Effects of geoengineering by stratospheric SO_2 injection on stratospheric sulfate aerosols and circulation

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Geoengineering is deliberate manipulation of climate system to counteract anthropogenic climate change due to greenhouse gases. In the geoengineering techniques, stratospheric SO_2 injection is analogically based on SO_2 injection by explosive volcanic eruption and subsequent surface cooling. However, climate models participating in the Geoengineering Model Intercomparison Project (GeoMIP) demonstrate diverse results. Some of uncertainties of the results are aerosol microphysical properties and stratospheric circulation. This study introduces an aerosol microphysics module of stratospheric sulfate aerosols into the MIROC-ESM-CHEM earth system model (hereinafter, MIROC-ESM-CHEM-AMP). The model can represent aerosol microphysical properties and aerosol transport explicitly. We conducted the geoengineering simulation using MIROC-ESM-CHEM-AMP in the same manner as the GeoMIP's G4 experiment. G4 experiment assumes stratospheric SO_2 injection of 5 Tg/year into the lower stratosphere at the equator during 2020–2070 under RCP4.5 scenario. We also compare the results of MIROC-ESM-CHEM-AMP with the results of MIROC-ESM-CHEM. G4 experiment with MIROC-ESM-CHEM prescribes stratospheric aerosol optical depth (SAOD) based on the observed SAOD after the 1991 eruption of Mt. Pinatubo. The results show that SAOD in MIROC-ESM-CHEM-AMP is twice as large as SAOD in MIROC-ESM-CHEM. In MIROC-ESM-CHEM-AMP, the effective radius of stratospheric sulfate aerosols grew by 0.51 μm in the tropical lower stratosphere because of the stratospheric SO_2 injection. Mean residence time of stratospheric sulfate aerosols is 1.13 year. The stratospheric burden is 2.85 TgS that is larger than the yearly injected SO_2 amount (2.5 TgS).
This study also investigates effects of the stratospheric SO_2 injection on mean age of stratospheric air. In the both models, the stratospheric SO_2 injection increases the mean age by 0.15 year at maximum and decreases the mean age by 0.25 year at maximum. The changes in the mean age in MIROC-ESM-CHEM-AMP are more than three times as large as the changes in MIROC-ESM-CHEM. We furthermore assess the effects of the stratospheric SO_2 injection on the mean age of stratospheric air using the G4 experiment with sea surface temperature (SST) of the RCP4.5 experiment (without geoengineering). The results suggest that the increase in the mean age is caused by slow response (e.g., SST changes) and that the decrease is caused by fast response (e.g., longwave radiation absorption of sulfate aerosols). The model results also demonstrate that the slow response leads to weakened circulation in the lower stratosphere, resulting in a slight increase in SAOD (about 5%).

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