

Stratospheric Aerosol Injection Effects on Global Climate Distribution

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Introduction

As the world struggles to limit global warming, interest in **stratospheric aerosol injection (SAI)** has increased in recent years. SAI would aim to cool the Earth by injecting sulfate particles into the upper atmosphere, which would reflect incoming sunlight back to space¹. Previous studies have shown that SAI could produce regionally varying temperature and precipitation impacts^{2,3,4}. The aim of this research is to evaluate the effectiveness of SAI by quantifying climate zone changes over time, ultimately identifying these regional fluctuations.

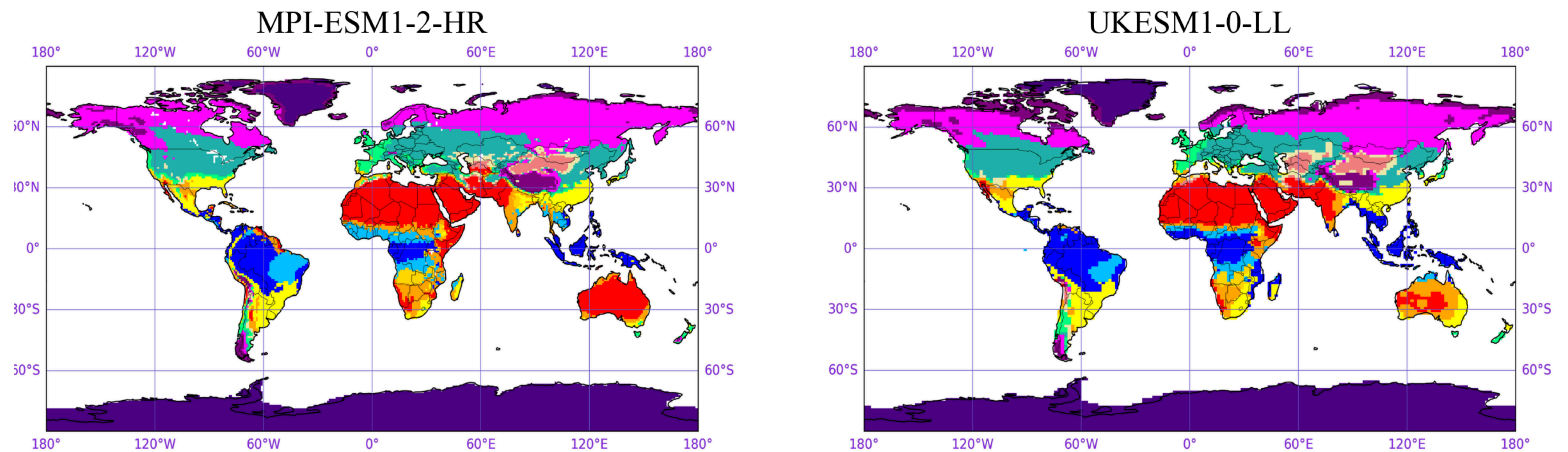
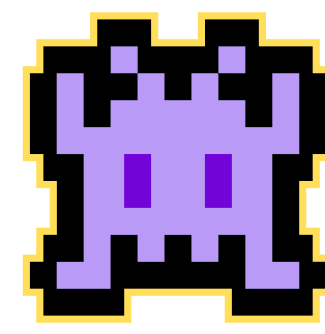
Methods

- A modified version of the Köppen-Trewartha climate classification system is used to illustrate global climate distribution.
- The classification system was modified to condense it, and the major climate zone xA was added to represent predicted extreme heat over the tropics.
- We identify climatic changes by comparing the projected distribution of climate under future scenarios (2085-2099), such as a high emission scenario (SSP5-8.5), a medium-tier emission scenario (SSP2-4.5) and an SAI scenario (G6sulfur), to that of historical emissions (1985-2014) in six different CMIP6 climate models (2 are used as examples).
- G6sulfur: Experiment where global emissions are set at the level of SSP5-8.5, but due to SAI implementation, global temperatures have been reduced to what they would amount to under mitigation (SSP2-4.5) instead.
- Hypothesis 1 (H1): SAI is not effective and would not necessarily prevent shifts in climate zones. This could be for a number of reasons (global reductions in precipitation⁵, unsettling of global circulation⁶, etc.).
- Hypothesis 2 (H2): SAI is effective and would produce changes similar in magnitude and type to the mitigation (SSP2-4.5) scenario, therefore preventing climate shifts.

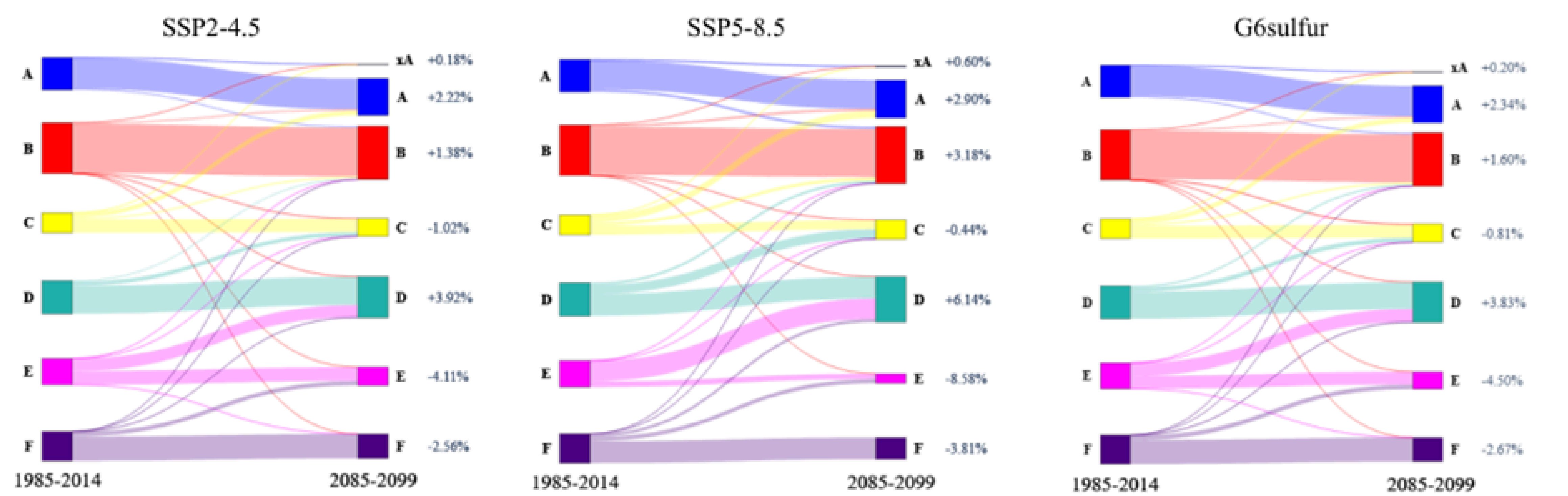
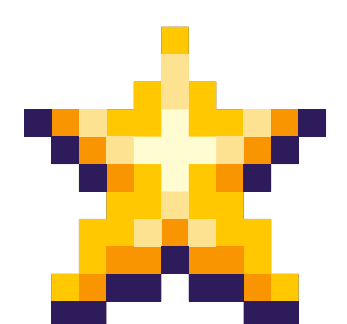
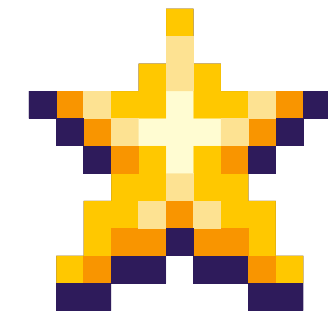
Köppen-Trewartha Climate Zones

xAr: novel tropical; rainforest	xAw: novel tropical; savanna
BWh: arid; hot desert	BWk: arid; cold desert
BSh: semi-arid; hot steppe	BSk: semi-arid; cold steppe
Ar: tropical; rainforest	Aw: tropical; savanna
Cf: subtropical; humid	Cm: subtropical; mediterranean
DC: temperate; continental	DO: temperate; oceanic
E: subpolar	Ft: polar; tundra
	Fi: polar; icecap

Historical Global Climate Distribution (1985-2014)



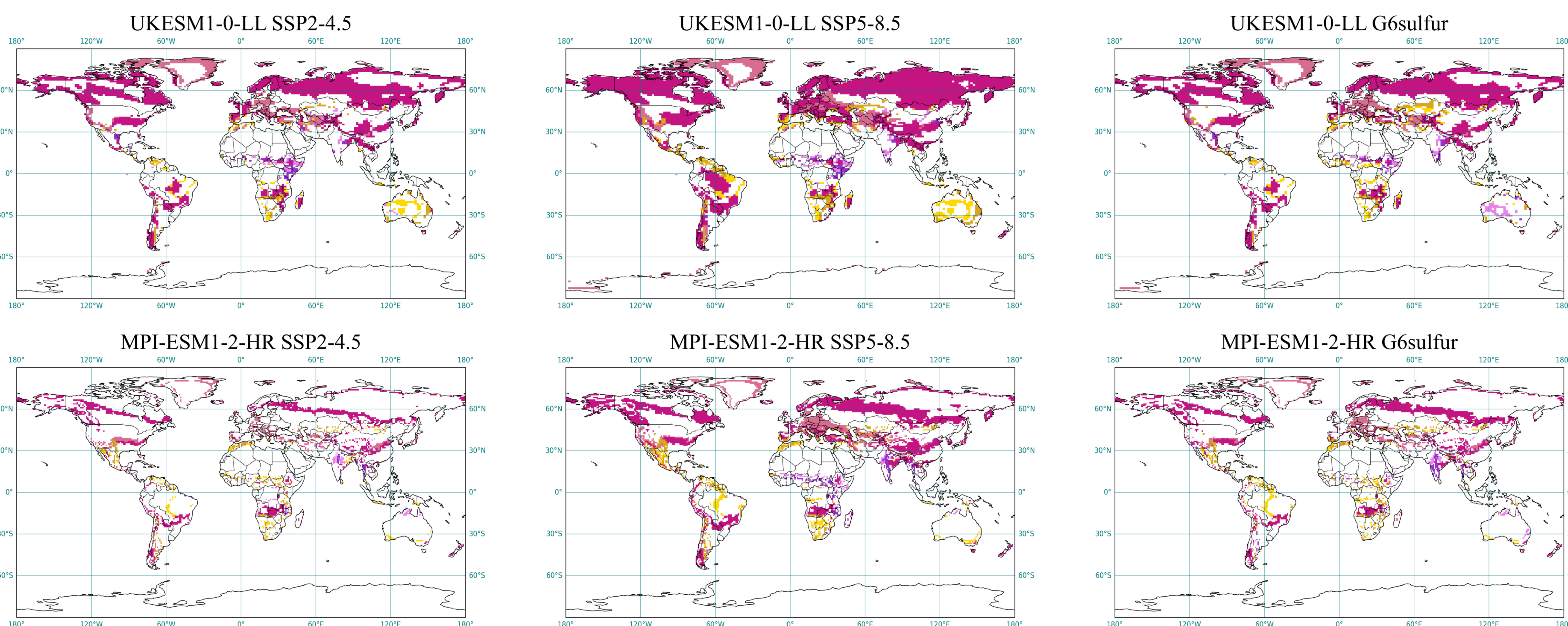
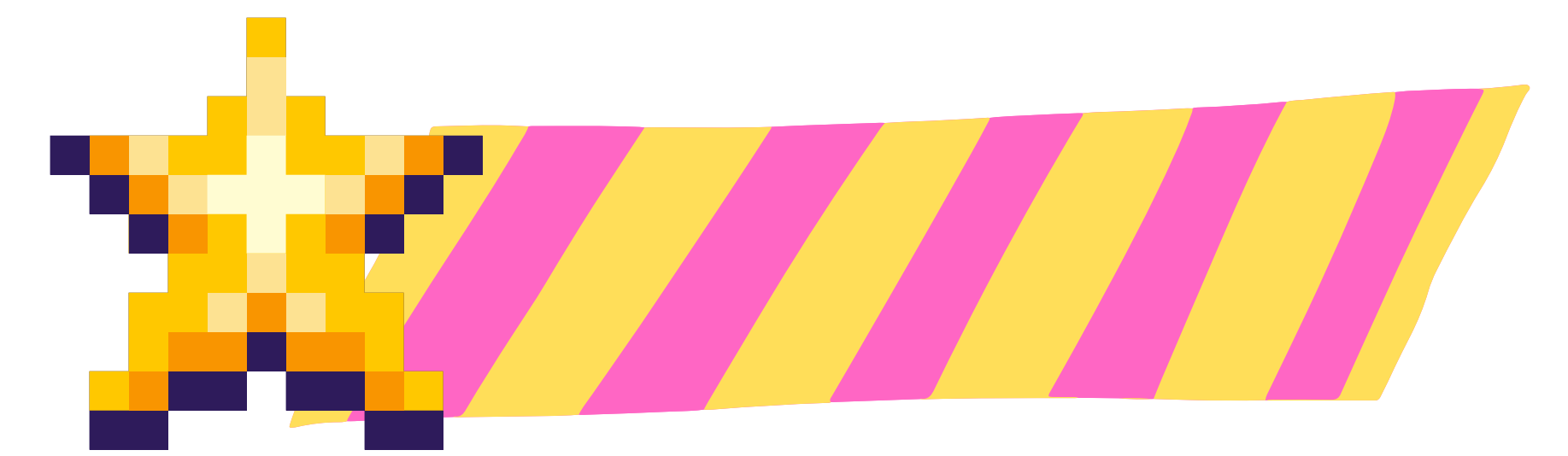
Major Climate Transitions



Sankey diagrams illustrating all major climate zone transitions averaged across all models between the historical and future periods, categorized by future scenario. Percentages on the left of each diagram represent the net change in land area of a climate zone relative to global land area. The thickness of the links is proportional to the share of global land area a zone occupies in the future as well as the amount of land that is transitioning to a different climate zone.

Key Messages: SSP2-4.5 and G6sulfur share very similar results, both in type and magnitude of transition. SSP5-8.5 has similar transitions, but their magnitudes are significantly larger, especially for temperate (D) and subpolar (E) zones.

Temperature and Precipitation Based Climate Transitions (2085-2099)



Major and minor climate zone shifts for all future scenarios quantified by their relation to average temperature and precipitation. Data is from models UKESM1-0-LL and MPI-ESM1-2-HR, as they are relatively "hot" and "cold" models, respectively (UKESM1-0-LL has the highest transient climate response (TCR), while MPI-ESM1-2-HR has the lowest TCR value out of the model spread⁷). Pie chart data is the average percent breakdown of transitioning land area in all models quantified by this same relation.

Key Messages: Although UKESM1-0-LL and MPI-ESM1-2-HR are on opposite ends of the TCR spectrum, the trend towards warmer and drier transitions is observed in both models. Additionally, G6sulfur significantly reduces transitions between climate zones in comparison to SSP5-8.5 in both models. These trends are also observed in average of the full model spread, as seen in the pie charts.

Conclusions

- All models agree with H2, showing that climatic changes produced under SAI are very similar to those produced under mitigation (SSP2-4.5), much more so than those in a high emissions world without SAI (SSP5-8.5).
- The climate transitions under G6sulfur observed in all models are systematic, usually going from colder to warmer and drier climate types.
- Even between models on opposite ends of the warming spectrum, this trend remains constant, reducing uncertainty.
- While SAI is effective, it is not as effective as reducing carbon emissions.
- Despite general agreements on the effectiveness of SAI across models, there is not a model consensus on the exact magnitude in which SAI is effective based upon the individual percentages of shifts in land area between different major climate types and subtypes.
- Differences in model response may be a result of internal variability, TCR value, inclusion of interactive aerosol microphysics, SAI algorithm, resolution, or the injection scenario used in G6sulfur.
- These factors are important, and further analysis is needed in the future to truly understand individual model response to SAI.

Supporting Information

