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Key Points:

- We simulate the mid-Holocene with and without the Green Sahara using four fully coupled global climate models
- The mid-Holocene simulation with the Green Sahara shows intensification of orbitally-driven changes in precipitation over northern Africa and South America
- Incorporation of the Green Sahara leads to greater proxy-model agreement over both northern Africa and South America

Supporting Information:

Supporting Information may be found in the online version of this article.

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On the Remote Impacts of Mid-Holocene Saharan Vegetation on South American Hydroclimate: A Modeling Intercomparison

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Abstract Proxy reconstructions from the mid-Holocene (MH: 6,000 years ago) indicate an intensification of the West African Monsoon and a weakening of the South American Monsoon, primarily resulting from orbitally-driven insolation changes. However, model studies that account for MH orbital configurations and greenhouse gas concentrations can only partially reproduce these changes. Most model studies do not account for the remarkable vegetation changes that occurred during the MH, in particular over the Sahara, precluding realistic simulations of the period. Here, we study precipitation changes over northern Africa and South America using four fully coupled global climate models by accounting for the Saharan greening. Incorporating the Green Sahara amplifies orbitally-driven changes over both regions, and leads to an improvement in proxy-model agreement. Our work highlights the local and remote impacts of vegetation and the importance of considering vegetation changes in the Sahara when studying and modeling global climate.

Plain Language Summary Paleoclimate modeling offers a way to test the ability of climate models to detect climate change outside the envelope of historical climatic variability. The mid-Holocene (MH: 6,000 years ago) is a key interval for paleoclimate studies, as the Northern Hemisphere received greater summer-time insolation and experienced stronger monsoons than today. Due to a stronger MH West African Monsoon, the Saharan region received enough rainfall to be able to host vegetation. The vegetation changes in the Sahara affected not only the local climate but also far-afield locations through teleconnections in the global climate system. In this study, we simulate the MH climate using four climate models, each with two types of simulations—with and without the Green Sahara. We show that simulations with the Green Sahara capture greater drying over the South American continent than the simulations which only account for changes in orbital forcing and greenhouse gas concentrations. The simulations with the Green Sahara are more in line with proxy reconstructions, lending further support to incorporating vegetation changes as a necessary boundary condition to simulate the MH climate realistically.

1. Introduction

Vegetation cover is known to impact regional climate variability, but the magnitude and global implications of vegetation changes are not well constrained due to the limited variability over the historical period. The Paleoclimate Modeling Intercomparison Project (PMIP) coordinates experiments to determine consistent responses across models that, when constrained against proxy reconstructions, can provide for a deeper understanding of how the climate system operates (Braconnot et al., 2012; Kageyama et al., 2018; Otto-Bliesner et al., 2017). A key interval for study is the mid-Holocene (MH), which refers to the time-slice around 6,000 years ago. The MH was characterized by paleogeographic and ice-sheet distributions comparable to today, but the orbital configuration and greenhouse gas (GHG) composition differed. Most notably, the perihelion occurred during boreal

autumn as opposed to boreal winter today, enhancing Northern Hemisphere seasonality. The Northern (Southern) Hemisphere received greater (lesser) summer insolation relative to the present day. In addition, carbon dioxide and methane compositions were lower by $\sim 7\%$ and $\sim 26\%$ respectively, relative to the pre-industrial (PI) period (Otto-Bliesner et al., 2017). These differences are prescribed in the coordinated PMIP4 *midHolocene* experiments. The PMIP4 MH simulations indicate stronger monsoons in the Northern Hemisphere, especially over northern Africa (Brierley et al., 2020). This is supported by multi-proxy reconstructions from various archives such as organic biomarkers (Collins et al., 2017; Shanahan et al., 2015; Tierney et al., 2017), dust (McGee et al., 2013; Palchan & Torfstein, 2019), pollen (Bartlein et al., 2011; Hély et al., 2014), speleothems (Sha et al., 2019) and paleohydrological records (Gasse, F., 2000; Lézine et al., 2011). However, proxy-model comparisons indicate that climate models generally under-estimate the magnitude of African precipitation change with too little rainfall to support the proxy reconstructed vegetation (Braconnot et al., 2012; Brierley et al., 2020; Tierney et al., 2017).

The proxy-model discrepancy over northern Africa may be resolved to great extent through the incorporation of appropriate vegetation in climate models. There is considerable evidence that there were large-scale vegetation changes throughout the world during the MH (Bartlein et al., 2011). Most notably, the expansion of grasslands and shrubs into the current desert region of the Sahara (the so-called “Green Sahara”; e.g., Hély et al., 2014) led to significant amplification of the orbital-driven strengthening of the West African monsoon (WAM) through positive nonlinear feedbacks such as vegetation, dust and albedo feedbacks (Pausata et al., 2020; Swann et al., 2014). The incorporation of these changes, either through dynamic vegetation (e.g., Dallmeyer et al., 2021; Levis et al., 2004; Rachmayani et al., 2015) or through the prescription of vegetation distributions (e.g., Chandan & Peltier, 2020; Pausata et al., 2016; Thompson et al., 2021), leads to simulations that are more consistent with proxy reconstructions. An important consequence of more realistic simulations is the enhanced ability to identify the far-afield impacts of the Green Sahara. For example, simulations accounting for the MH Green Sahara have elucidated the influence of the WAM on the El-Niño Southern Oscillation (Pausata, Zhang, et al., 2017), tropical cyclone activity (Pausata, Emanuel, et al., 2017), global monsoon systems (Griffiths et al., 2020; Huo et al., 2021; Piao et al., 2020; Sun et al., 2019; Tabor et al., 2020) and high latitude climate (Muschitiello et al., 2015). While the regional changes that accompanied the Green Sahara are well-recognized, its remote impacts warrant further exploration.

The MH WAM intensification occurred in parallel with a reduction in precipitation over parts of South America. Proxy reconstructions from pollen, sedimentological and isotopic records indicate that a drier MH climate prevailed over most of tropical South America (Baker et al., 2001; Cruz et al., 2005; Novello et al., 2017; see Gorenstein et al., 2022 for a synthesis); some exceptions are found from the Cariaco Basin (Haug et al., 2001), northeast Brazil (Cruz et al., 2009), and eastern Amazonia (Wang et al., 2017). While PMIP4 models in general capture this reduction in precipitation (Brierley et al., 2020; Brierley & Wainer, 2018), closer inspection reveals less consistency amongst them regarding the reduction in South American precipitation, compared with northern Africa where the models display greater agreement (Brierley et al., 2020).

The South American Monsoon System (SAMS) brings precipitation during austral summer over the region extending from southern Amazon to southeastern Brazil (Garreaud et al., 2009; Marengo et al., 2012). The MH drying over South America has been attributed primarily to lower summer insolation and dampened seasonality in the Southern Hemisphere, which led to a weakening of the SAMS. However, few studies have addressed the mechanisms by which the MH Green Sahara could have impacted South American climate. Silva Dias et al. (2009) studied the effect of vegetation changes with two MH experiments: the first considered changes only in orbital parameters, the second additionally incorporated vegetation changes by asynchronously coupling a vegetation model to an ocean-atmosphere climate model. They observed that vegetation feedbacks could enhance some orbitally driven patterns, especially the displacement of the Intertropical Convergence Zone (ITCZ). Recently, Tabor et al. (2020) used a water isotope-enabled Earth System Model to simulate $\delta^{18}\text{O}$ changes during the MH and compare them with speleothem reconstructions. They found that the incorporation of the Green Sahara led to better proxy-model agreement with the amplification of the drying signal over South America.

Therefore, tropical African vegetation changes are a critical prerequisite for a realistic simulation of MH climate. Given the influence of Africa over South American climate (Chen et al., 1999; Cook et al., 2004), inclusion of vegetation changes is necessary for the estimation of the remote impacts of the Green Sahara. In this study, we investigate the response of the climate of northern Africa and South America to the incorporation of a Green Sahara. To this end, we examine the differences between two MH simulations—with and without the Green

Sahara—based on simulations from four coupled global climate models. To the best of our knowledge, this is the first model intercomparison study regarding the effects of land surface changes due to the Green Sahara. We also present a semi-quantitative assessment of the improved proxy-model agreement upon the inclusion of the Green Sahara, which lends further support to our approach.

2. Methods

For this study, we analyzed outputs from four global climate models—(a) EC-Earth version 3.1 (Hazeleger et al., 2010), (b) the water isotope-enabled Community Earth System Model version 1.2 (iCESM1; Brady et al., 2019), (c) University of Toronto version of CCSM4 (hereby referred to as UofT-CCSM4; Peltier & Vettoretti, 2014), and (d) the water isotope-enabled GISS-E2.1-G (Kelley et al., 2020). Details about the atmospheric and oceanic components of these models and their associated grids are provided in Table S1 in Supporting Information S1. Three simulations were analyzed for each model—one for the pre-industrial (PI) and two for the MH climate state. The first MH experiment follows the standard forcings and boundary conditions as specified by the PMIP4 guidelines (Otto-Bliesner et al., 2017) and is referred to as MH_{PMIP} . The second MH simulation, which additionally incorporates a Green Sahara by prescribing vegetation over northern Africa, is referred to as MH_{GS} . While the representation of the Green Sahara is different in each climate model, it follows the paleo distributions of vegetation suggested for the PMIP4 sensitivity experiments (Otto-Bliesner et al., 2017; further details in Text S2 in Supporting Information S1).

To validate the models, we compared climatological outputs from PI simulations with the Global Precipitation Climatology Center (GPCC) Reanalysis Dataset from 1951 to 1980 (Schneider et al., 2011) and the Global Precipitation Climatology Project (GPCP) dataset v2.2 from 1979 to 2009 (Adler et al., 2003) (Text S1 and Figure S2 in Supporting Information S1). Models have varying ability to simulate the climate over South America and the equatorial Atlantic Ocean, with EC-Earth showing superior ability to represent modern climate (see Text S1 in Supporting Information S1 for details about model biases and differential model performance). However, all models broadly reproduce the magnitudes and distributions of annual precipitation over the study area. Further, to redress the effect of model biases, we discuss our results in terms of MH—PI differences. We interpret the MH_{PMIP} – PI anomalies to reflect the effects of changes in orbital parameters and GHG concentrations, and the MH_{GS} – MH_{PMIP} anomalies to reflect the additional effect of the Green Sahara. All model climate variables are analyzed as averages over 100 simulation years.

To quantify proxy-model agreement, we use the Cohen's κ statistic, modifying it to implement weights for total disagreement, partial disagreement and agreement (Text S3 in Supporting Information S1).

3. Results

The MH_{PMIP} simulations indicate a small but significant increase in precipitation of 0.5 mm/day over almost the entirety of northern Africa, extending beyond 30°N (Figures 1a–1d). The intensification of the WAM is larger over the Sahel, where it reaches the order of 1–2 mm/day between the equator and 15°N and is also reflected in stronger low-level (850 hPa) southwesterly monsoon winds. The patterns and magnitude of the increase in mean annual precipitation over northern Africa are consistent across all four models. EC-Earth 3.1 shows the highest increase of 2 mm/day over the core rainfall belt. The intensification of the WAM in the MH_{PMIP} simulations is accompanied by a decrease in mean annual precipitation over some regions of South America. This decrease is on the order of 0.5–2 mm/day but the spatial extent of the change differs among the models. EC-Earth 3.1 and GISS-E2.1-G capture a widespread decrease across nearly the full meridional extent of the continent. The UofT-CCSM4 simulation shows a greater decrease, but limited to parts of northwestern Amazon, while iCESM 1.2 shows a modest decrease of up to 0.5 mm/day in the southern half of the continent. All models show a decrease in precipitation just north of the equator in the Atlantic Ocean.

Comparing the MH_{PMIP} (Figures 1a–1d) and the MH_{GS} (Figures 1e–1h) simulations, we observe an amplification of orbitally-driven changes in rainfall. The increase in precipitation over northern Africa is intensified and extends further north, with three out of four models showing an increase of 0.5–1 mm/day up to 25°N. The core rainfall belt is between 10 and 20°N, with an increase in precipitation in the order of 1–3 mm/day. EC-Earth 3.1 shows the greatest increase in the core rainfall belt, exceeding 4 mm/day between 12 and 16°N. Across the Atlantic, all models suggest greater and more widespread drying of up to 2 mm/day over South America. The

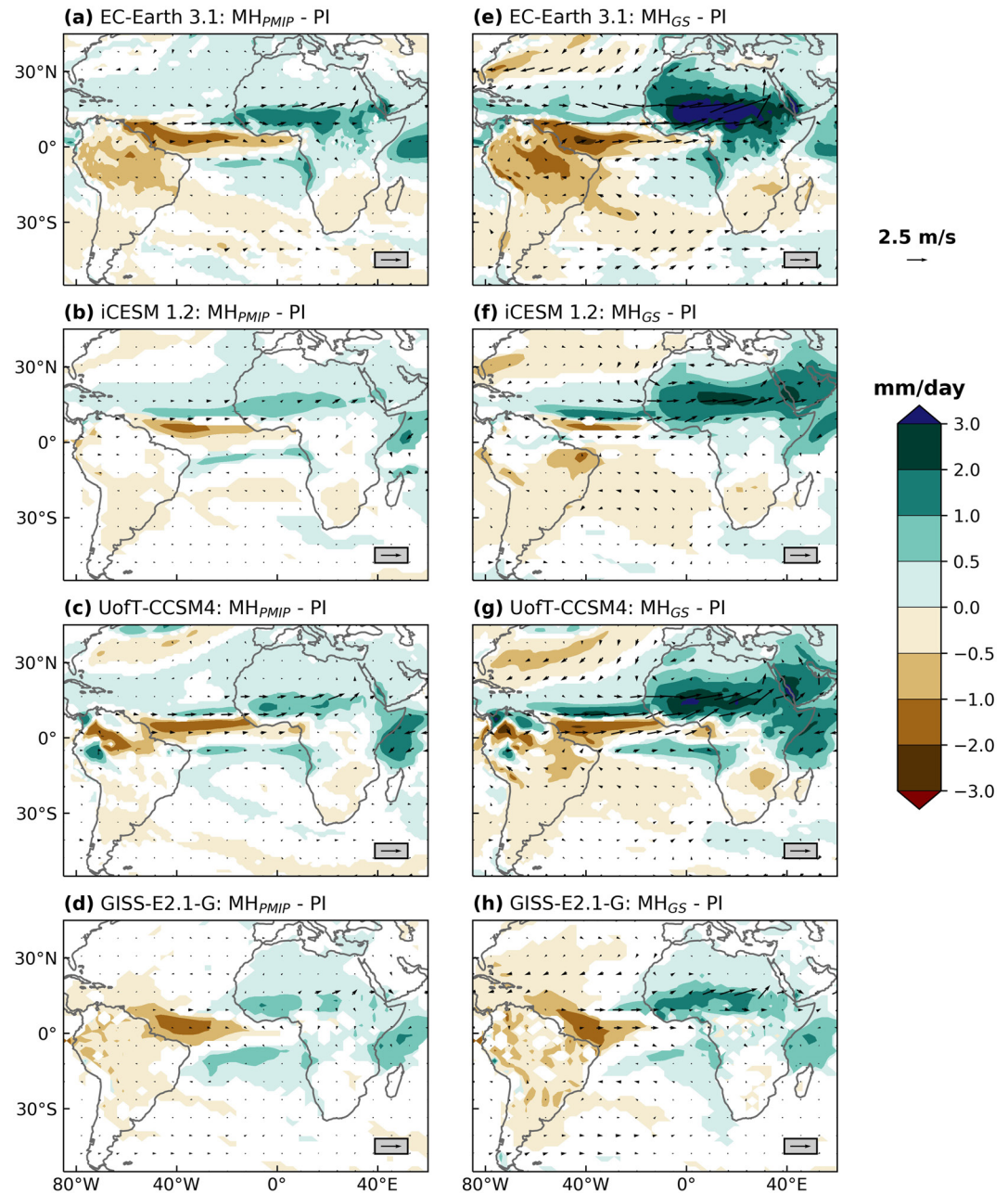


Figure 1. Change in annual precipitation in the MH_{PMIP} (a–d) and MH_{GS} (e–h) experiment relative to the PI simulation. Colors represent precipitation change in mm/day. Only changes significant at the 95% confidence level are shaded. Vectors indicate changes in low-level (850 hPa) wind strength.

drying patterns appear stronger over northern South America, but more consistent over southern South America. Notably, iCESM 1.2 shows little change from the PI over northwestern South America, with a modest but significant increase in some parts of the Amazon. All models show a decrease in precipitation immediately north of the equator and an intensification in precipitation northwards of this region, suggesting a northward shift in the position of the ITCZ. None of the MH simulations indicate an increase in precipitation over northeastern Brazil, likely due to anomalous upper-level convergence over this region (Figures 4a–4d).

As the WAM and the SAMS operate over different seasons and different regions in South America experience different annual precipitation cycles (Marengo et al., 2012; Figure S1 in Supporting Information S1), it is helpful to investigate MH-PI anomalies in monthly precipitation. The multi-model mean rainfall changes in the MH_{PMIP}

simulation relative to the PI indicate an intensification of the WAM from May–October (Figure S3 in Supporting Information S1). With the exception of austral spring (October–November), the dominant change observed over South America is a drying throughout the year. During austral winter (May–July), this drying is restricted to regions north of 10°S, which are dominantly influenced by the ITCZ. The multi-model mean change in the MH_{GS} relative to PI indicate that the increase in precipitation over northern Africa lasted longer, from March–November, with a very prominent increase over the core rainfall belt around 15°N from May–October (Figure S4 in Supporting Information S1). Two notable patterns are observed in the MH_{GS} simulation relative to the PI: firstly, except for November, the domain of the SAMS was drier throughout the year; secondly, the ITCZ-influenced regions in northern South America were wetter between January–May and drier through the rest of the year. Changes in annual average values aggregate some of these seasonal changes and result in a weaker drying signal in the MH_{PMIP} simulation relative to the PI. However, since the drying signal is stronger, more widespread, and extended to a longer duration through the year in the MH_{GS} simulation relative to the PI, it remains evident in the annual average as well (Figure 1).

The effects of incorporating the Sahara greening into the models are evident in the multi-model mean anomalies between MH_{GS} and MH_{PMIP} (Figure 2). The Sahara greening leads to higher precipitation over northern South America between December–May, but drying over other regions throughout the year. Notably, the Green Sahara leads to a larger amplitude of precipitation seasonality in the equatorial areas such as the northern Amazon. This is because the expansion of the seasonal migration range of the ITCZ in the MH_{GS} scenario leads to an increase in precipitation over equatorial South America during austral summer and a decrease during the boreal summer. Lastly, the Saharan vegetation changes are associated with enhanced subsidence and drying over northeastern Brazil throughout the year (Figures 4e–4h).

We assessed the agreement between proxies and models under different MH experiments using weighted Cohen's κ statistic, a semi-quantitative metric to estimate the frequency of agreement between categorical data. All models show higher κ scores in the MH_{GS} (i.e., $\kappa > 0.49$, $p < 0.01$) compared to MH_{PMIP} (i.e., $\kappa < 0.48$, $p < 0.01$) experiment, with EC-Earth 3.1 and iCESM 1.2 showing the most significant improvements (Figure 3; Figures S5a and S6 in Supporting Information S1). This indicates that the MH_{GS} simulation better simulates the extent of a wetter northern Africa and/or a drier South America during this period relative to the MH_{PMIP} simulation. Considering the proxy-model agreement between the continents, northern Africa consistently shows higher κ scores than South America (Figures S5b and S5c in Supporting Information S1) with all models showing a general improvement in reflecting a greener Sahara. Over South America, all models except for GISS-E2.1-G show an improvement in capturing the drier conditions in this region in the MH_{GS} experiment (Figure S5c in Supporting Information S1). UofT-CCSM4 performed well over northern Africa but worse over South America resulting in overall comparable κ scores between MH scenarios (Figure 3; Figure S5 in Supporting Information S1). For GISS-E2.1-G, the κ score over South America decreases but there is a general improvement over northern Africa in the MH_{GS} simulation with comparable κ scores between MH experiments (Figure 3; Figure S5 in Supporting Information S1). The observed overall improvement in iCESM 1.2 originates from the more apparent drying over South America under MH_{GS} relative to MH_{PMIP} (Figure 1). EC-Earth 3.1 shows the highest κ score for both continents, outperforming all models under MH_{GS} scenarios (Figure S5 in Supporting Information S1).

4. Discussion and Conclusions

In this study, we assessed the impact of paleovegetation changes during the MH by considering two simulations—with and without the Green Sahara. A model intercomparison to robustly assess the northern African land cover changes was hitherto missing. For the first time, we compare four different Earth system models in which vegetation changes over northern Africa are accounted for, and focus on the associated hydroclimate changes over northern Africa and South America. The four models in this study have varying performance over South America, with EC-Earth representing the modern fundamental features most satisfactorily. However, irrespective of the methods used to prescribe vegetation or the ability to simulate South American climate, the models share similarities in their teleconnections across the tropical and extra-tropical Atlantic, indicating the overwhelming importance of the Green Sahara. The Sahara greening (MH_{GS}) enhances the rainfall over northern Africa, while further decreasing precipitation over South America relative to the case in which only orbital forcings are accounted for (MH_{PMIP}).

Several modeling studies have shown a reduction in precipitation over South America as well as changes to the monsoonal cycle due to changes in seasonal insolation (Shimizu et al., 2020). The orbital-driven weakening of the

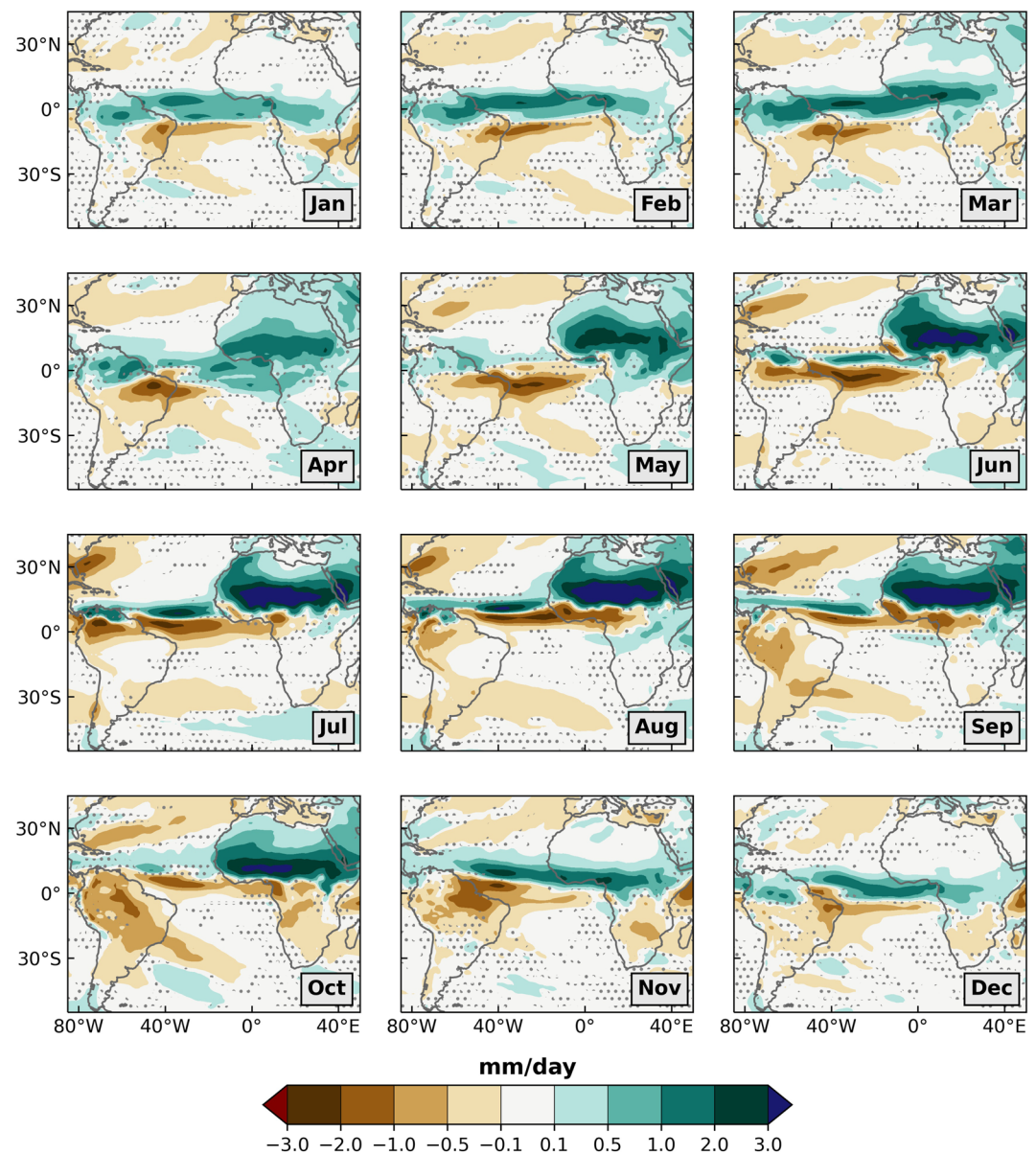


Figure 2. Monthly evolution of the multi-model average precipitation anomalies between MH_{GS} and MH_{PMIP} . Stippling indicates areas in which less than three models agree on the sign change.

SAMS during austral summer is indicated by PMIP3 (Prado et al., 2013; Shimizu et al., 2020) as well as PMIP4 models (Brierley et al., 2020). Our MH_{PMIP} simulations similarly capture a drying signal, particularly over north-western South America (Figure 1) and provide drying estimates comparable to previous results (around 1 mm/day). Examining the seasonal cycle indicates that South America received less insolation during austral summer and more insolation during austral spring during the MH compared with the PI, which could have altered the cycle of the SAMS (Shimizu et al., 2020). Our MH_{PMIP} simulations also capture these changes through a decrease in precipitation over the SAMS region during December–February, but an increase during October–November. However, few of the previous modeling studies focused specifically on how the Sahara greening may have influenced the MH South American hydroclimate (Silva Dias et al., 2009; Tabor et al., 2020). Our results support their findings regarding the impact of the Green Sahara in amplifying orbital-driven weakening of the SAMS, through consistent results from four different models. Furthermore, in our study we show that South America also experienced a significant reduction in precipitation during austral winter, most likely because the prescribed vegetation led to widespread moisture redistribution during austral winter (Figure 2). Combined with a weakening of the

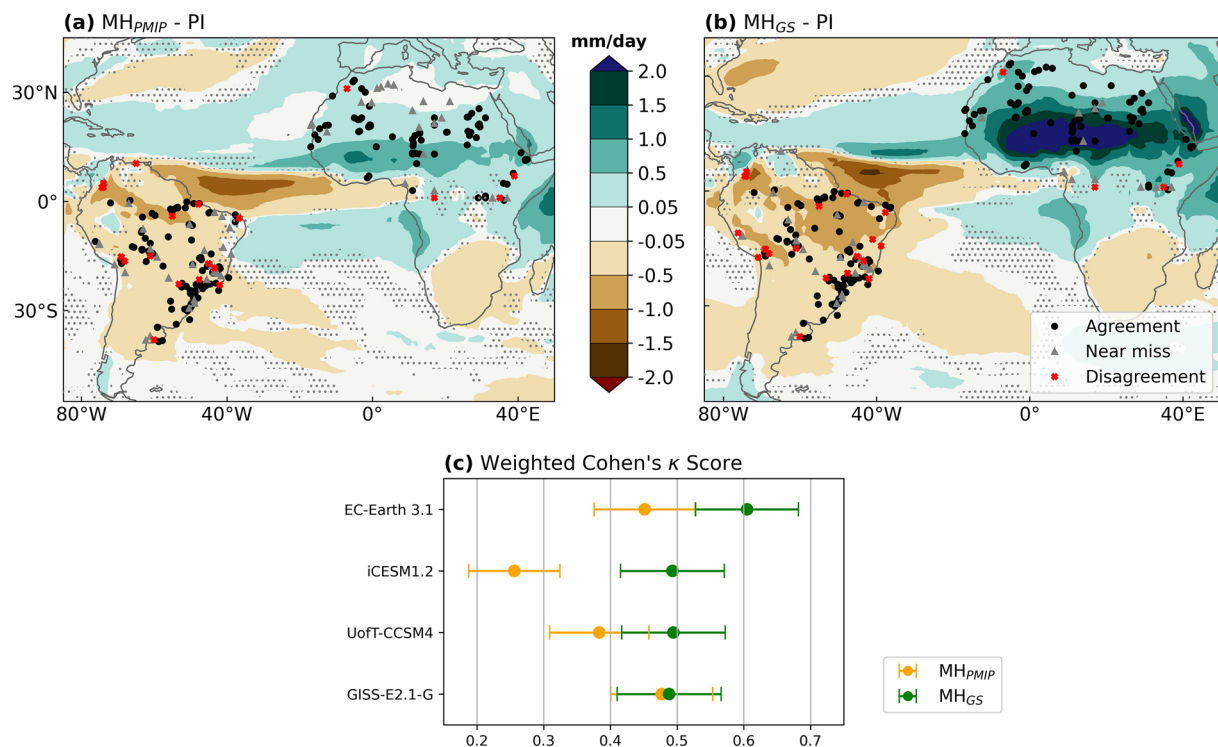


Figure 3. Multi-model mean change in annual precipitation, with proxy-model agreement overlain. Colors indicate (a) MH_{PMIP}—PI and (b) MH_{GS}—PI changes in annual precipitation in mm/day. Stippling indicates areas in which less than three models agree on the sign change. (c) Weighted Cohen's κ Scores for MH_{PMIP} (orange symbols) and MH_{GS} (green symbols) runs. Error bars indicate 95% confidence intervals.

SAMS during austral summer, this led to longer and greater drying over South America than seen when only considering changes in orbital forcings. Thus, the drying in South America during the MH was prevalent throughout the year and not exclusively related to changes in the SAMS.

Lastly, an interesting result of this study is the absence in our MH simulations of an east-west precipitation dipole over tropical South America, which is a key feature of modern (Chen et al., 1999; Cook et al., 2004; Lenters & Cook, 1997) and last millennium (Orrison et al., 2022) South American hydroclimate. All our MH_{PMIP} simulations show anomalous upper-level convergence over northeastern Brazil leading to greater subsidence and drying in the region, an effect that is reinforced by the vegetation changes in the MH_{GS} simulations (Figure 4). In this regard, our results differ from previous modeling studies that performed MH_{PMIP}-type simulations and found a wetter northeastern Brazil and a drier rest of tropical South America during the MH (Cruz et al., 2009; Liu & Battisti, 2015). Despite the presence of some well-dated proxy reconstructions that point to the presence of a wetter MH northeastern and central Brazil (Barreto, 2010; Cruz et al., 2009; Utida et al., 2020; Wang et al., 2017), there is considerable disagreement among proxy records. Gorenstein et al. (2022) noted that out of 43 records from this region, only six sites indicate a MH wetting, whereas 26 archive a MH drying. Thus, our results point to two possibilities: (a) the presence of the Green Sahara amplifies the models' inability to simulate this feature of South American hydroclimate, or (b) the east-west precipitation dipole is not a stationary feature of South American climate and may be masked by the presence of the Green Sahara.

Various mechanisms have been proposed to explain the influence of northern African vegetation changes on South American hydroclimate. The influence of an African heat source on eastern and northeastern Brazil has previously been established by idealized experiments (Cook et al., 2004; Gandu & Silva Dias, 1998). Silva Dias et al. (2009) suggested a northward migration of the SACZ associated with a weakening of the upper-level Bolivian High and a weakened tropical circulation, influencing inland climate. Tabor et al. (2020) discussed the role of substantial regional warming due to the Green Sahara, which resulted in a more northerly ITCZ between November and March. Precipitation over South America was likely also modulated by MH changes in the equatorial Atlantic (Brierley & Wainer, 2018) and the equatorial Pacific variability (Pausata, Zhang, et al., 2017),

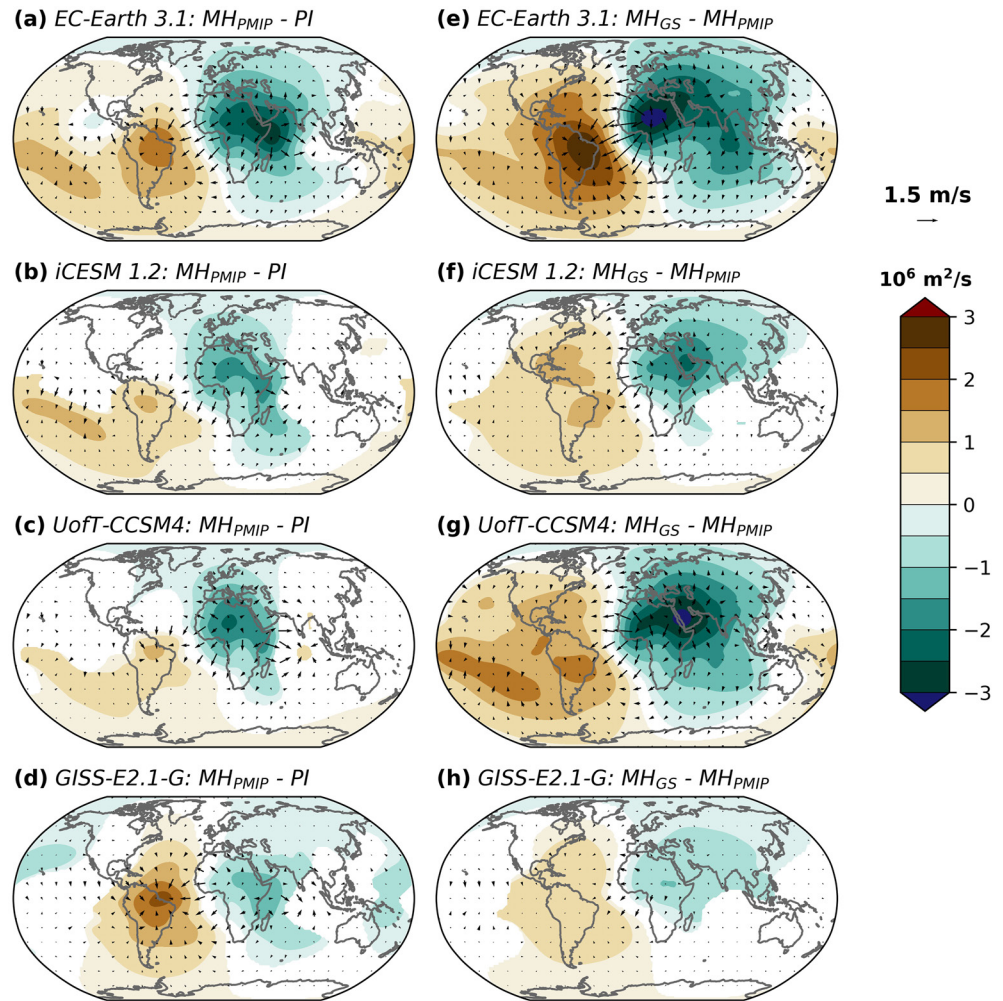


Figure 4. Changes in annual upper-level (200 hPa) velocity potential (a–d) for the MH_{PMIP} relative to the PI experiment and (e–h) for the MH_{GS} relative to the MH_{PMIP} simulation. Only changes significant at the 95% confidence level are shaded. Vectors indicate changes in upper-level divergent wind.

which affected the moisture budgets through perturbations to the Hadley and Walker Circulations (D'Agostino et al., 2020). Further, different mechanisms could have contributed during different times of the year. For example, Moura and Shukla (1981) suggested that anomalously warm SSTs in the northern equatorial Atlantic during boreal summer led to thermally forced subsidence and subsequent droughts in northeastern Brazil. Grimm et al. (2007) highlighted the role of reduced soil moisture during austral spring in driving summer precipitation. Thus, various factors may have led to the widespread drying observed over different regions of South America during different parts of the year. While an in-depth investigation of the mechanism(s) behind the Green Sahara's modulation of South American hydroclimate is beyond the scope of this study, our work nonetheless shows the importance of Saharan vegetation in more accurately simulating northern African and South American teleconnections during the MH. This is clear through an analysis of the annual upper-level (200 hPa) velocity potential anomalies (Figure 4). A comparison of $MH_{PMIP} - PI$ and $MH_{GS} - MH_{PMIP}$ anomalies shows that the impact of the Green Sahara is comparable to the impact of the changes in orbital configuration and GHG concentrations (Figure 4). An inadequate representation of the substantial forcing imposed by the Saharan vegetation precludes an analysis of its remote impacts.

Among all simulations, the MH_{GS} simulation from EC-Earth shows the greatest proxy-model agreement over both regions. The inclusion of vegetation changes over northern Africa in the models leads to an overall improvement in Cohen's κ scores. Over Northern Africa, the MH_{PMIP} simulations capture increases of 0.5–2 mm/day, consistent with the expansion of Sahelian and Sudanian vegetation. The MH_{GS} simulations capture a northward extension of

the core rainfall belt between 10 and 20°N, with increases of 1–3 mm/day which are further consistent with the expansion of Guineo-Congolian vegetation (Hély et al., 2014). In both sets of MH simulations, proxy-model disagreement in northern Africa is limited to regions which are not dominantly influenced by the WAM. However, improvement in κ scores is less apparent over northern Africa due to the reasonable ability of MH_{PMIP} simulations to capture the spatial extent of the increase in precipitation. The drivers of improvement over South America are less straightforward. On one hand, an inclusion of the Green Sahara leads to an increase in the number of sites showing proxy-model disagreement in some regions, particularly eastern Brazil. On the other hand, inclusion of the Green Sahara leads to an improvement in the ability of models to capture the spatial extent of precipitation changes over South America, leading to an increase in sites showing proxy-model agreement. These two contending factors lead to an overall improvement in three models (except GISS-E2.1-G) to capture changes indicated by proxy reconstructions over South America. A key limitation of our work is the inclusion of proxy data irrespective of dating resolution or demonstrated fidelity to extracting climatic variability. Further, our work only assesses model-proxy agreement with respect to spatial extent, and not magnitude of precipitation changes. Notwithstanding these limitations, our work highlights the importance of vegetation as key boundary condition that should be included when simulating MH climate and comparing models to paleoclimate archives.

Data Availability Statement

All data presented here are accessible from the Zenodo repository: <https://doi.org/10.5281/zenodo.7651155>. This repository contains the model outputs as well as Python scripts that can be used to reproduce the figures discussed in this article.

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