African monsoon changes in the Late Cenozoic from the climate modelling perspective

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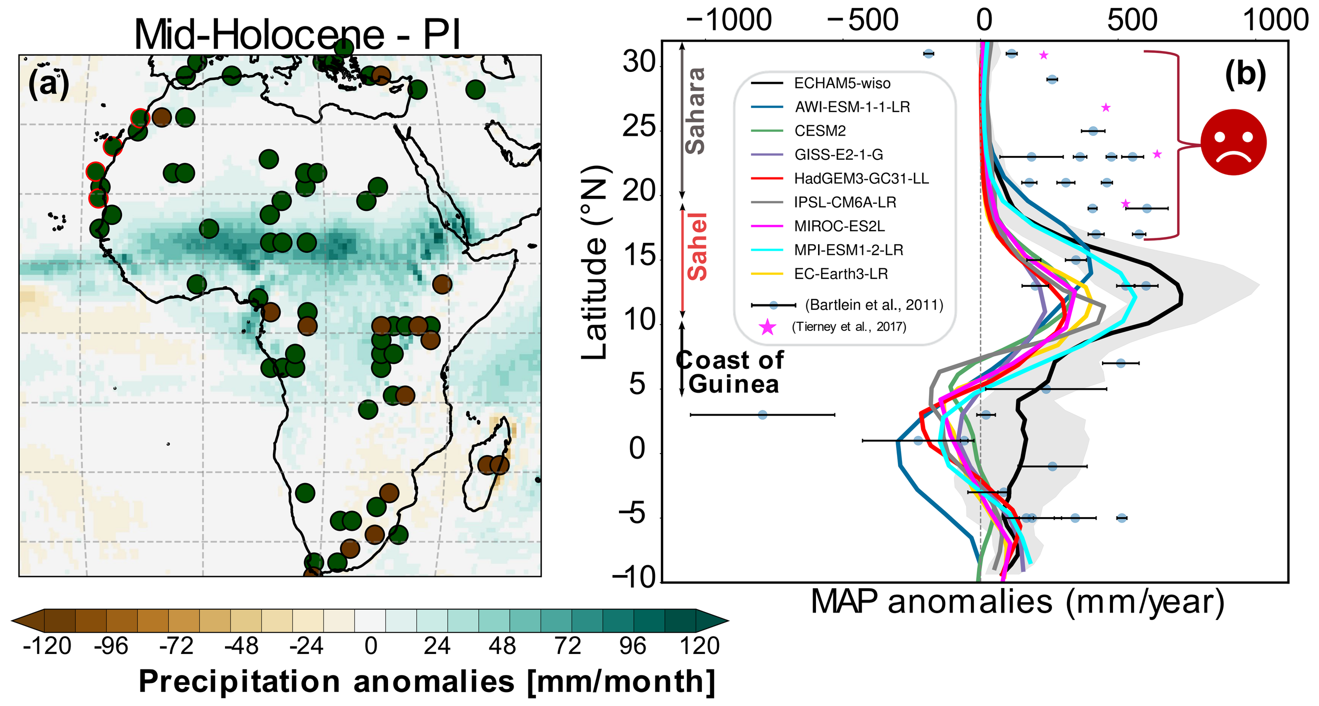
1 Motivation

Understanding the atmospheric dynamics, and teleconnections of African monsoons is one of the most challenging issues in climate science (Fig.1). Most climate models struggle to accurately represent the region's historical variability and demonstrate little consensus regarding future projections. Most importantly, due to their high vulnerability, regional climate change has significant socio-economic consequences for African countries. Hence, accurate climate change information is essential for their adaptation and mitigation strategies. Studying past hydroclimate and atmospheric dynamics changes beyond the historical period can help constrain the key features of the African monsoon system that require improvement in models. **This study presents model-based estimates of West African (WAM) and East African (EAM) monsoon responses to paleoenvironmental forcings and feedbacks (changes in $p CO_2$, orbital forcing, vegetation, and orography) for the past ~15 Ma.**

Fig.1: (a) Mean Annual Precipitation (MAP) anomalies model-proxy[1,2] comparison in MH



2 Method

- Model: ECHAM5-wiso[3]
- Model validation: comparison with ERA5 and CRU (present-day; 1979-2014) (Fig. 2)
- Paleoclimate simulations: Mid-Miocene, Mid-Pliocene (MP), Mid-Holocene (MH), and Pre-industrial (PI)
- Topographic sensitivity[4]: East Africa Rift System (EARS) (Fig.3)

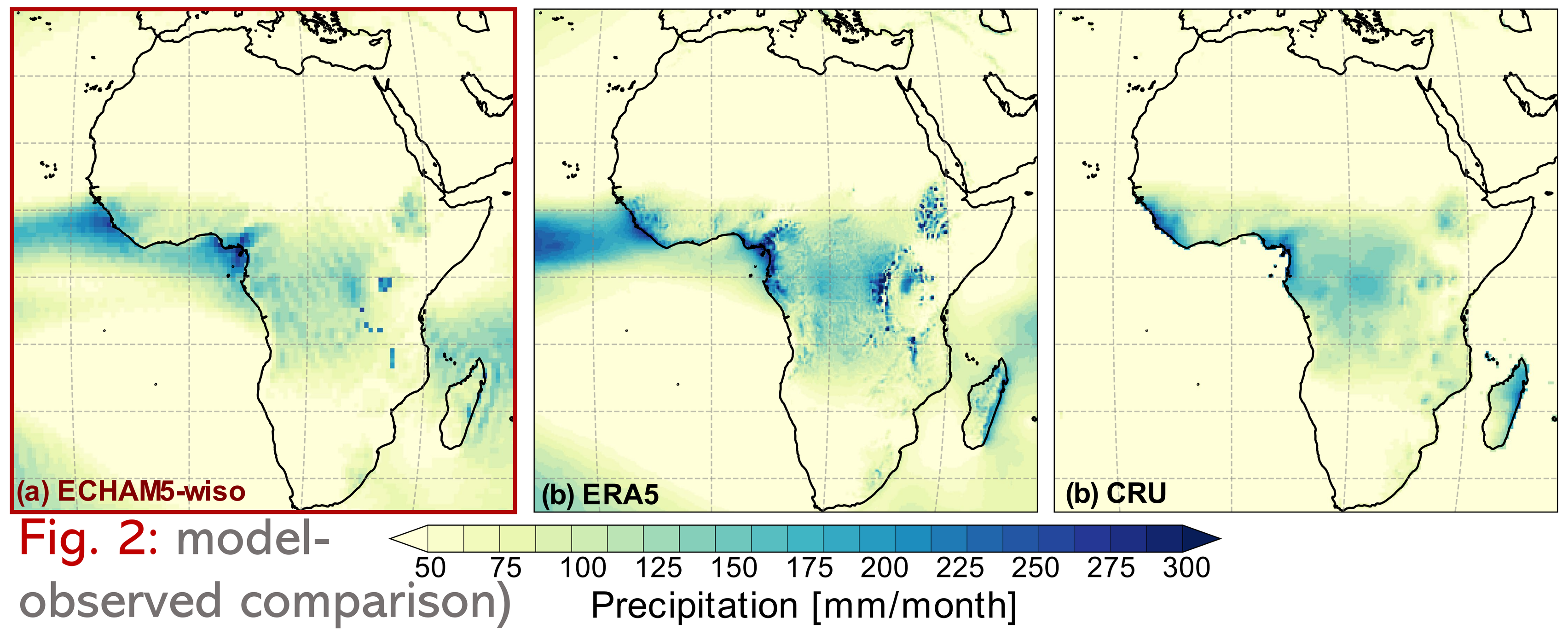


Fig. 2: model-observed comparison)

- Moisture budget diagnostic analysis[5]: decompose precipitation changes across the Sahel into thermodynamic (dTH; $-\langle\overline{\omega}\partial_p q'\rangle$), dynamics (dD; $-\langle\omega'\overline{q}\partial_p\rangle$), and non-linear terms (d(NL); $-\langle\omega'\partial_p q'\rangle$) (Fig. 5)

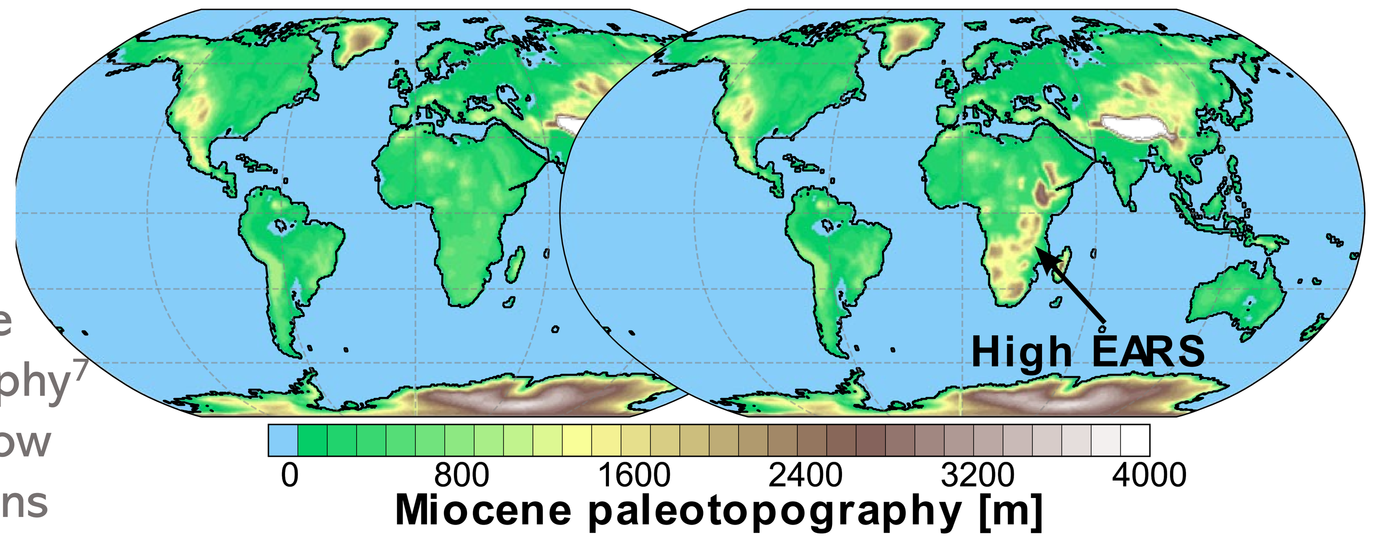


Fig.3: Miocene palaeogeography[7] for high and low EARS conditions

3 Results and Discussion

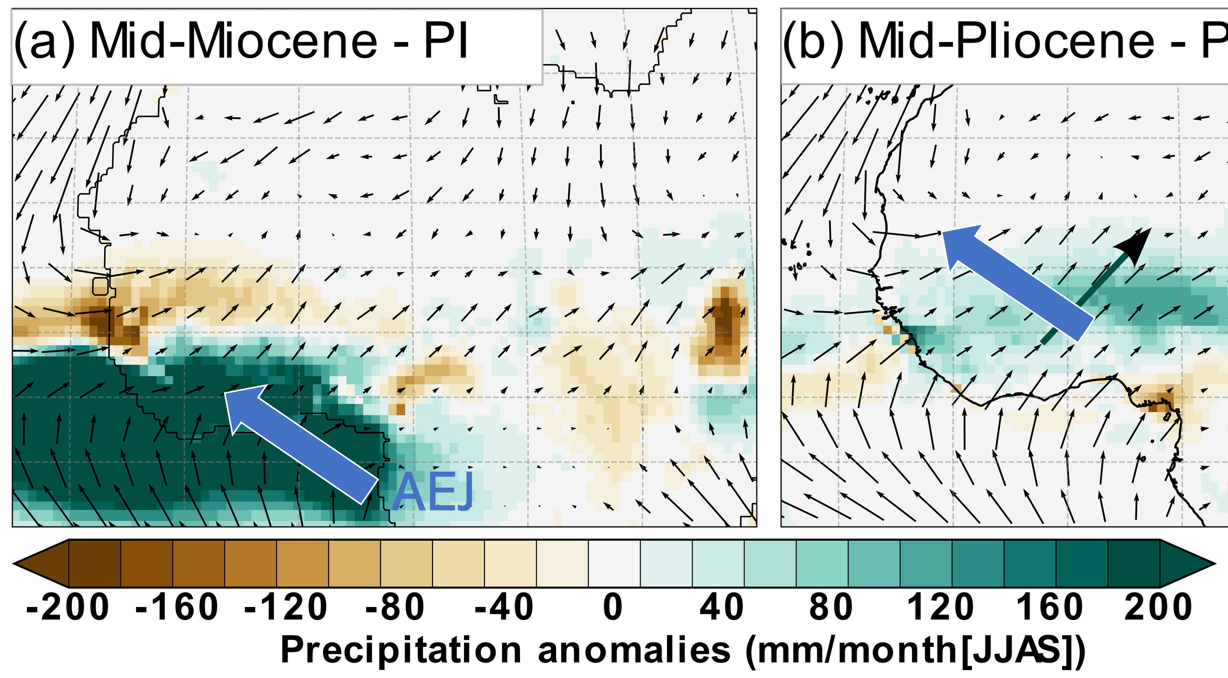


Fig. 4: MAP anomalies and wind patterns in JJAS months across West Africa

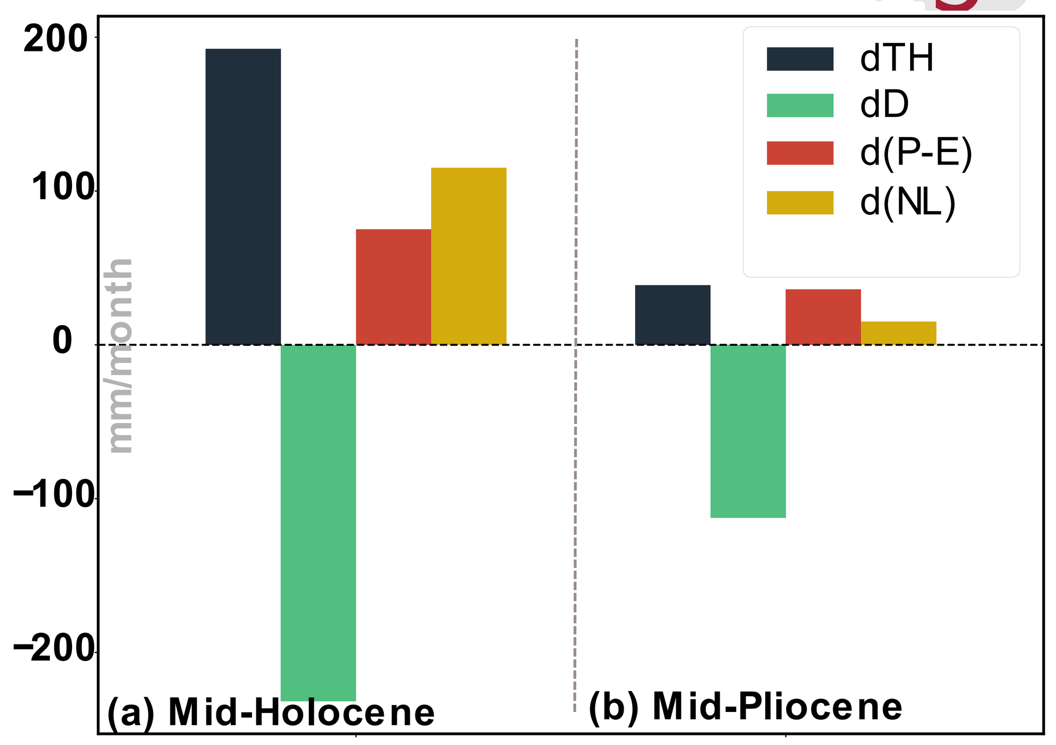


Fig. 5: Moisture budget terms for the precipitation increase across the Sahel in the MH and MP

- Most strengthened and northward reach of WAM in MH, despite the enhanced hydrological cycle and high $p CO_2$ in MP and Mid-Miocene (Fig. 4)
- The intensification is driven by a pronounced temperature gradient, the northward position of the Africa Easterly Jet (AEJ), and Intertropical discontinuity, and increased vertical thermodynamics (moisture)[6] responses (Fig. 4, 5)

Summary

This study suggests that accurate simulation of future African monsoon climate changes will require improvement in both **land-atmosphere feedbacks and large-scale atmospheric dynamics** in climate models

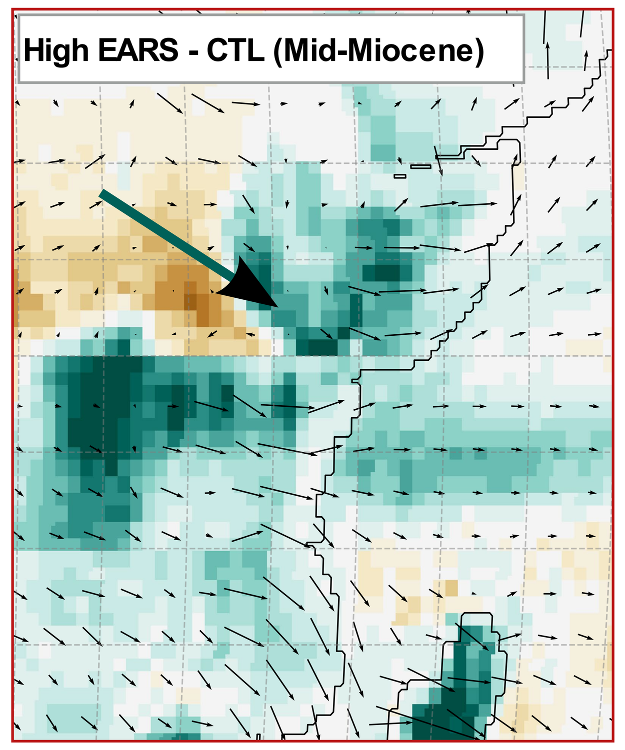


Fig. 7: MAP difference between the high and low EARS topography scenarios in the Mid-Miocene

- High EARS in the Miocene produces orographic precipitation that strengthens the EAM (Fig. 7)

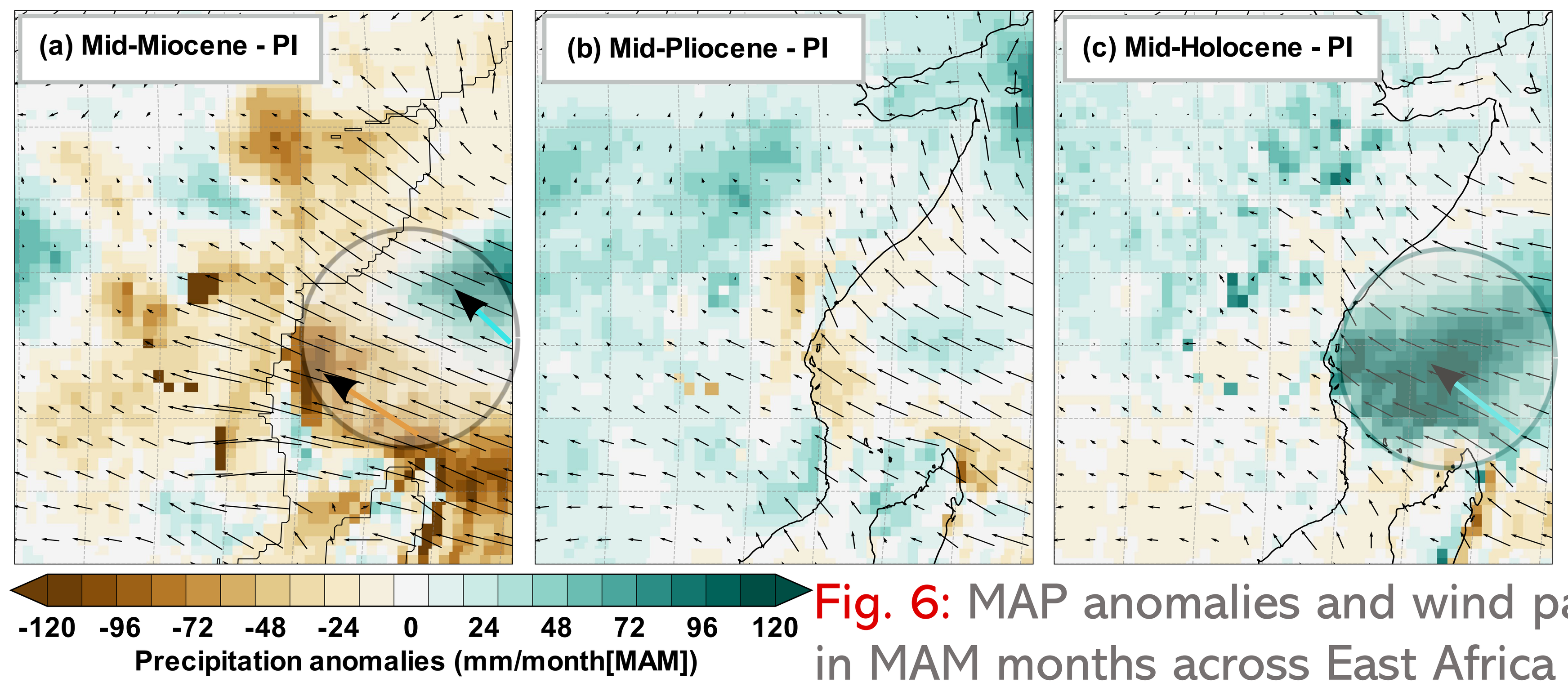


Fig. 6: MAP anomalies and wind patterns in MAM months across East Africa

- Significant drier conditions across East Africa with anti-phase conditions over the adjacent Indian Ocean in the Mid-Miocene (Fig. 6 a)
- Most strenghtened EAM conditions in MP, while MH significantly increases over the ocean (Fig. 6 a, b)

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Preprint

Abstract

References: 1. Bartlein et al. (2011), Climate Dynamics.
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Photography encouraged