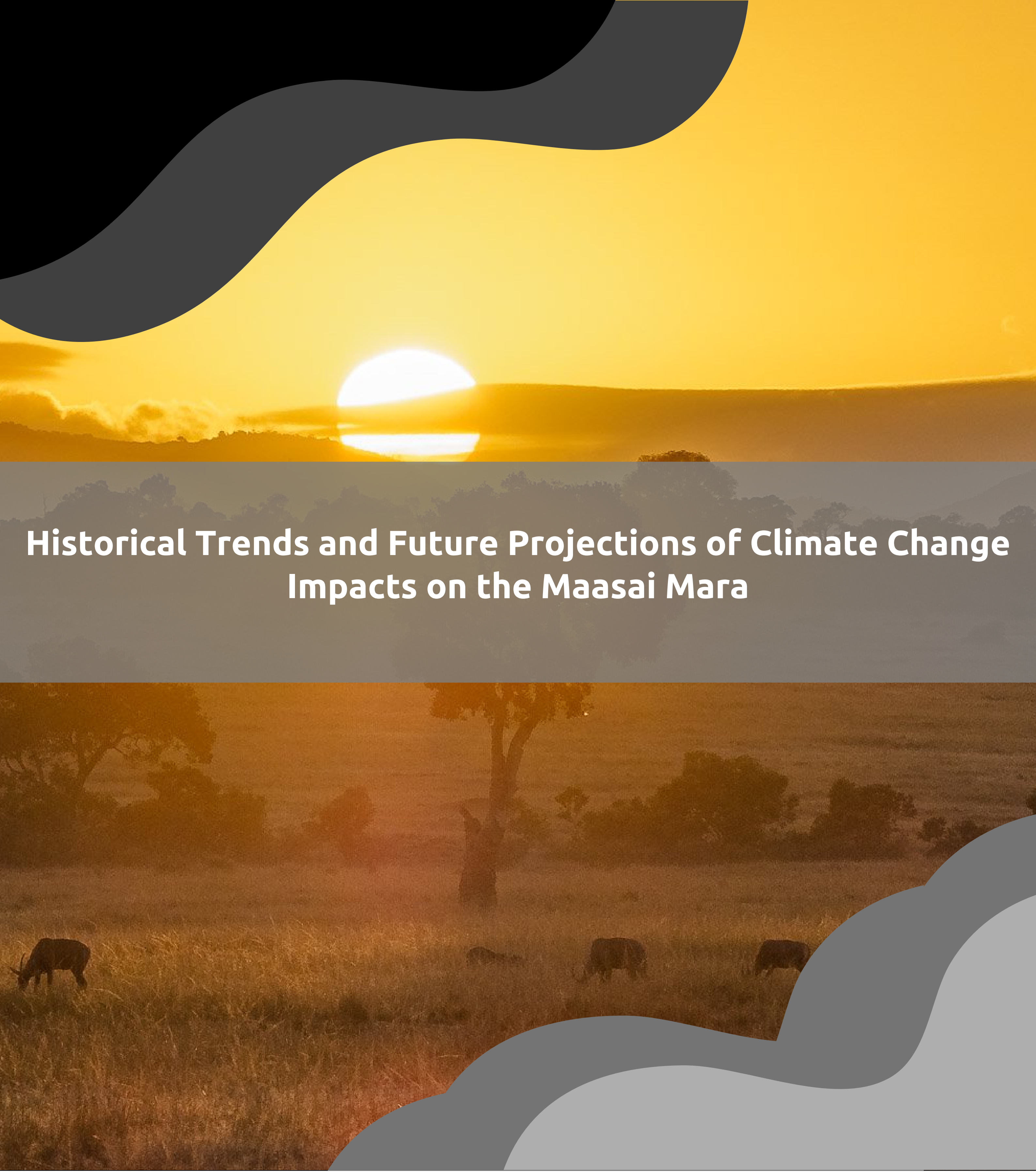

Historical Trends and Future Projections of Climate Change Impacts on the Maasai Mara

the climate centre

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Introduction

- The Maasai Mara National Park covers approximately 1,510 km² in southwestern Kenya and forms the northern extension of the greater Mara-Serengeti ecosystem, one of the most ecologically significant savanna systems on Earth (Sinclair & Norton-Griffiths, 1979). The park is divided into two main areas the inner portion which features pristine wilderness and the outer portion which allows for cattle of the Masai people to graze. The Maasai people have inhabited the surrounding landscape for several centuries, with traditional pastoral practices historically integral to the ecology of the region. The reserve is internationally recognised for its biodiversity and abundance of wildlife, however this is declining over time (Global Alliance of National Parks, 2024).
- The area hosts a variety of animals including the African lion (Panthera leo), African bush elephant (Loxodonta africana), leopard (Panthera pardus), plains zebra (Equus quagga), cheetah (Acinonyx jubatus) and African wild dog (Lycaon pictus). It also hosts the annual Great Migration, the largest overland mammal migration on Earth, driven by the movement of vast heards of wildebeest (Connochaetes taurinus; Subalusky et al. 2017).
- Despite its ecological significance, the Maasai Mara is underrepresented in quantitative climate research relative to its global conservation importance. Wildlife populations have already shown measurable declines linked to rainfall variability and land use change in the surrounding areas (Ogutu et al., 2011). Sub-Saharan Africa, including East Africa, is projected to experience severe climate change impacts, with rising temperatures and shifts in precipitation threatening biodiversity and ecosystem services (IPCC, 2022).
- This study examines historical climate trends and future projections for temperature, rainfall, and cloud cover to characterise long-term climate variability and anticipated changes to this critical conservation area.

Fig. 1 Habitats and animals found in the Maasai Mara National Park include: the cheetah (far left), savannah landscape (second from left), a birds-eye view of Wildebeest herds (middle), African bush elephant (second from right), and an aerial view of the Mara River (far right).

Methods

- Three complementary datasets were used: ERA5 (ECMWF fifth-generation reanalysis; Hersbach et al. 2020), CMIP6 (Coupled Model Intercomparison Project Phase 6; Eyring et al. 2016) climate model projections, and SAI (Stratospheric Aerosol Injection) scenario data. ERA5, spanning 1940 to present, was used for long-term historical analysis of observed climate conditions over the Maasai Mara region. CMIP6 was used for historical validation and future projections through to 2100. SAI data, derived from CESM (Community Earth System Model) and UKESM (UK Earth System Model) simulations, was used to evaluate the potential for stratospheric aerosol injection geoengineering to offset projected warming.

- Quantities investigated included ambient surface air temperature, rainfall (total precipitation), and cloud cover. Not all quantities were available across all datasets, limiting some cross-dataset comparisons.
- Daily and subdaily data was converted into annual data capturing annual minimum, mean, and maximum values, as well as the 25th to 75th percentile range. Differences in values over time were assessed using linear regression unless otherwise stated.
- ERA5 and CMIP6 datasets overlapped for a shared historical period (2015 - 2025), allowing assessment of the ability of climate models to represent observed local conditions over historical timeframes.
- A range of CMIP6 models were investigated using data for two emissions scenarios: SSP5-8.5 (high-end emissions) and SSP2-4.5 (intermediate emissions). The ensemble mean of available models was used to characterise projected change.
- SAI simulations from CESM and UKESM were compared against itself to quantify the degree to which stratospheric aerosol injection may reduce surface temperatures in the Maasai Mara region over the 2035–2069 period. Only surface air temperature data was available for the SAI scenario.

Results

Air temperature

- ERA5 annual mean surface air temperature increased at a rate of 0.024°C per year over the 1940–2025 period, yielding a total regression-based increase of approximately 2.0°C.
- CMIP6 ensemble mean projections from 2015 to 2100 indicate annual average temperature increases of approximately 4.4°C under SSP5-8.5 (slope: 0.052°C/yr) and approximately 2.2°C under SSP2-4.5 (slope: 0.026°C/yr) over the 2015–2100 period.
- ERA5 data averaged over the period 2015 to 2025 was 0.62°C warmer than the SSP245 model ensemble average, and 0.04°C cooler than the SSP585 model ensemble average.
- SAI simulations (CESM and UKESM models, available for 2035–2069) showed a temperatures decrease of 0.44°C over the period, indicating SAI reduces warming from a state initially higher than the SSP585 ensemble mean to a state comparable to SSP245 ensemble mean. While the overall benefit for this region is still beneficial, it is limited. No SAI data was available for precipitation or cloud cover.

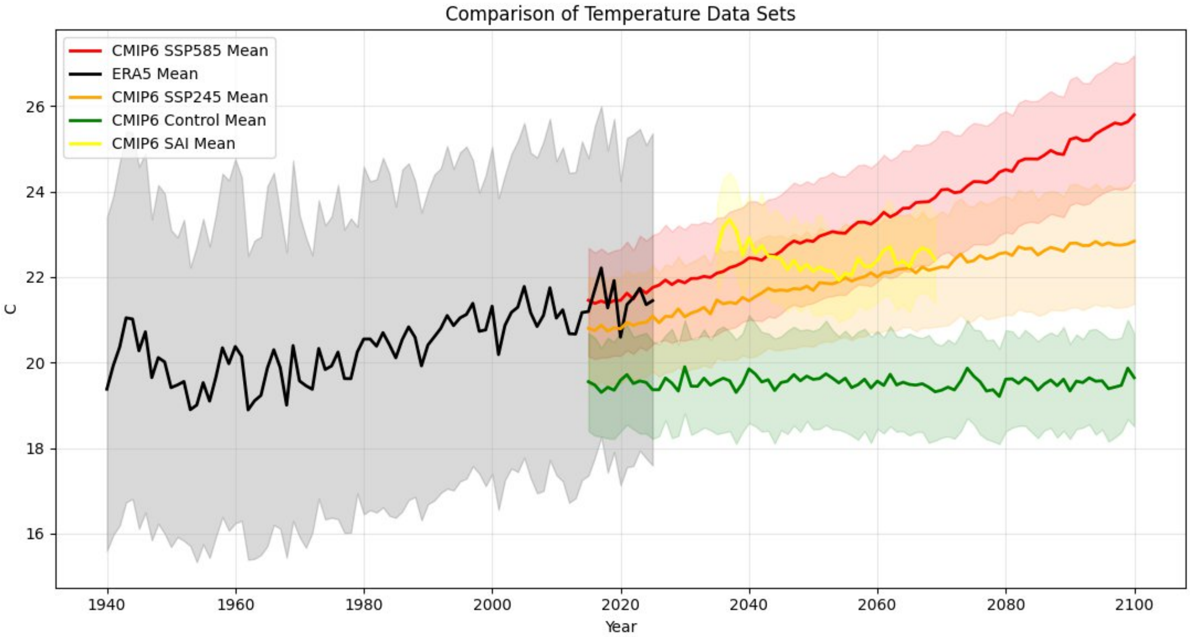

Fig. 2 ERA5 and CMIP6 air temperature values from 1940 to 2025 and 2015 to 2100, respectively. Air temperature values under select SAI scenarios are plotted from 2035 to 2069.

Rainfall and cloud cover

- ERA5 mean annual total precipitation over 1940–2025 was approximately 833 mm per year. The regression trend over this period was −1.19 mm per year, representing a total regression-based decrease of approximately 101 mm.
- CMIP6 ensemble mean projections from 2015 to 2100 show regression-based increases in annual total rainfall of approximately +369 mm under SSP5-8.5 (slope: +4.3 mm/yr) and +198 mm under SSP2-4.5 (slope: +2.3 mm/yr), in contrast to the historical decrease observed in ERA5.
- ERA5 total cloud cover showed a regression-based decrease of approximately 2.9% over the 1940–2025 period (slope: −0.034% per year).
- CMIP6 ensemble mean projections from 2015 to 2100 showed increases in cloud cover of approximately +3.8% under SSP5-8.5 (slope: +0.044%/yr) and +1.2% under SSP2-4.5 (slope: +0.014%/yr). Both scenarios project increasing cloud cover, in contrast to the slight historical decrease observed in ERA5.
- CMIP6 ensemble mean projections over the 2015 to 2025 period demonstrate reasonable alignment with ERA5 observations for cloud cover, but mean annual rainfall over this period (~1,236 mm/yr) is substantially higher than ERA5 historical observations (~833 mm/yr).

Discussion

- The Maasai Mara faces significant climate-driven threats, with rising temperatures representing the most immediate and substantial pressure on biodiversity and ecosystem function. A projected increase of up to 4°C under SSP5-8.5 by 2100 is consistent with broader East African climate projections, which identify sub-Saharan Africa among the most vulnerable regions to anthropogenic climate change (IPCC, 2022).

- Wildebeest and other migratory ungulates, whose population dynamics are tightly coupled to seasonal rainfall patterns, face increasingly altered habitat suitability as temperatures rise and if rainfall patterns change. This could have flow on impacts to other species in the region, including predators. While CMIP6 projections indicate increased temperatures, they also indicate increased rainfall and cloud cover, which differs to the ERA5 data indicating longer term drying and decreases to cloud cover. This would align with other research indicating that while IPCC predicts increased rainfall over Eastern Africa, annual rainfall has been decreasing in the Mara (Bartzke et al. 2018).
- CMIP6 ensemble mean projections over the 2015 to 2025 period demonstrate reasonable alignment with ERA5 observations for temperature and cloud cover over the historical validation period, but mean annual rainfall (~1,236 mm/yr) is substantially higher than ERA5 historical observations (~833 mm/yr), suggesting a model wet bias for this region. This discrepancy further indicates that precipitation values from CMIP6 models needs to be treated with caution, and highlights the importance of bias correction when applying CMIP6 rainfall outputs to local assessments.
- The application of SAI geoengineering strategies, while reducing surface temperatures by a measurable amount, provides only limited mitigation benefits for the Maasai Mara specifically. This highlights that SAI alone is unlikely to fully offset climate change impacts for this region, and that adaptation strategies remain essential regardless of the geoengineering trajectory pursued.
- These results highlight the importance of generating localised climate assessments for lesser-studied but globally significant ecosystems such as the Maasai Mara. Stakeholders must prepare and implement adaptive and resilient management strategies. Priority actions may include wildlife corridor protection, water resource management, and climate-informed land use planning to safeguard this critical region amid ongoing environmental change.

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