Modulation of the Southern Hemisphere climate by solar radiation management

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1. Introduction

- Geoengineering is increasingly being discussed as a means to lessen the climatic impacts of greenhouse gas emissions.
- Solar radiation management (SRM) has, in particular, been proposed as a fast-acting and cost-effective solution.
- However, geoengineering is not without significant risks of its own, including a potential weakening of the hydrological cycle.
- We therefore explore how the Southern Hemisphere atmospheric circulation and hydrological cycle may be modulated by SRM.

2. Data and methods

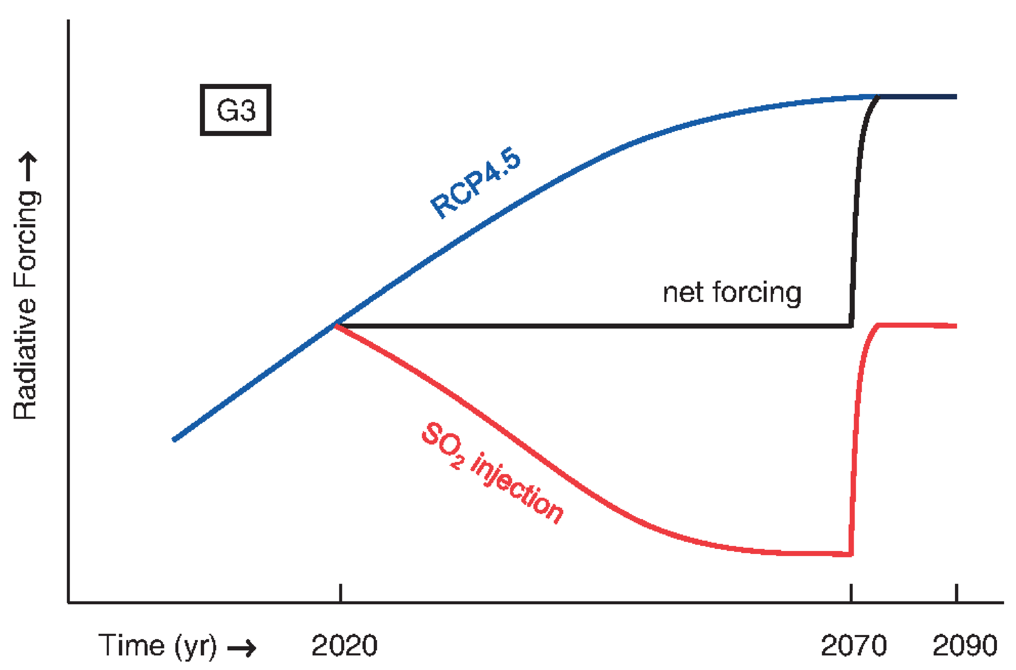

Figure 1. GeoMIP experiment G3 (from Kravitz et al., 2011).

- We analyse two Geoengineering Model Intercomparison Project (GeoMIP) experiments:
  - G3 simulates the introduction of stratospheric sulphate aerosols during the period 2020 to 2069, with the aim of keeping the net radiative forcing constant at the 2020 level.
  - Geoengineering ceases abruptly in 2070, such that the radiative forcing returns to what it would have been under RCP4.5.
  - G3solar resembles G3, but uses a reduction in the solar constant to balance the radiative forcing due to increasing greenhouse gases.

3. Global response and Southern Annular Mode

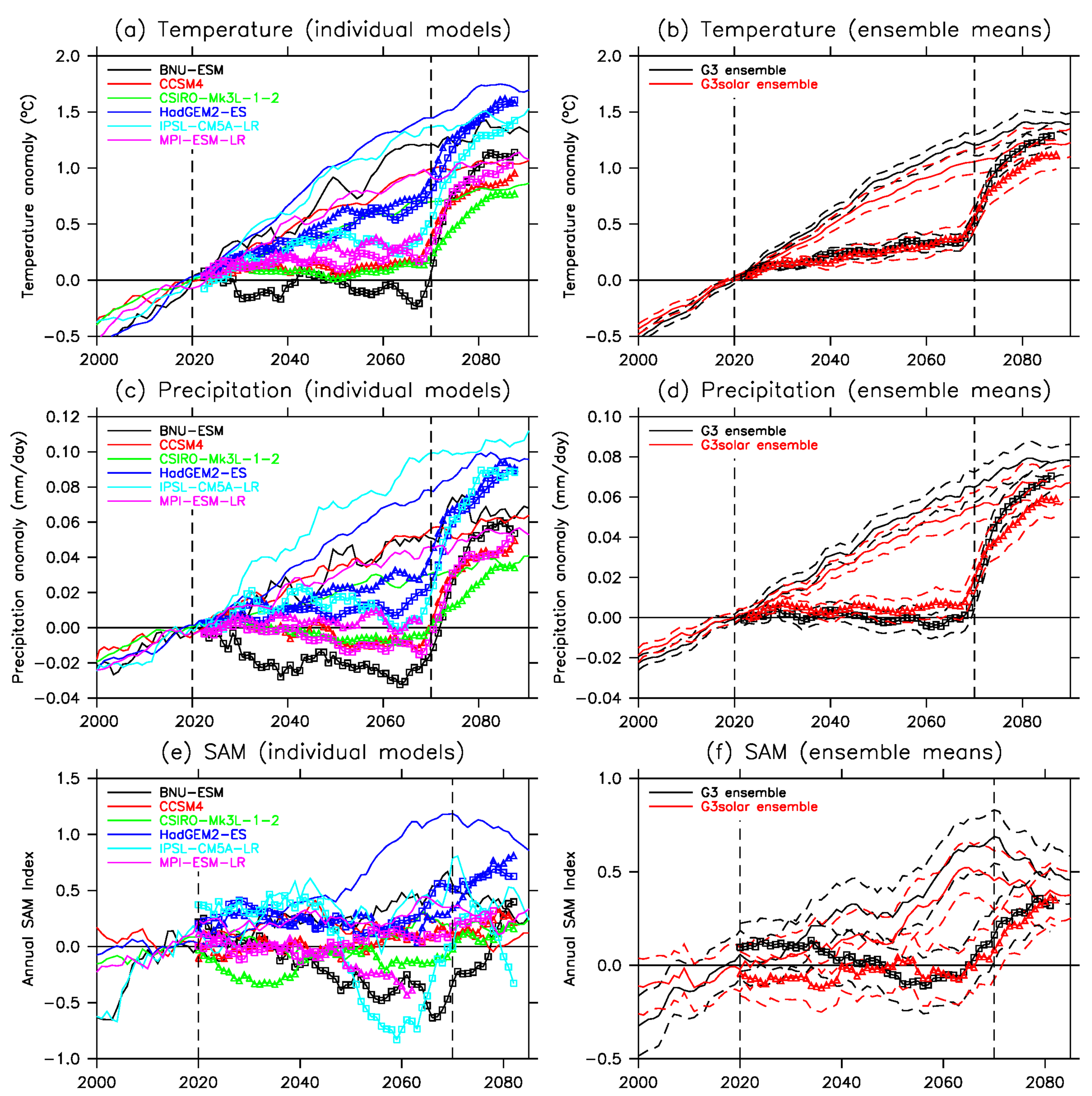

Figure 2. Changes in the global climate within RCP4.5 (no symbols), G3 (squares) and G3solar (triangles): (a)–(b) global-mean surface air temperature (5-year mean), (c)–(d) global-mean precipitation (5-year mean), and (e)–(f) the SAM Index (15-year mean). In panels (b), (d) and (f), dashed lines indicate the 95% confidence interval.

- During the geoengineering phase, SRM reduces the simulated warming. In contrast to a mean increase in global temperature of more than 1°C between 2020 and 2070 under RCP4.5, there is an increase of only ∼0.3°C in G3 and G3solar.
- Despite the ongoing warming, global precipitation remains close to 2020 levels in the G3 and G3solar ensembles. This occurs because the hydrological cycle is more sensitive to SRM than to GHG changes (Bala et al., 2008; Tilmes et al., 2013).
- SRM counteracts the ongoing shift towards a more positive phase of the Southern Annular Mode (SAM) under RCP4.5. The SAM Index is stabilised at around 2020 levels throughout the geoengineering phase.
- An abrupt termination effect is apparent after 2070. As soon as geoengineering ceases, global temperature, global precipitation and the SAM Index all rapidly converge towards the levels simulated under RCP4.5.

4. Atmospheric circulation

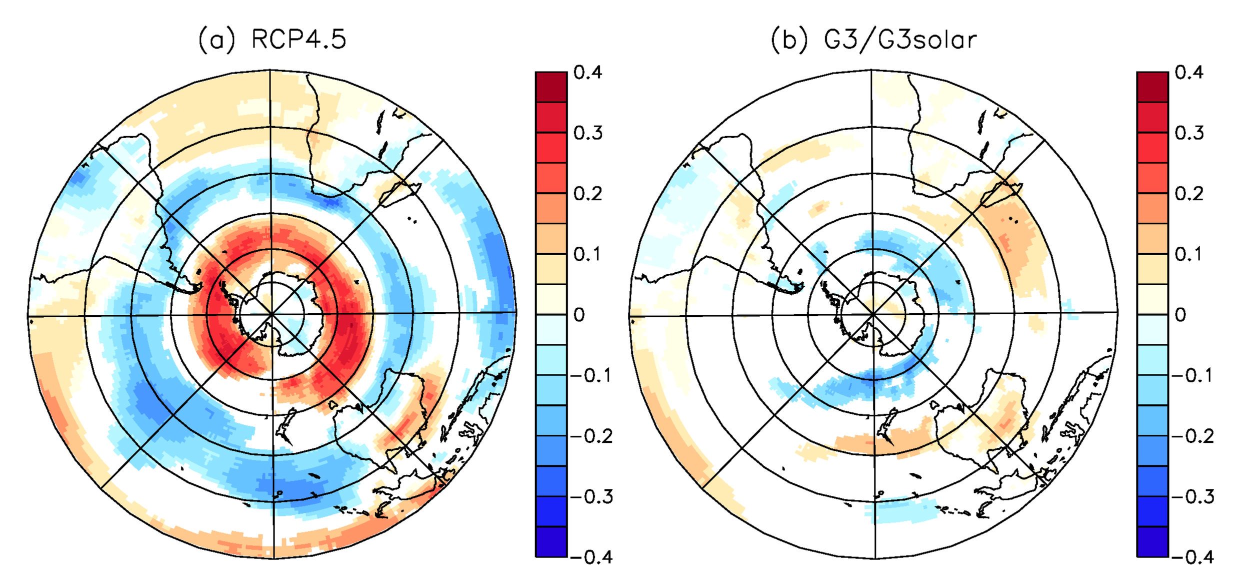

Figure 3. The mean changes in the zonal surface wind speed (2050–2069 minus 2010–2029, $m\,s^{-1}$) within the RCP4.5 and G3/G3solar multi-model ensembles. Only anomalies that are significant at the 5% probability level are shown.

- The response to anthropogenic forcing is dominated by two features: a strengthening and a poleward shift of the mid-latitude westerlies, which is consistent with the shift towards a more positive phase of the SAM; and a decrease in zonal wind speed in the subtropics, which is consistent with a strengthening and expansion of the Hadley Cell (Ma and Xie, 2013).
- Overall, SRM is effective at mitigating the circulation changes under RCP4.5. Within the G3/G3solar ensemble, changes in the atmospheric circulation are weak and are generally not statistically significant.

5. Hydrological cycle

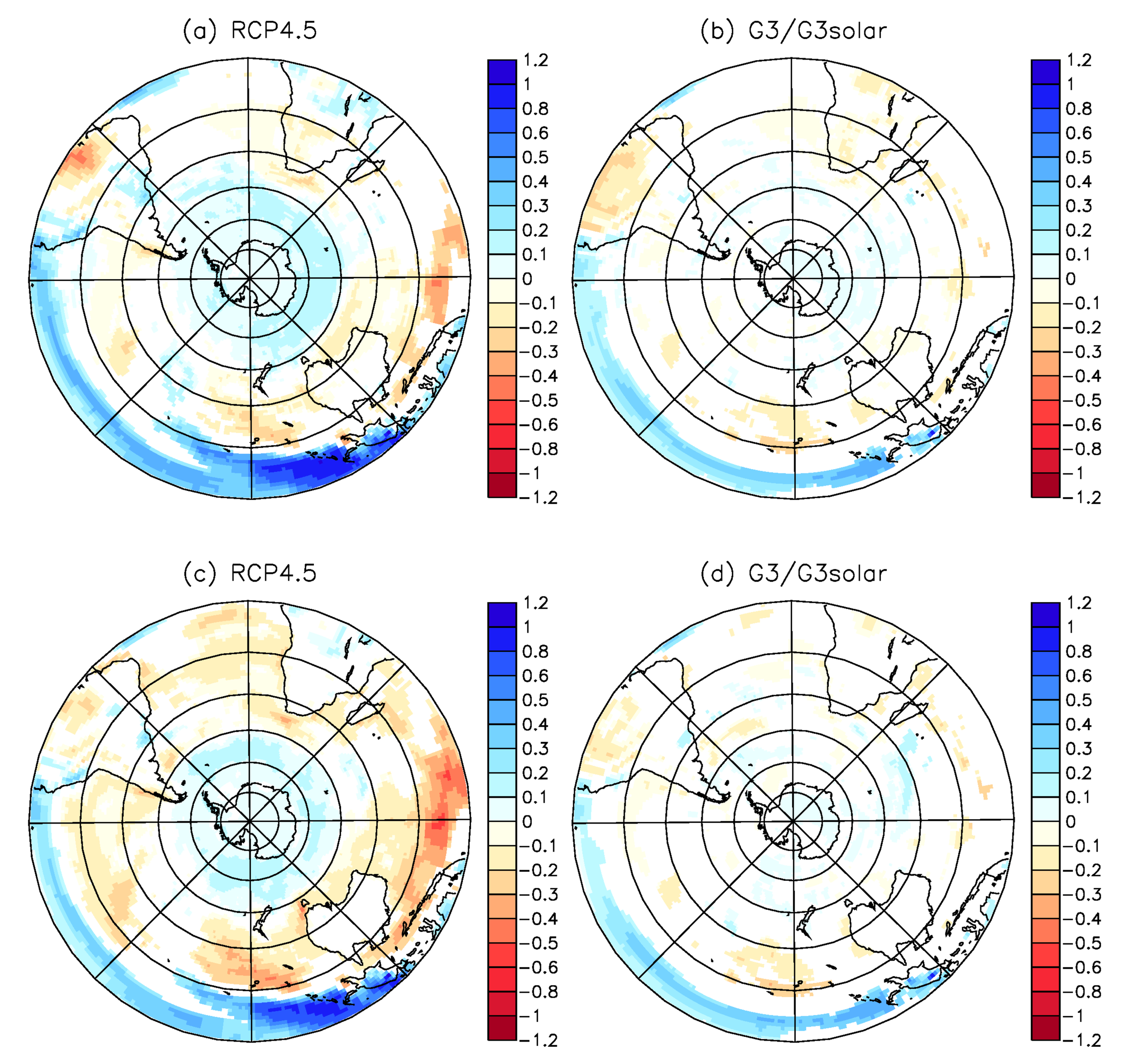

Figure 4. As Figure 3, but for precipitation (mm/day; top row) and P-E (mm/day; bottom row).

- Under RCP4.5, there are increases in precipitation and P-E throughout the tropics and at high latitudes. These are accompanied by decreases over large parts of the subtropics.
- Reduced subtropical precipitation is partially thermodynamic in origin, due to the "wet gets wetter"/"dry gets drier" mechanism (Held and Soden, 2006). However, there is also a dynamical contribution due to the expansion of the Hadley Cell (Seager et al., 2010).
- Overall, SRM is effective at mitigating the hydrological changes under RCP4.5. However, there are some residual decreases in precipitation and P-E throughout the subtropics.

References

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