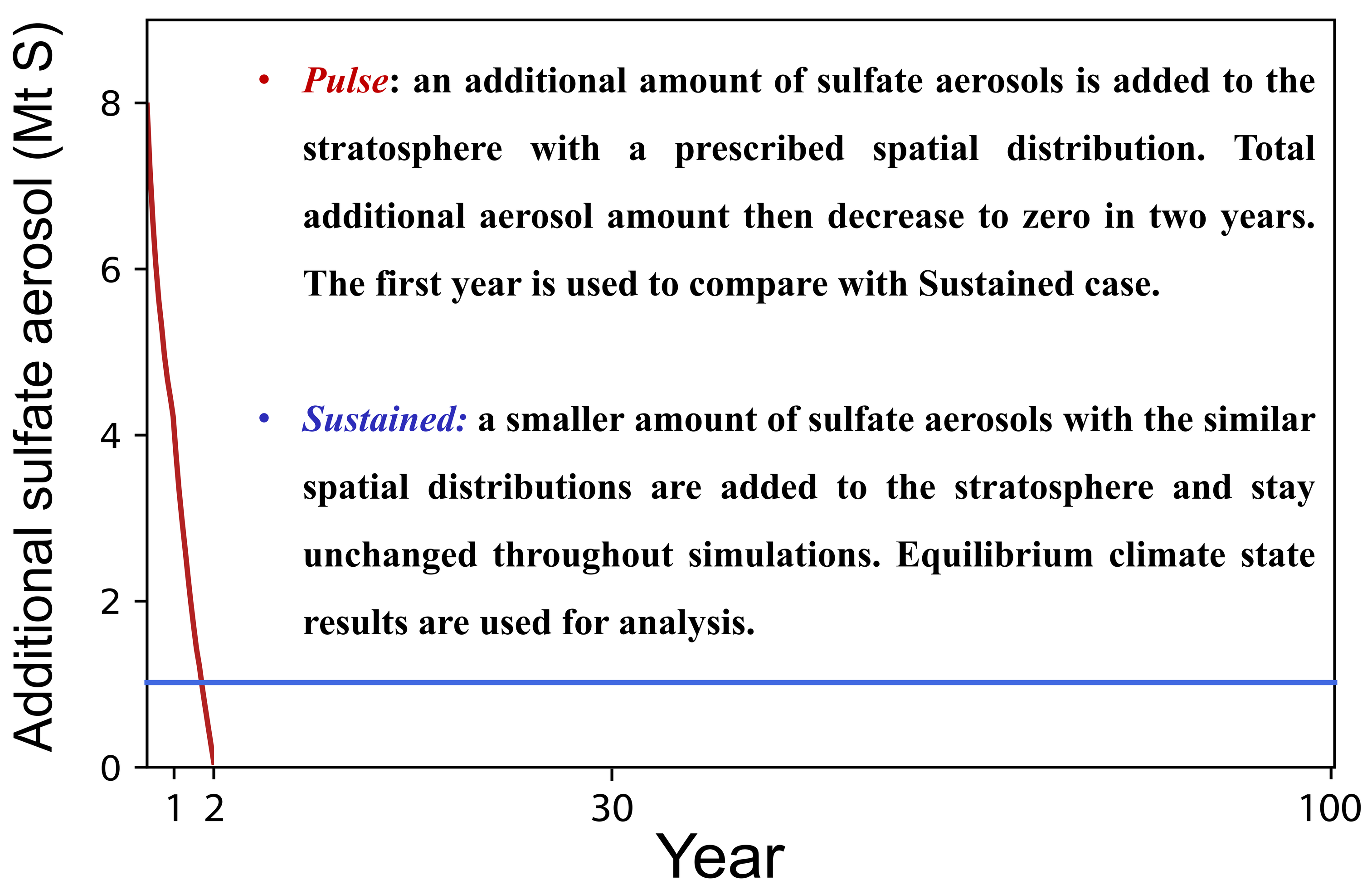
Lei Duan[1], Long Cao[2], Govindasamy Bala[3], and Ken Caldeira[1]

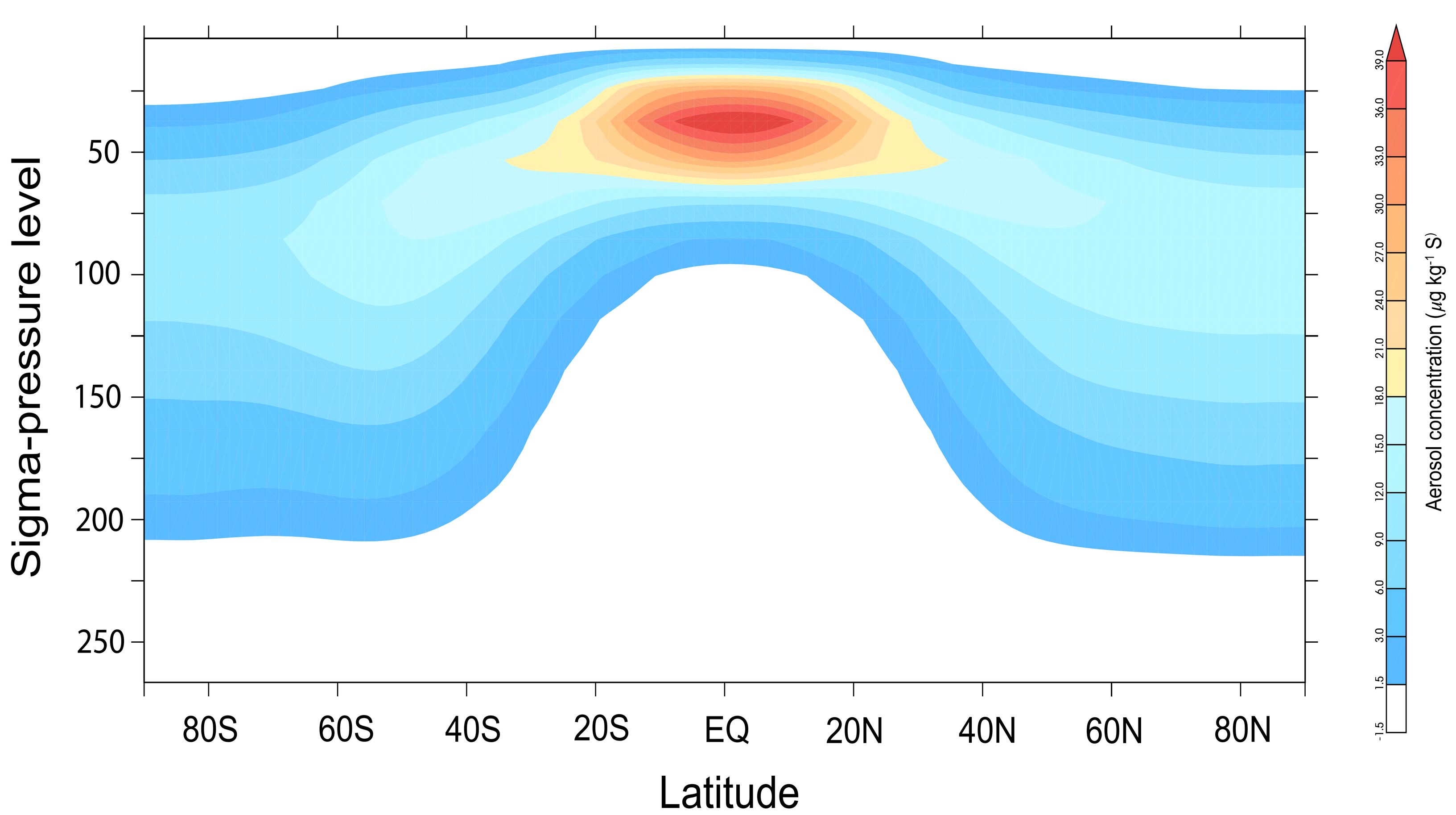
SCAN ME

Key Points

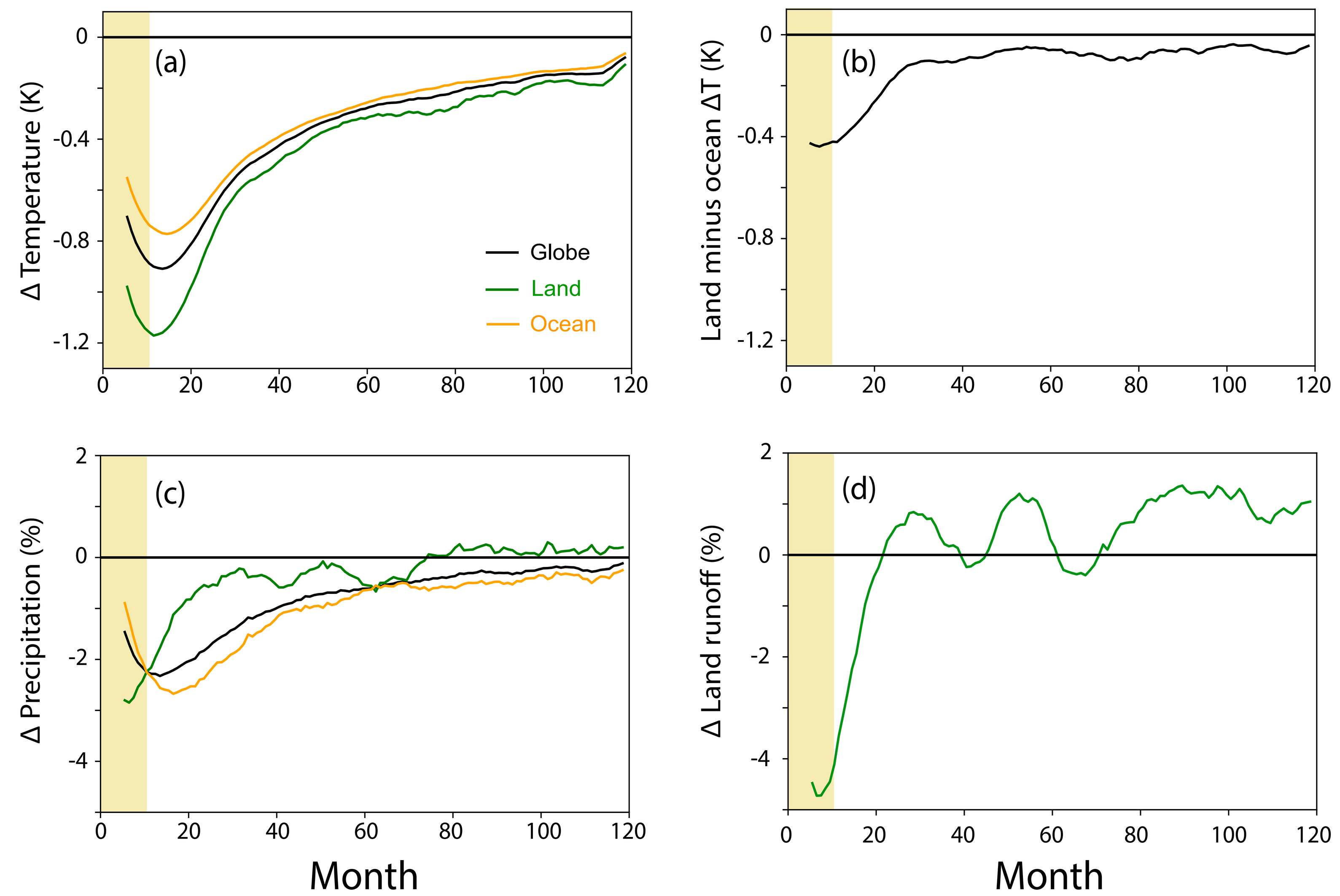
- We used NCAR CESM to simulate the climate impact of a volcanic-like pulse and a geoengineering-like sustained stratospheric sulfate aerosol forcing
- For the same global mean cooling, decrease in land temperature, precipitation, and runoff is much larger under the pulse forcing
- Different timescales of aerosol forcing related to volcanic eruptions and geoengineering would produce quite different climate outcomes

Stratospheric sulfate aerosol forcing



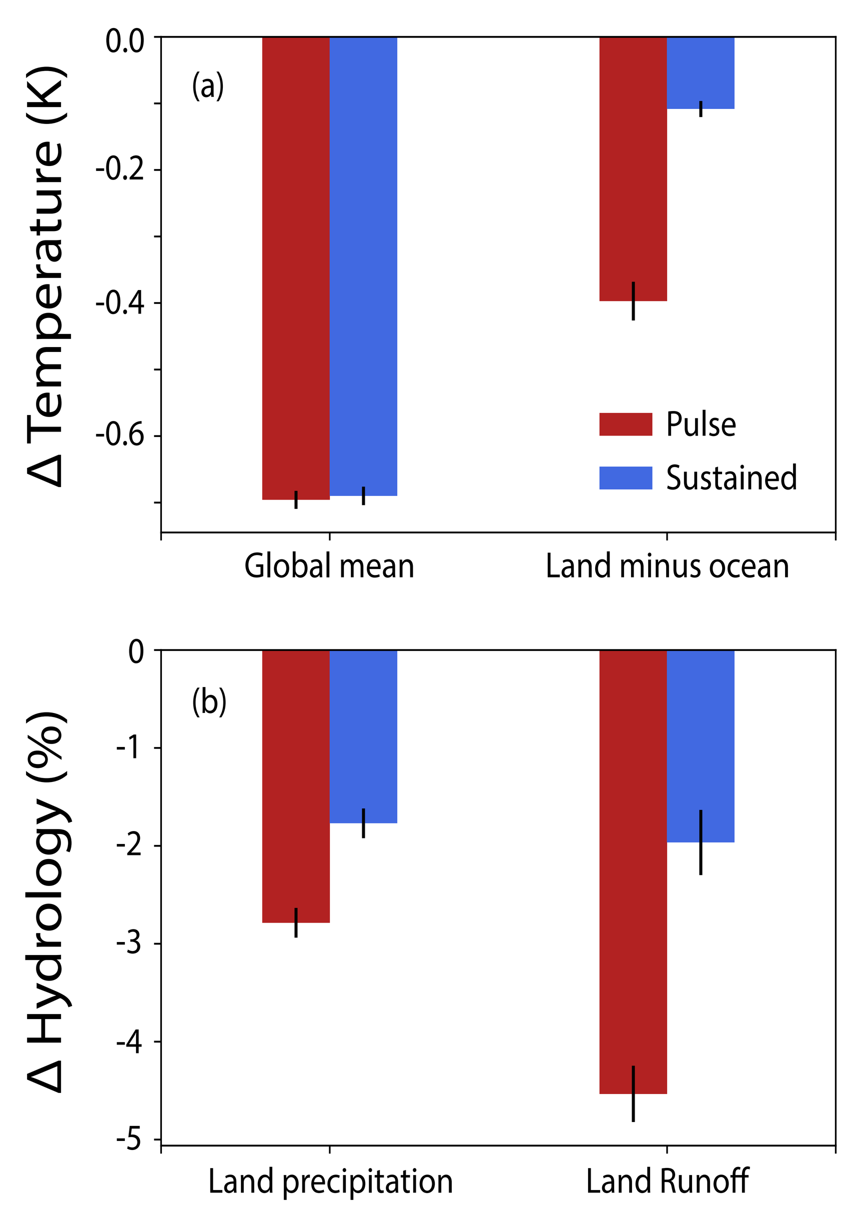


Time series responses



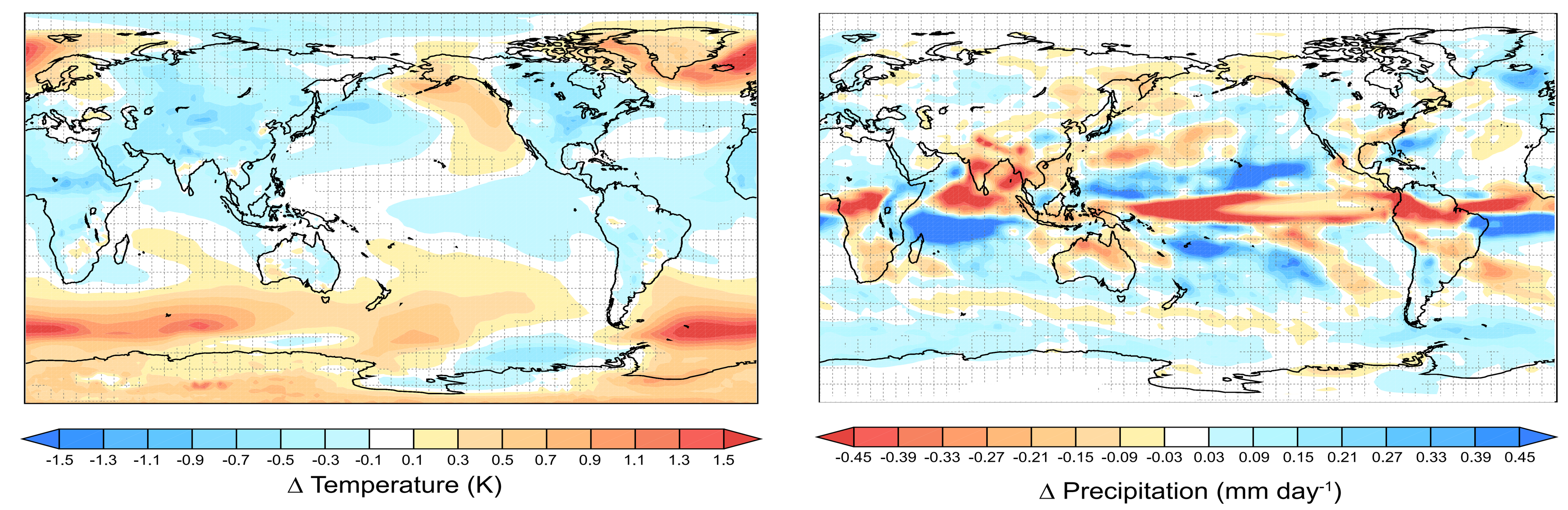
- For the *Pulse* case, the land cools much quicker than the ocean leading to a large land-sea temperature difference;
- Difference in surface cooling in these cases would lead to different hydrological cycle response and thus the land precipitation and runoff.

Global and land mean responses

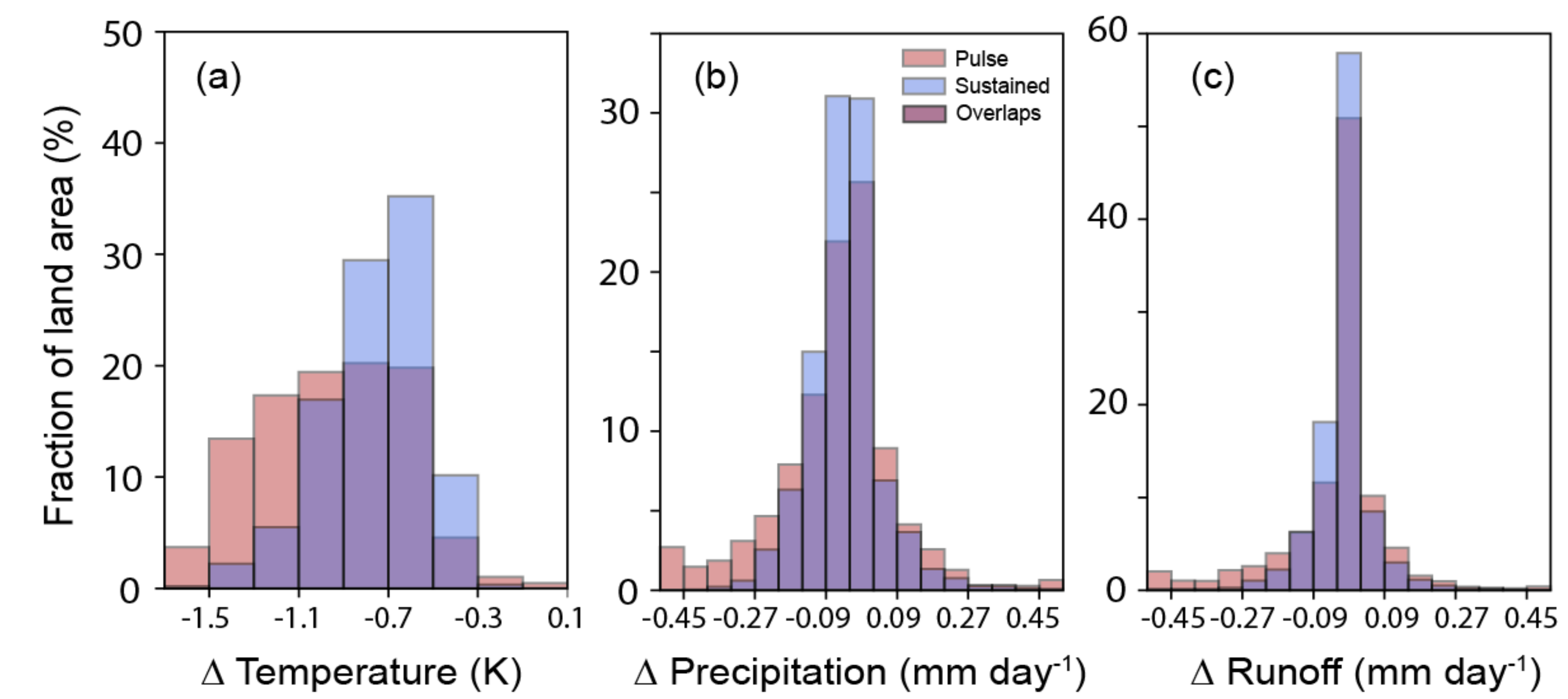


- When producing similar global mean surface temperature change, the land cools more in the *Pulse* case which leads to a larger land-sea surface temperature difference;
- Compared to *Pulse*, precipitation and surface runoff over land decreases less in the *Sustained* case. Decrease in runoff over land, which represents the water resource availability, is two times larger in the *Pulse* case than that in the *Sustained* case.

Spatial pattern of *Pulse* minus *Sustained*



- When producing the similar global mean temperature change, the *Pulse* case leads to more cooling over land and less cooling over the ocean compared to the *Sustained* case;
- The precipitation response is difference over both land and ocean for these cases, which is related to more cooling over land in the *Pulse* case and different land-sea temperature change contrast.



- For the similar global mean temperature change, more grid cells in the *Pulse* case have extreme temperature, precipitation, and runoff changes over the land;

Main conclusions

- Relative to the *Sustained* case, the *Pulse* case has much larger reductions in surface temperature over land, leading to a larger decrease in the upward motion of air over land in lower atmosphere, and reduces water vapor transport from the ocean to land.
- For similar amounts of cooling, the decrease in land runoff caused by a short-term pulse aerosol forcing is about twice as large as that caused by a sustained aerosol forcing.
- We demonstrate difference in the climate response to volcanic-like and geoengineering-like stratospheric aerosol forcings, and suggest that cares should be taken when extrapolating results from volcanic eruptions to the aerosol geoengineering deployments.

[1]Department of Global Ecology, Carnegie Institution for Science
[2]School of Earth Science, Zhejiang University
[3]Center for Atmospheric and Ocean Science, Indian Institute of Science