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Representing transient precipitation change of Solar Radiation Management and Carbon Dioxide Removal with fast and slow precipitation components

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Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR) have been proposed to mitigate global warming in the event of insufficient greenhouse gas emission reductions. We have studied temperature and precipitation responses to CDR and SRM with the RCP4.5 scenario using the MPI-ESM and CESM Earth System Models (ESMs). The two SRM scenarios were designed to meet different climate targets to keep either global mean 1) surface temperature or 2) precipitation at the 2010-2020 level via stratospheric sulfur injections. This was done in two-fold method, where global aerosol fields were first simulated with aerosol-climate model ECHAM-HAMMOZ, which were then used as prescribed fields in ESM simulations. In the CDR scenario the annual CO_2 increase based on RCP4.5 was counteracted by a 1% annual removal of the atmospheric CO_2 concentration which decreased the global mean temperature back to the 2010-2020 level at the end of this century.

Results showed that applying SRM to offset 21st century climate warming in the RCP4.5 scenario led to a 1.42% (MPI-ESM) or 0.73% (CESM) reduction in global mean precipitation, whereas CDR increased global precipitation by 0.5% in both ESMs for 2080-2100 relative to 2010-2020. To study this further we separated global precipitation responses to a temperature-dependent and a fast temperature-independent components. These were quantified by a regression method. In this method the climate variable (e.g. precipitation) is regressed against the temperature change due to the instantaneous forcing. Temperature-dependent slow response and temperature independent fast response are given by the fitted regression line. We showed that in all simulated geoengineering scenarios, the simulated global mean precipitation change can be represented as the sum of these response components. This component analysis shows that the fast temperature-independent component of atmospheric CO_2 concentration explains the global mean precipitation change in both SRM and CDR scenarios. Results showed relatively large differences in the individual precipitation components between two ESMs. This component analysis method can be generalized to evaluate and analyze precipitation, or other climate responses, basically in any emission scenario and in any ESM in a conceptually easy way.

Based on the SRM simulations, a total of or 292-318 Tg(S) (MPI-ESM) or 163-199 Tg(S) (CESM) of injected sulfur from 2020 to 2100 was required to offset global mean warming based on the RCP4.5 scenario. The distinct effects of SRM in the two ESM simulations mainly reflected differing shortwave absorption responses to water vapor. To prevent a global mean precipitation increase, only 95-114 Tg(S) was needed. Simultaneously this prevent the global mean climate warming from exceeding 2 degrees above preindustrial temperatures in both models.