Modulation of Southern Hemisphere climate drivers by large-scale geoengineering

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1. Introduction

The Southern Annular Mode (SAM) is the dominant mode of Southern Hemisphere (SH) extratropical variability, influencing the climate of the entire hemisphere (Gillett et al., 2006). Stratospheric ozone depletion and increasing greenhouse gases (GHGs) have caused a shift towards the positive phase of the SAM over recent decades, associated with a southward shift and intensification of winds over the Southern Ocean (Arblaster and Meehl, 2006). These trends are projected to continue in future (Zheng et al., 2013), playing an important role in driving future changes in SH temperature and precipitation.

Geoengineering is increasingly being discussed as a tool to lessen the impacts of anthropogenic climate change through deliberate modification of the climate system. For example, solar radiation management via stratospheric injection of sulphate aerosols has been proposed as a fast-acting and cost-effective solution (Robock et al., 2009). While geoengineering could play a key role in reducing the risk of dangerous climate change, it is not without significant regional risks of its own. To date, the effects on the SH climate have not been well studied, nor have the impacts on SH climate drivers been considered. The aim of this study is therefore to examine how the SAM is modulated by large-scale geoengineering.

2. Methods

We analyse three experiments conducted as part of the Geoengineering Model Intercomparison Project (GeoMIP; Kravitz et al., 2011). Each of these experiments explores the application of solar radiation management to counteract rising GHG concentrations within the CMIP5 RCP4.5 emissions scenario (Figure 1):

- G3 simulates the gradual introduction of stratospheric sulphate aerosols during the period 2020 to 2069, with the aim of keeping the net radiative forcing constant.
- G3solar is conducted in the same manner as G3, but uses a reduction in the solar constant to balance the radiative forcing due to increasing GHGs.
- G4 simulates the sudden onset of geoengineering in the year 2020, with aerosols being injected into the stratosphere at a constant rate of 5 Tg per year.

In each experiment, geoengineering ceases abruptly in 2070.

We examine the output of four climate models: BNU-ESM, CSIRO-Mk3L-1-2, HadGEM2-ES and IPSL-CM5A-LR. These models differ in their treatment of stratospheric ozone, employing three distinct approaches (Eyring et al., 2013): semi-offline chemistry (BNU-ESM, IPSL-CM5A-LR); prescribed changes (HadGEM2-ES); and fixed ozone (CSIRO-Mk3L-1-2).

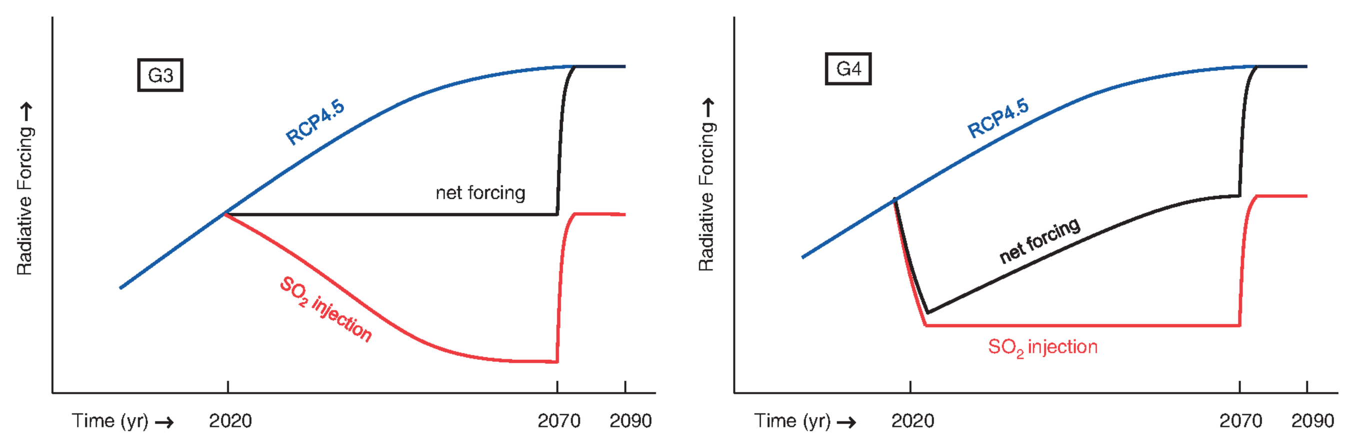


Figure 1. Schematics of GeoMIP experiments G3 and G4 (from Kravitz et al., 2011).

3. Global changes

In G3 and G3solar, geoengineering is broadly successful at stabilising global-mean surface air temperature within each model simulation (Figure 2). Geoengineering is also successful at reducing global-mean temperature in G4. However, within all three experiments, the temperature increases abruptly as soon as geoengineering ceases. Within 10 years, temperatures have reached levels similar to those simulated under the RCP4.5 scenario.

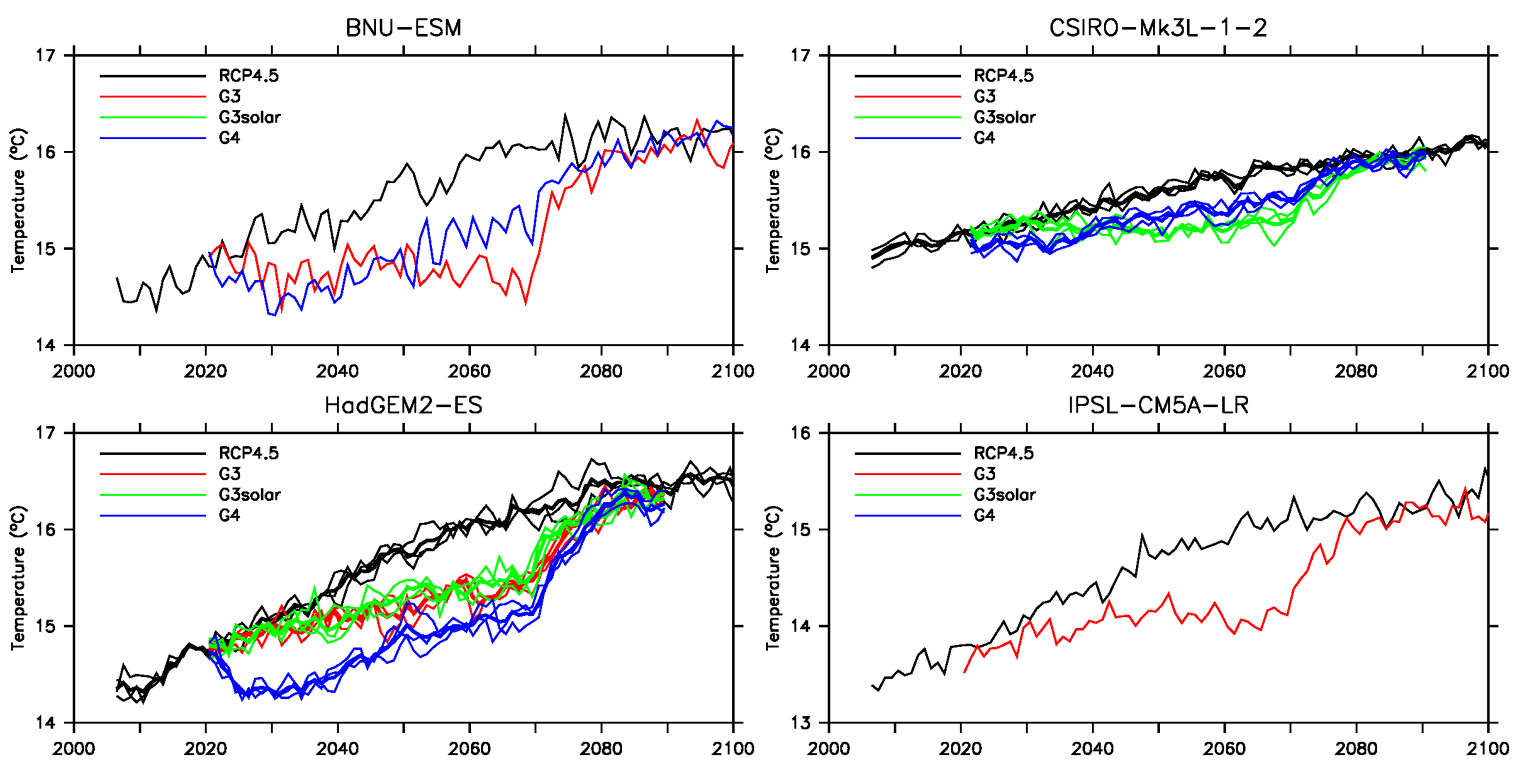


Figure 2. The evolution of global-mean surface air temperature within each experiment.

Similar changes are also seen in global-mean precipitation (Figure 3). Geoengineering causes a reduction in precipitation in all three experiments, with global-mean precipitation remaining roughly constant in G3 and G3solar during the geoengineering phase. However, an abrupt cessation effect is again apparent, with the effects of geoengineering dissipating within around 10 years.

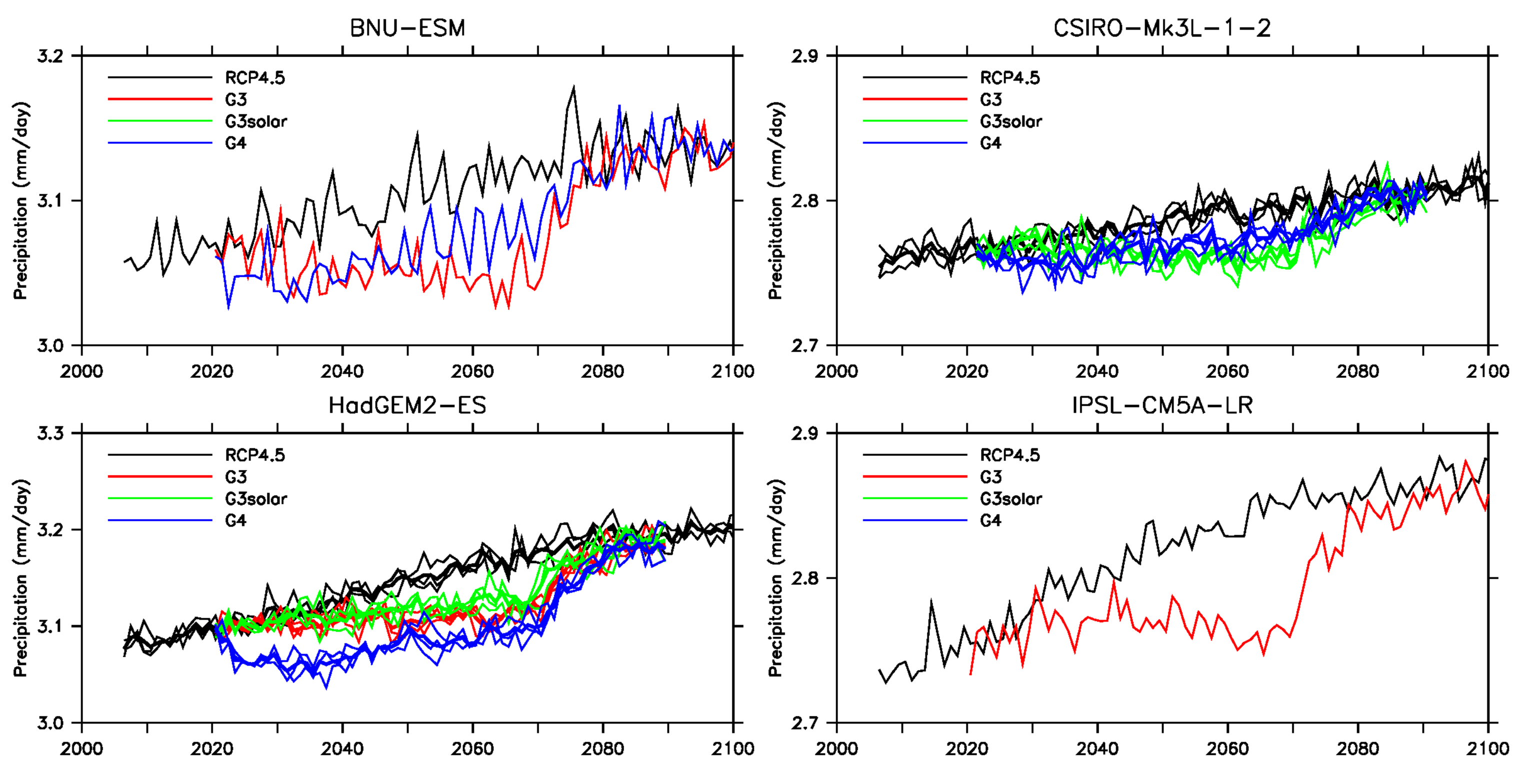


Figure 3. The evolution of global-mean precipitation within each experiment.

4. Southern Hemisphere

The evolution of the SAM within each experiment is shown in Figure 4. Under the RCP4.5 scenario, the historical shift towards a more positive phase becomes increasingly pronounced during the 21st century. This shift is weaker in CSIRO-Mk3L-1-2, which has fixed stratospheric ozone, than in the other models.

In all experiments, the application of geoengineering succeeds in shifting the SAM back towards a more neutral state.

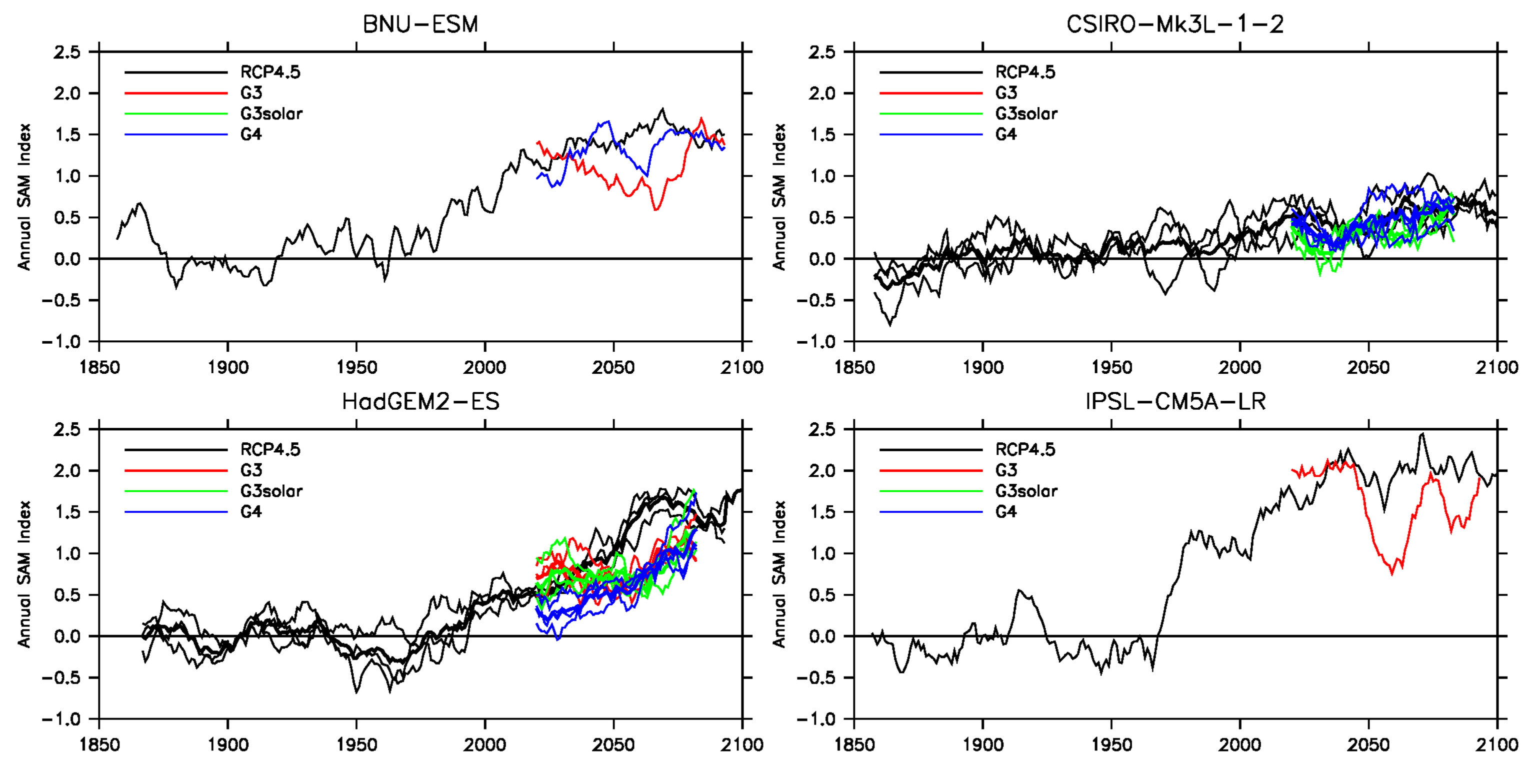


Figure 4. The evolution of the annual SAM Index within each experiment. The values shown are 15-year running means.

The effects of this shift towards a more neutral SAM are apparent in Figure 5, which indicates a northward shift and weakening of the SH westerly winds in G3.

However, the magnitude of these changes is model-dependent. IPSL-CM5A-LR exhibits the strongest response, while CSIRO-Mk3L-1-2 and HadGEM2-ES exhibit the weakest.

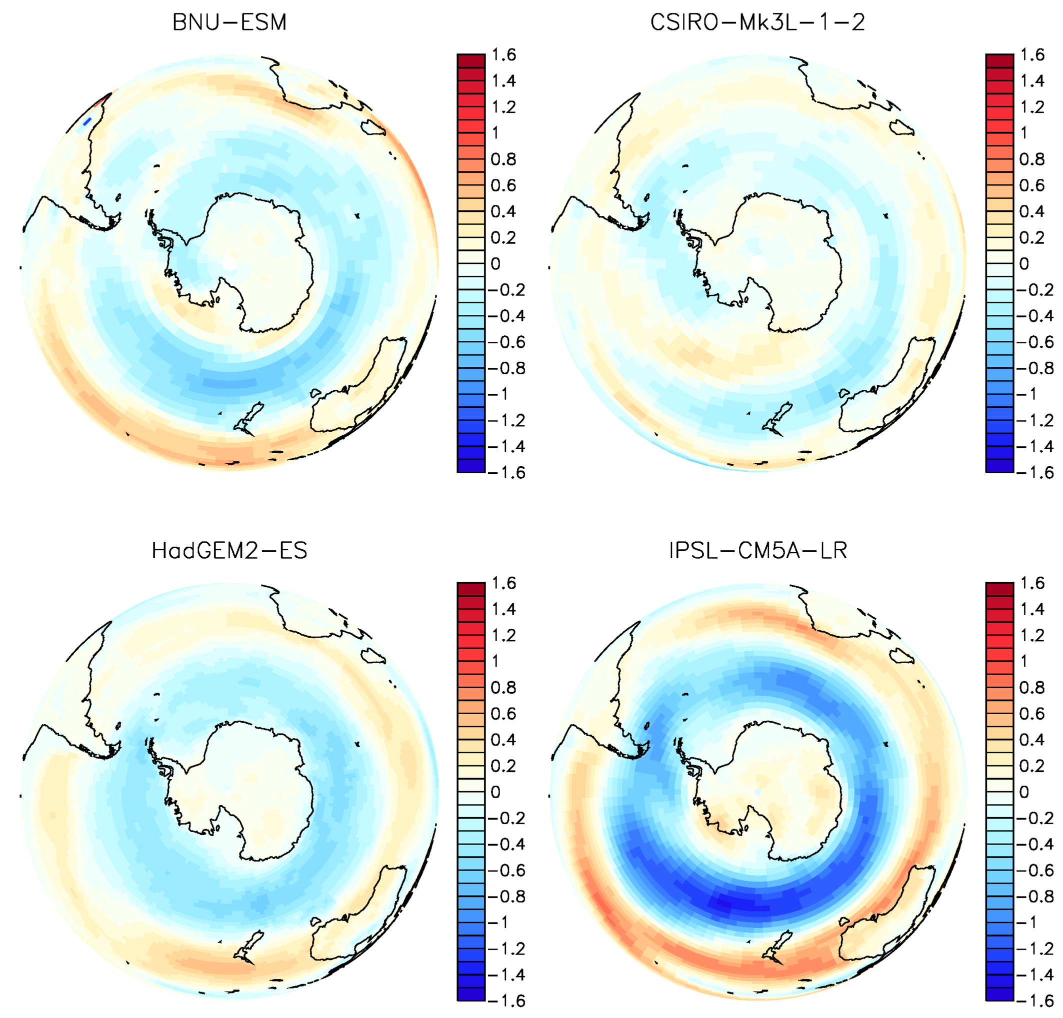
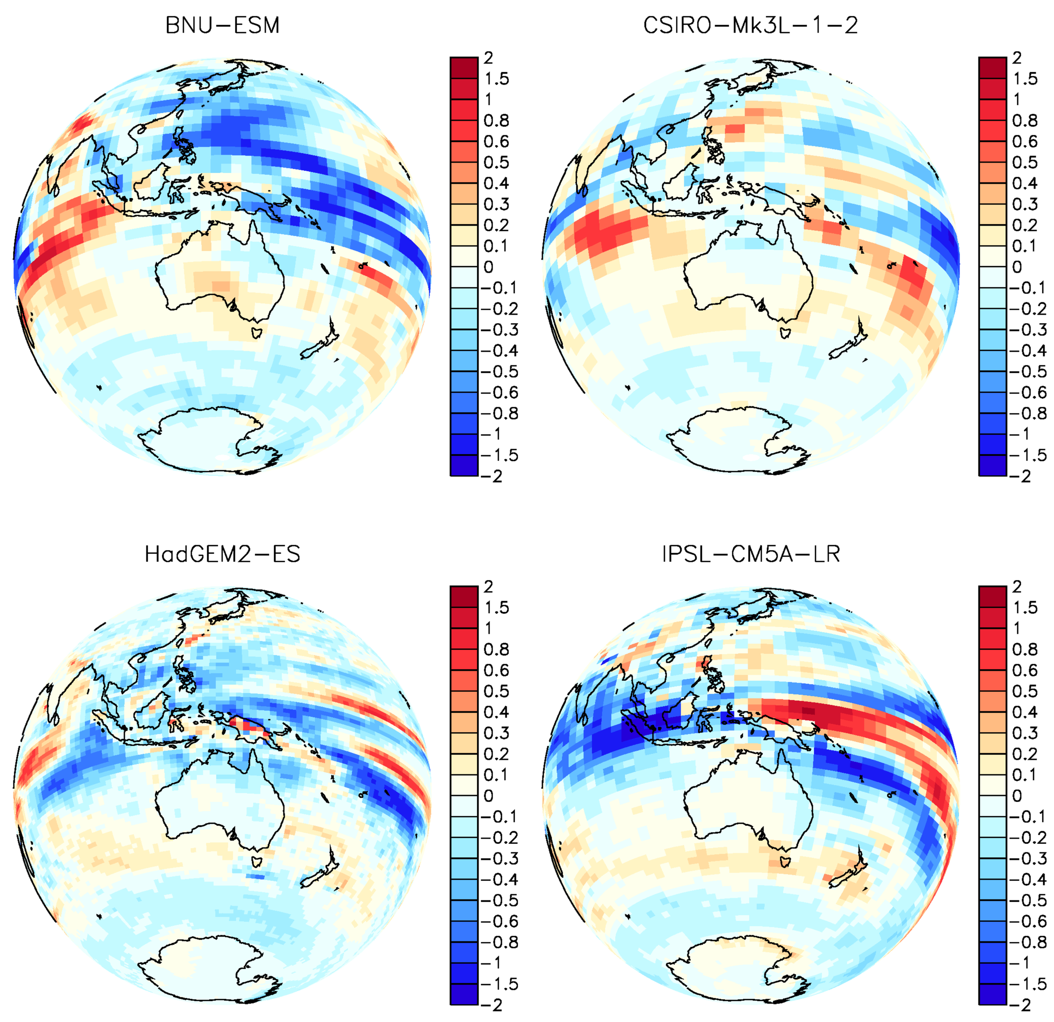


Figure 5. The impact of geoengineering on zonal surface wind speed during the period 2050-2069 (G3 minus RCP4.5, m s^{-1}).



Precipitation follows the changes in the westerly winds (Figure 6). All models simulate an increase in precipitation over southern Australia in response to geoengineering, accompanied by a reduction over the Southern Ocean.

Figure 6. The impact of geoengineering on precipitation during the period 2050-2069 (G3 minus RCP4.5, mm/day).

5. Conclusions

In the Southern Hemisphere, we show that the climatic response to large-scale geoengineering is characterised by a shift towards a more neutral state of the SAM. This counteracts the ongoing trend towards a more positive phase under the RCP4.5 scenario. As a result, there is a northward shift and weakening of the SH westerly winds. Precipitation increases over southern Australia, but decreases over the Southern Ocean.

However, the climatic impacts cease abruptly as soon as geoengineering ends. Any cessation of geoengineering would therefore lead to rapid changes in the Southern Hemisphere climate.

References

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