AFRICAN HUMID PERIOD PRECIPITATION SUSTAINED BY ROBUST VEGETATION, SOIL AND LAKE FEEDBACKS

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Associated paper: Chandan & Peltier, 2020 GRL

Physics
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SSHRC CRSH

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CRSNG

African humid period/Green Sahara

Evidence for green Sahara:

- **Vegetation reconstructions**
  (Hoelzmann et al., 1998, Harrison & Bartlein 2012)
- **Palæo lake reconstructions**
  (Lézine et al., 2011, Holmes & Hoelzmann, 2017)
- **Desiccated ancient river valleys**
  (Neumann 1989, Kröpelin 2007)
- **Eolian deposits in sedimentary cores in the Atlantic**
  (deMenocal et al., 2000)
- **Leaf wax deposits in sedimentary cores in the Atlantic**
  (Tierney et al., 2017)
- **Cave paintings depicting lush landscapes and fauna**
  (Barth 1857, Almásy 1934, di Lernia 2017)
- **Archæological findings supporting human habitation in presently uninhabited regions**
  (Gabriel 1987, Hoelzmann et al., 2001, Kröpelin 2004, Serano et al., 2008, Dunne et al., 2012, Manning & Timpson, 2014)

Image: NASA

African humid period/Green Sahara

Existing studies:

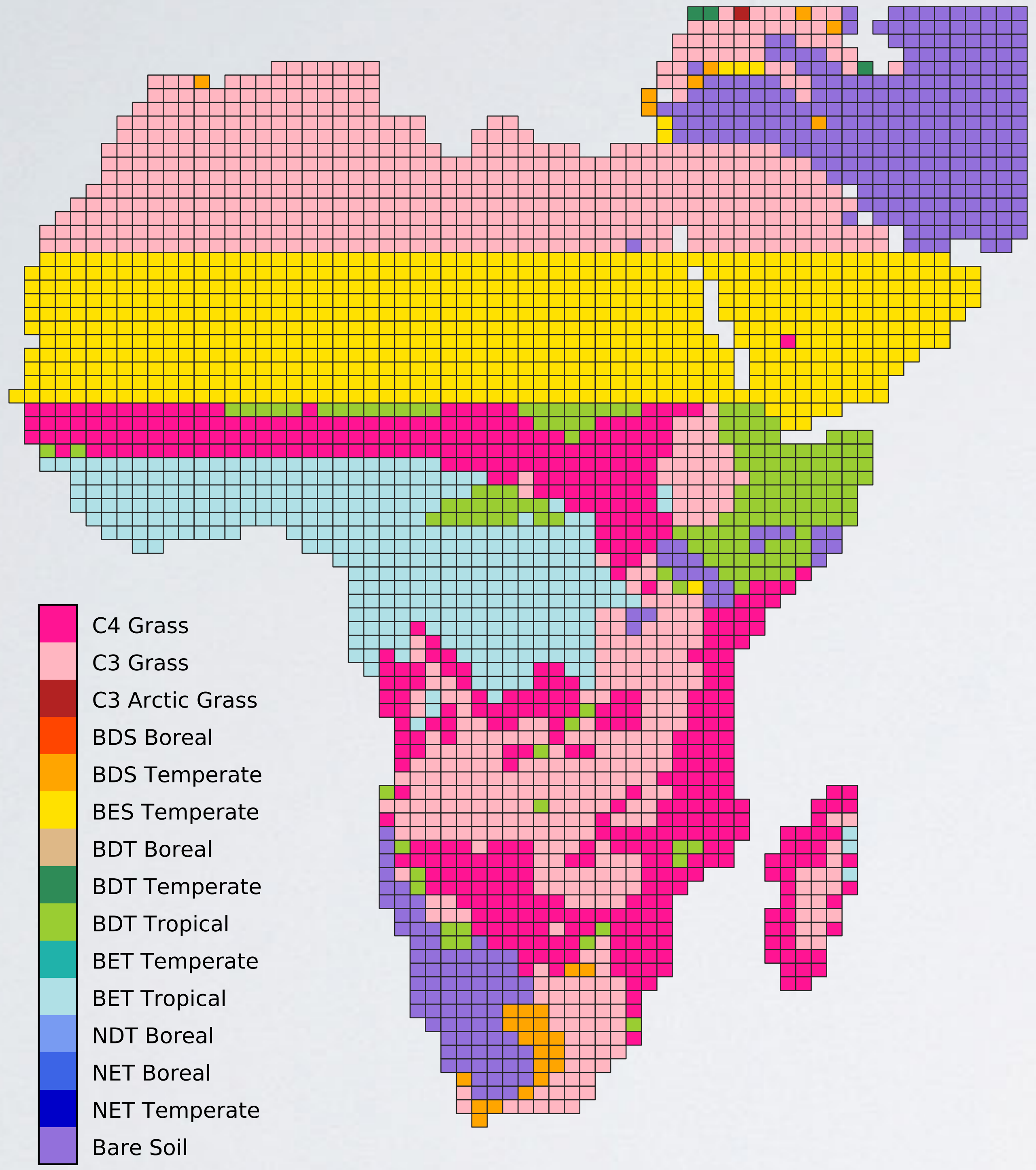
- Feedbacks important
- Only minor enhancement to precipitation from orbital changes in the absence of feedbacks
- Feedbacks from land surface most important: Vegetation, lake and soil changes
- Extensively studied. BUT….
- Collective feedback from these feedbacks rarely studied
- Those that did, are very old now; revised assessment needed
- Understanding of mid-Holocene land surface has changed a lot since these studies

Image: NASA

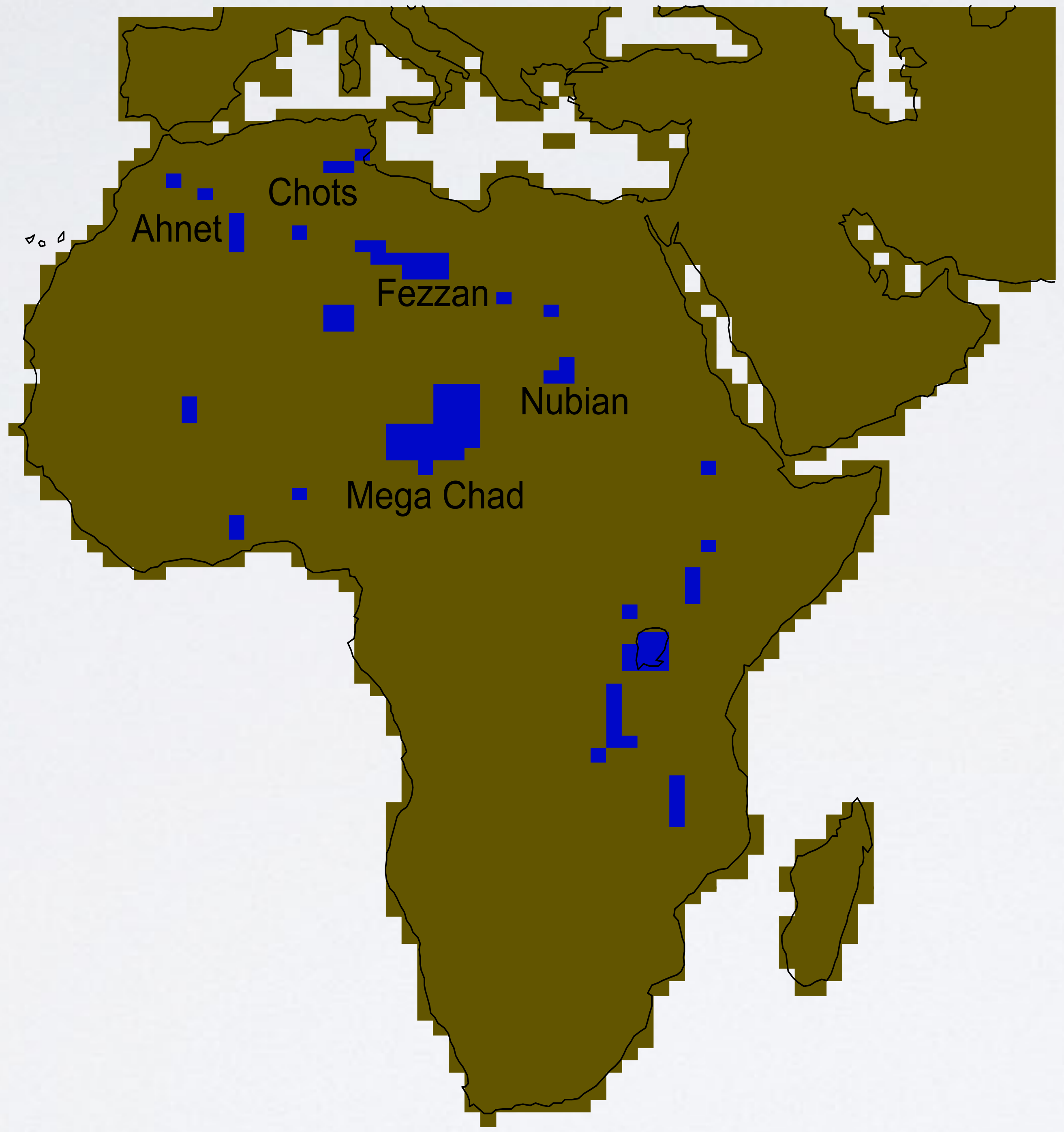
Modeling the mid-Holocene Africa

To simulate mid-Holocene Green Sahara we modify three land surface properties, in addition to orbital parameters and GHGs: vegetation, soil and lakes. Our model is the UofT version of CCSM4.

We change soil composition and soil colour (albedo) over northern Africa and the Arabian Peninsula. Dry soil albedo reduces from 18% to 9%.



mid-Holocene map of dominant plant functional types in GS



mid-Holocene lakes implemented in our model

Simulation	Description
PI_{REF}	*PI Control*
MH_{REF}	*Mid-Holocene Control*
MH_{V}	MH_{REF} + *Vegetation*
MH_{VS}	MH_{V} + *Soil*
MH_{VL}	MH_{V} + *Lakes*
MH_{VSL}	MH_{V} + *Soil* + *Lakes*

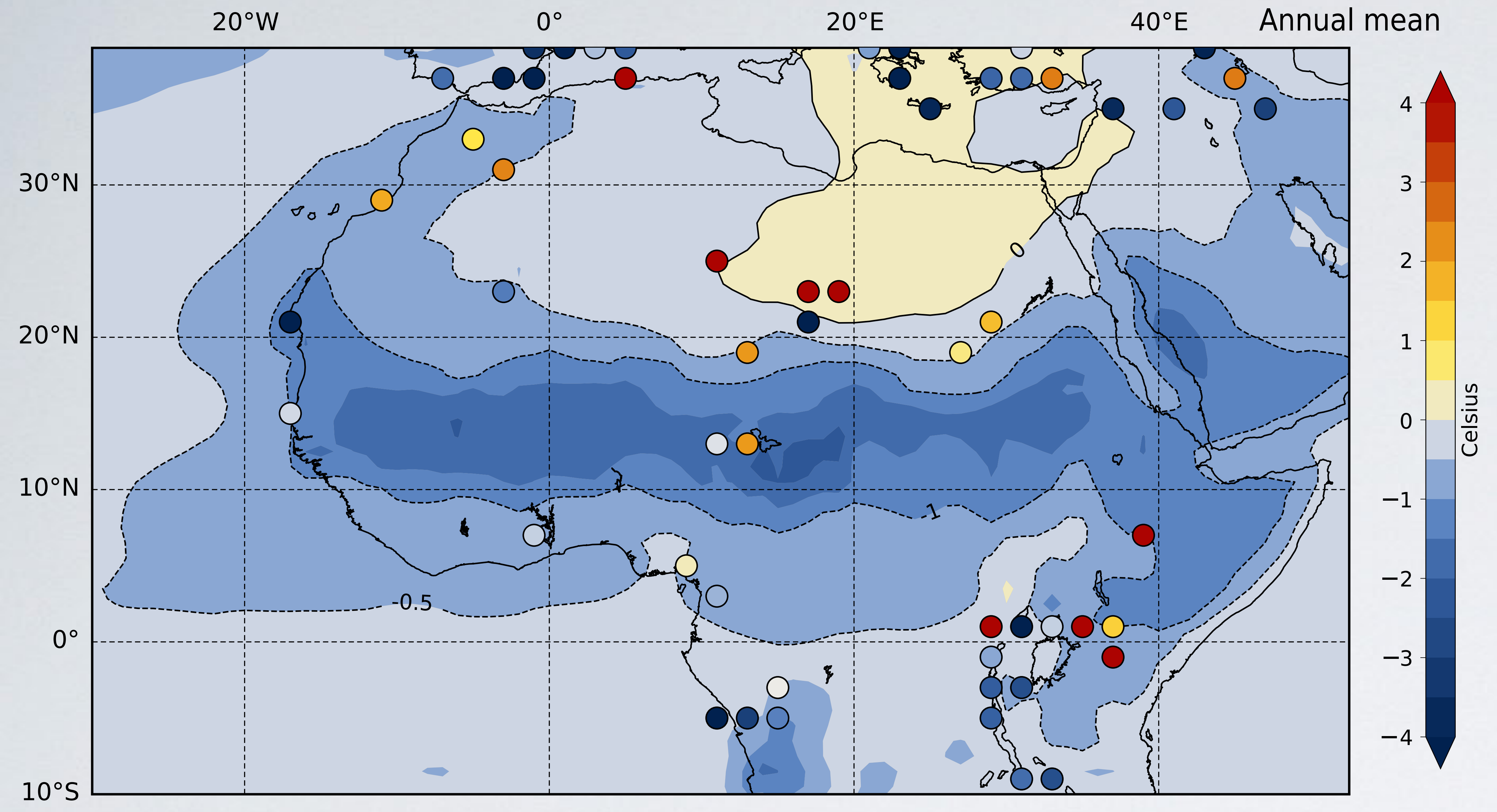
List of experiments performed for this study

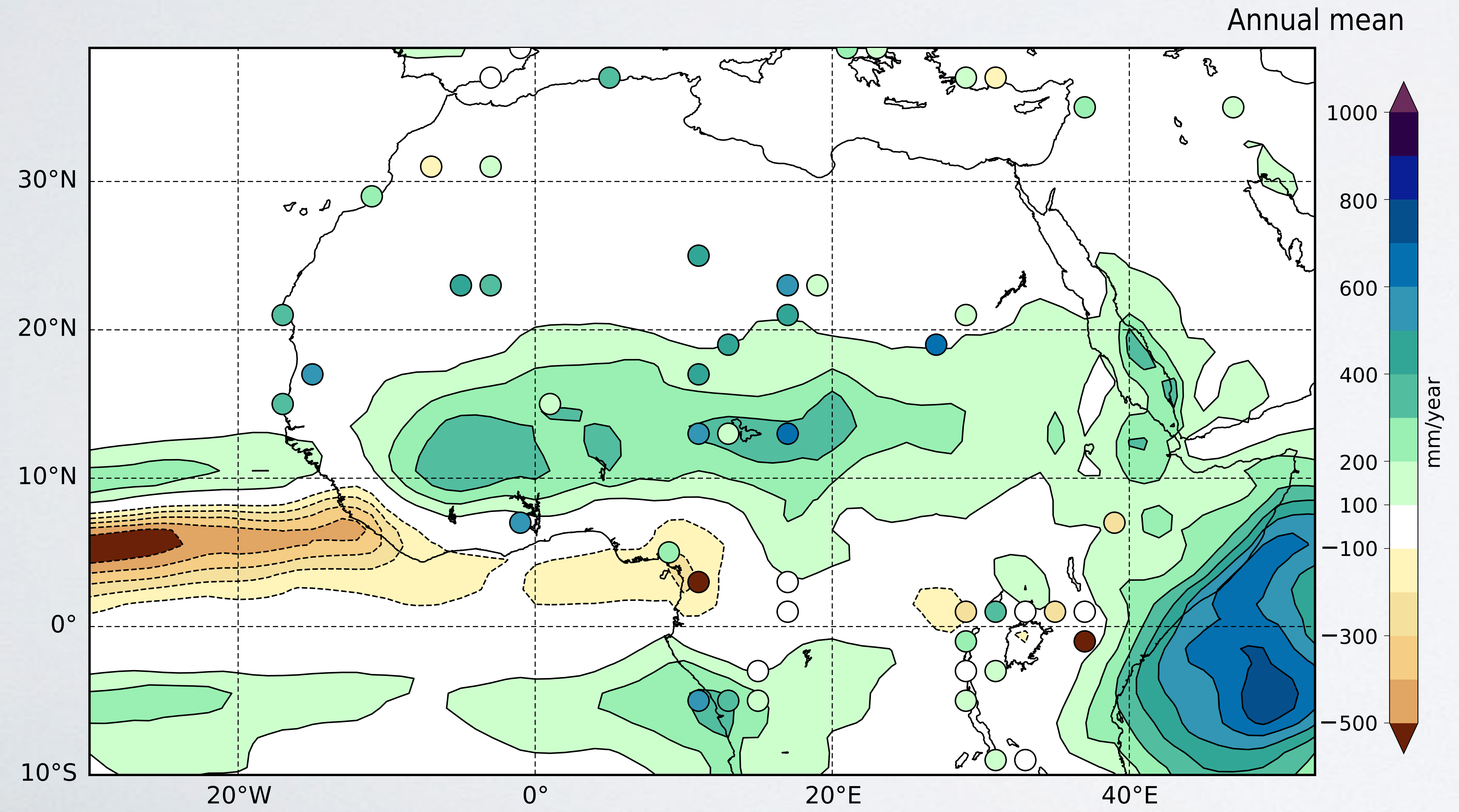
Orbital only (MH_{REF})

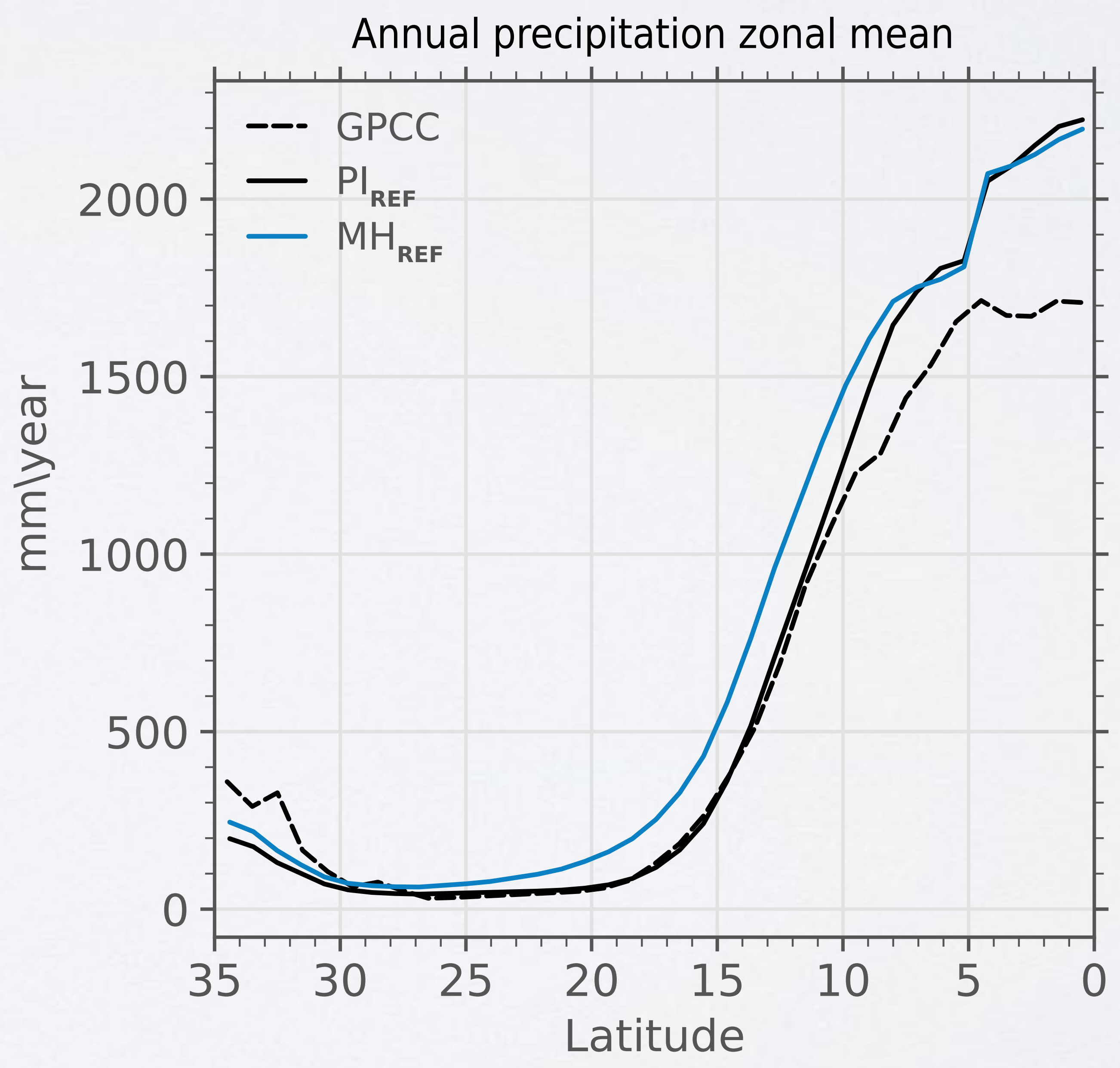
Only includes solar insolation changes from the mid-Holocene orbit

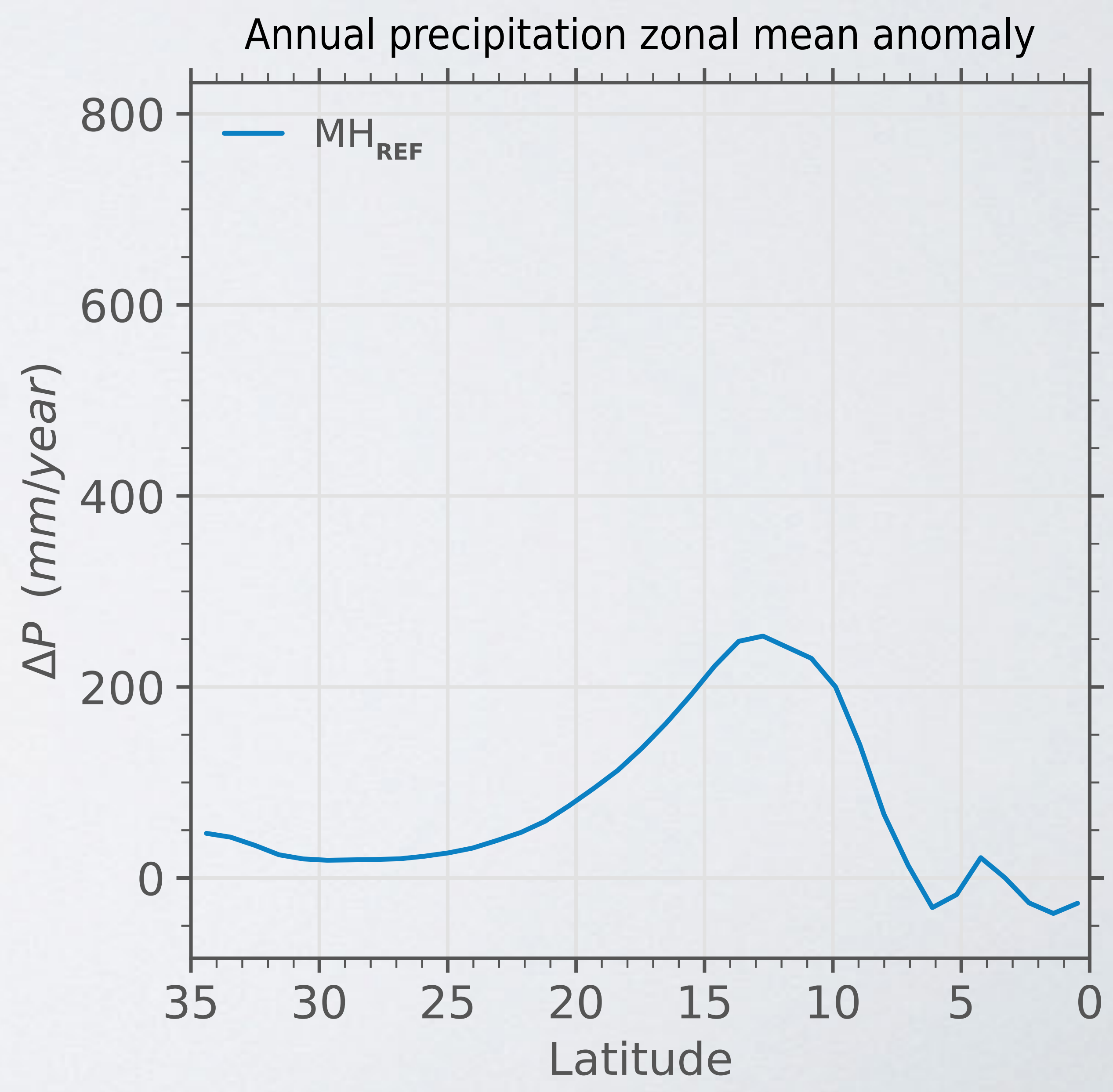
Slight enhancement to summer monsoon driven precipitation

On the annual mean, mid-Holocene northern Africa colder than today









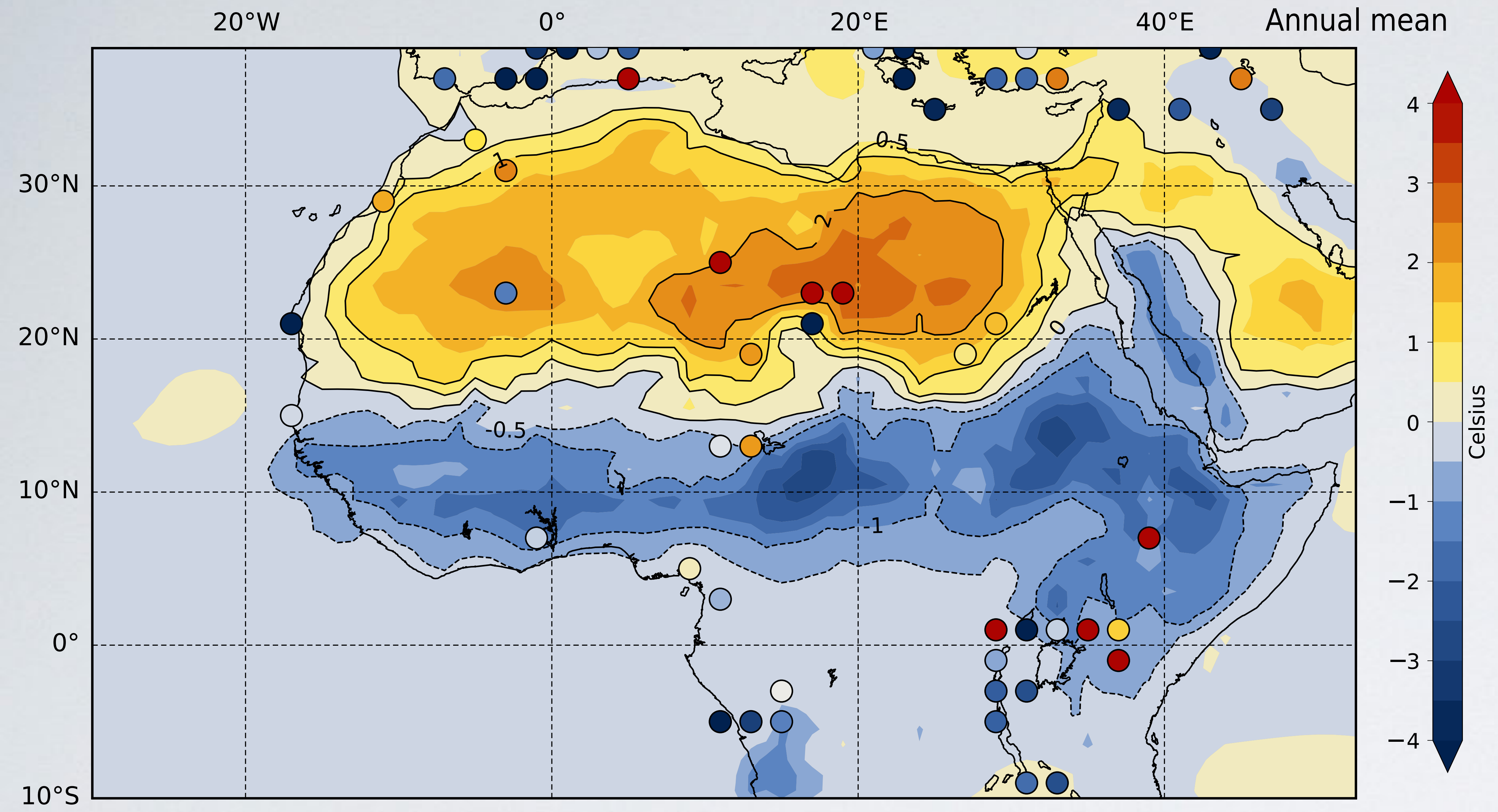
Orbital + Veg (MH_V)

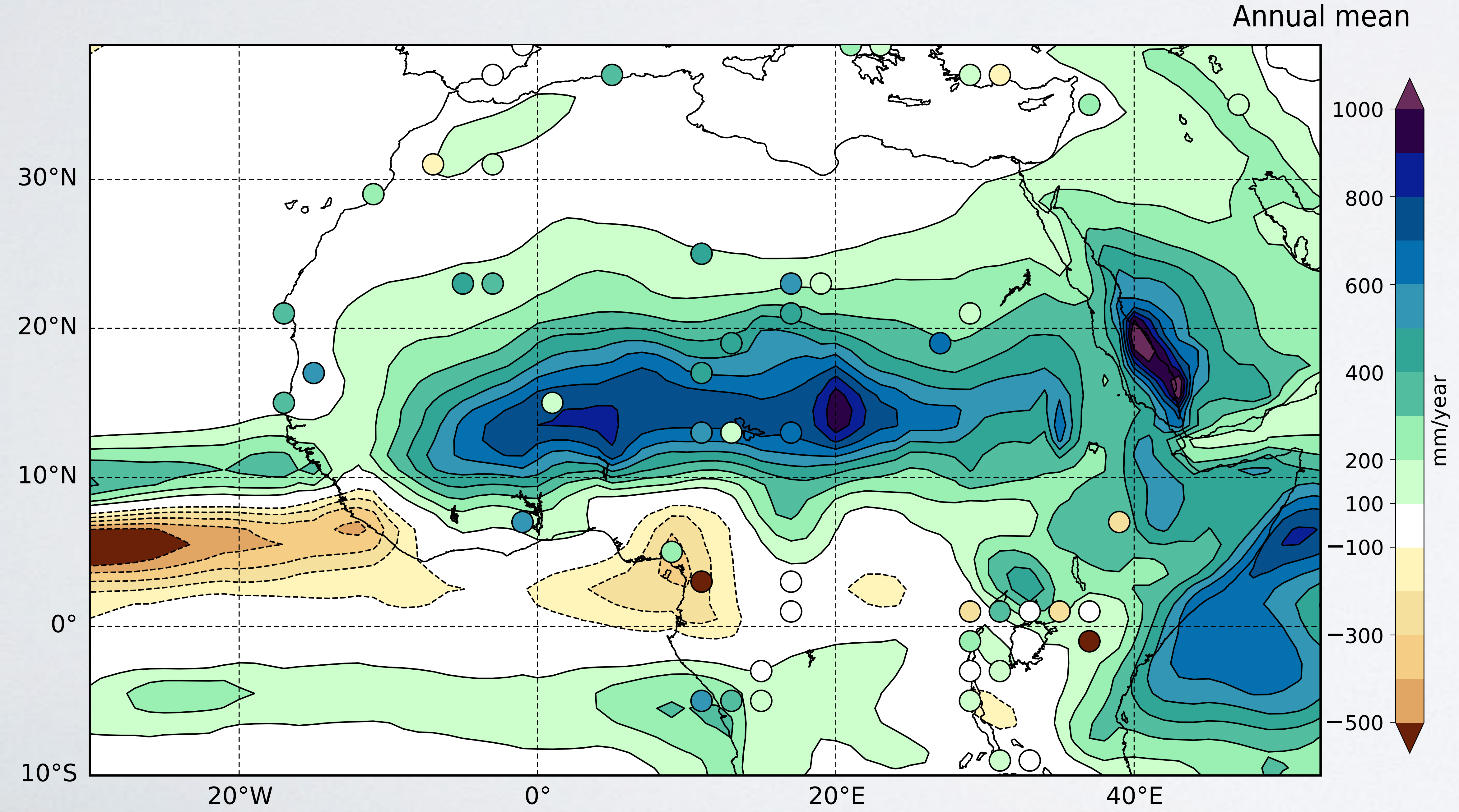
Solar insolation changes from the mid-Holocene orbit and prescribed mid-Holocene vegetation

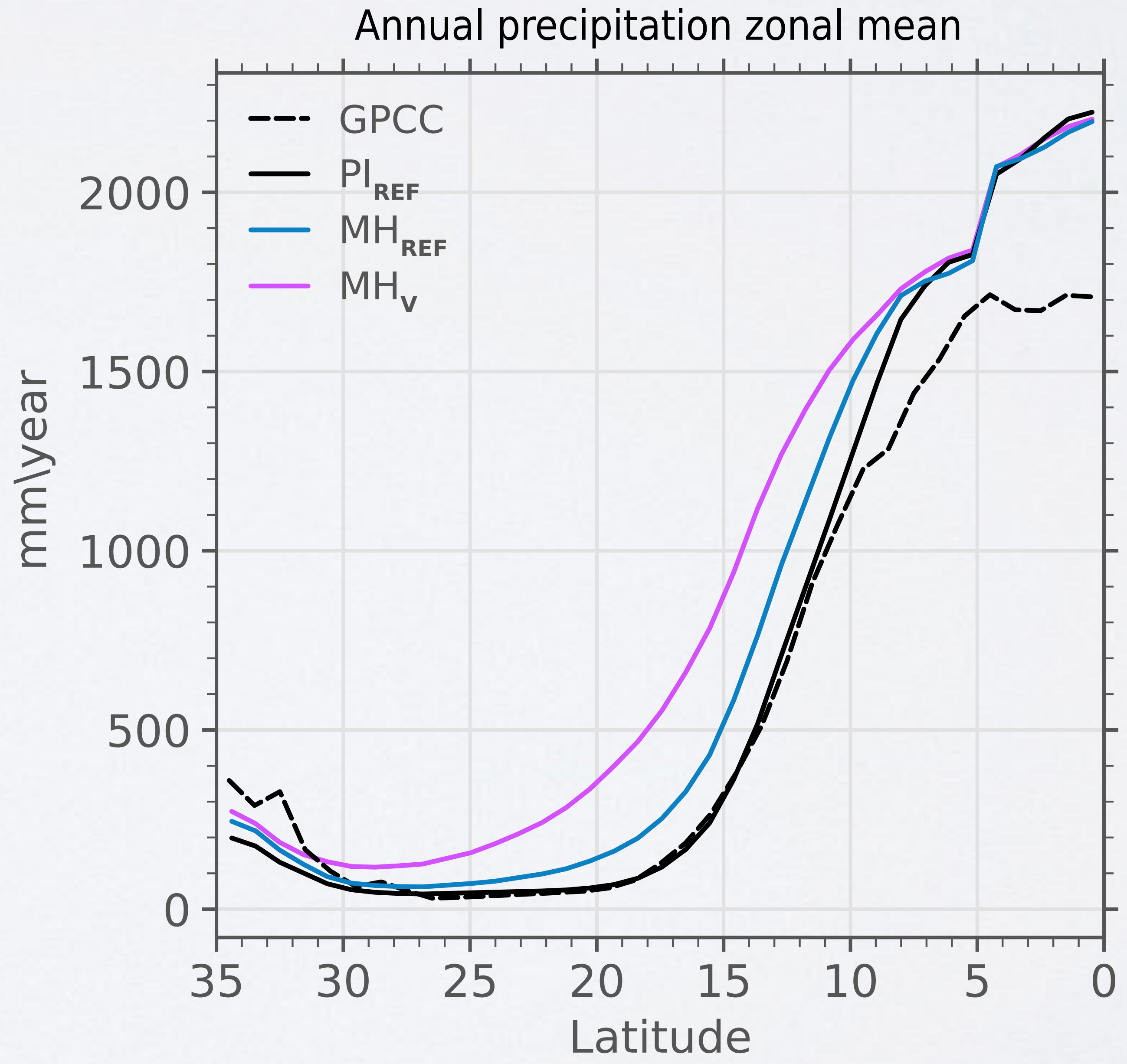
Further increase to summer monsoon driven precipitation

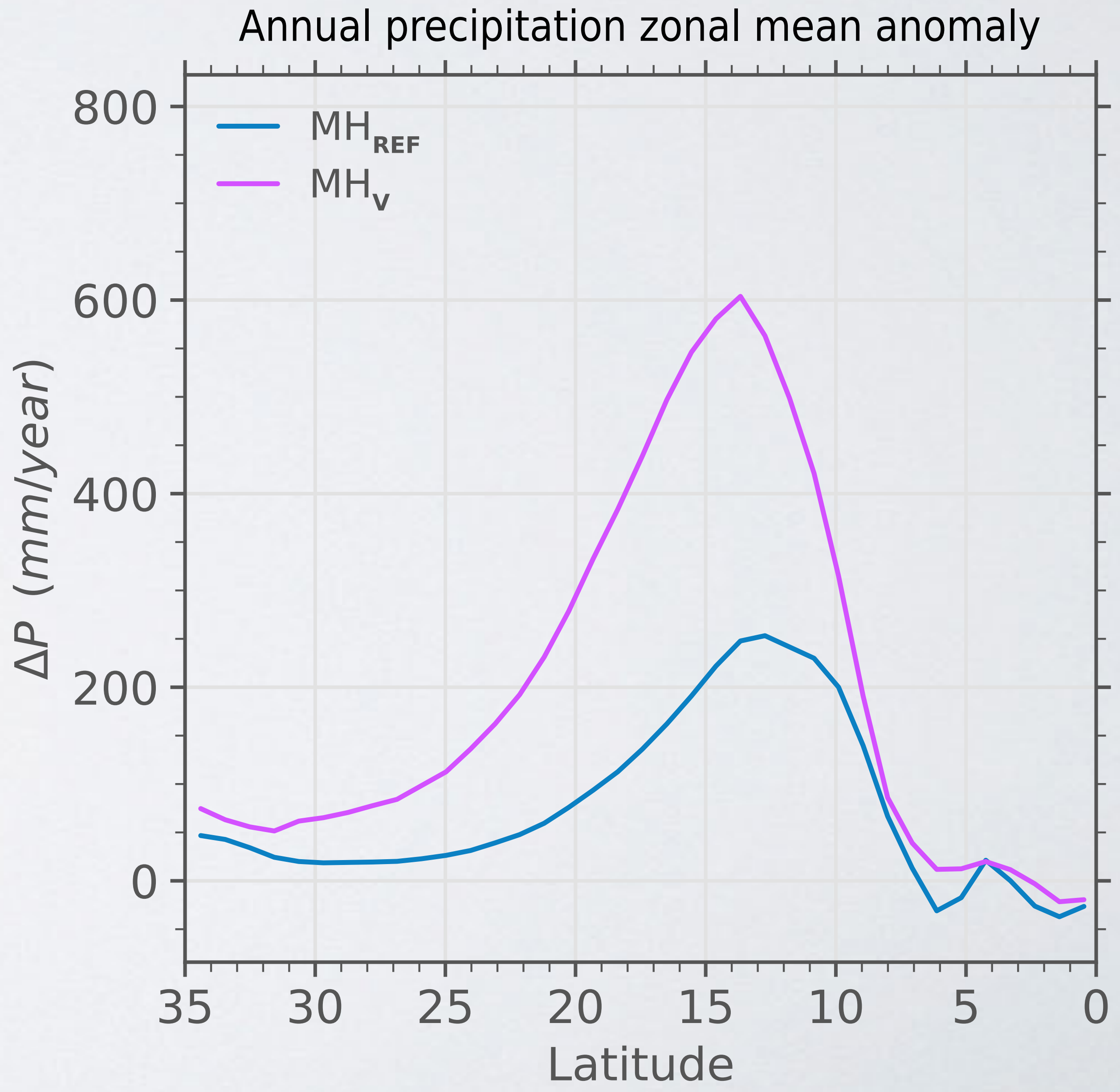
On the annual mean, mid-Holocene northern Africa becomes warmer than today

Beginning to reconcile with both precipitation and temp proxies









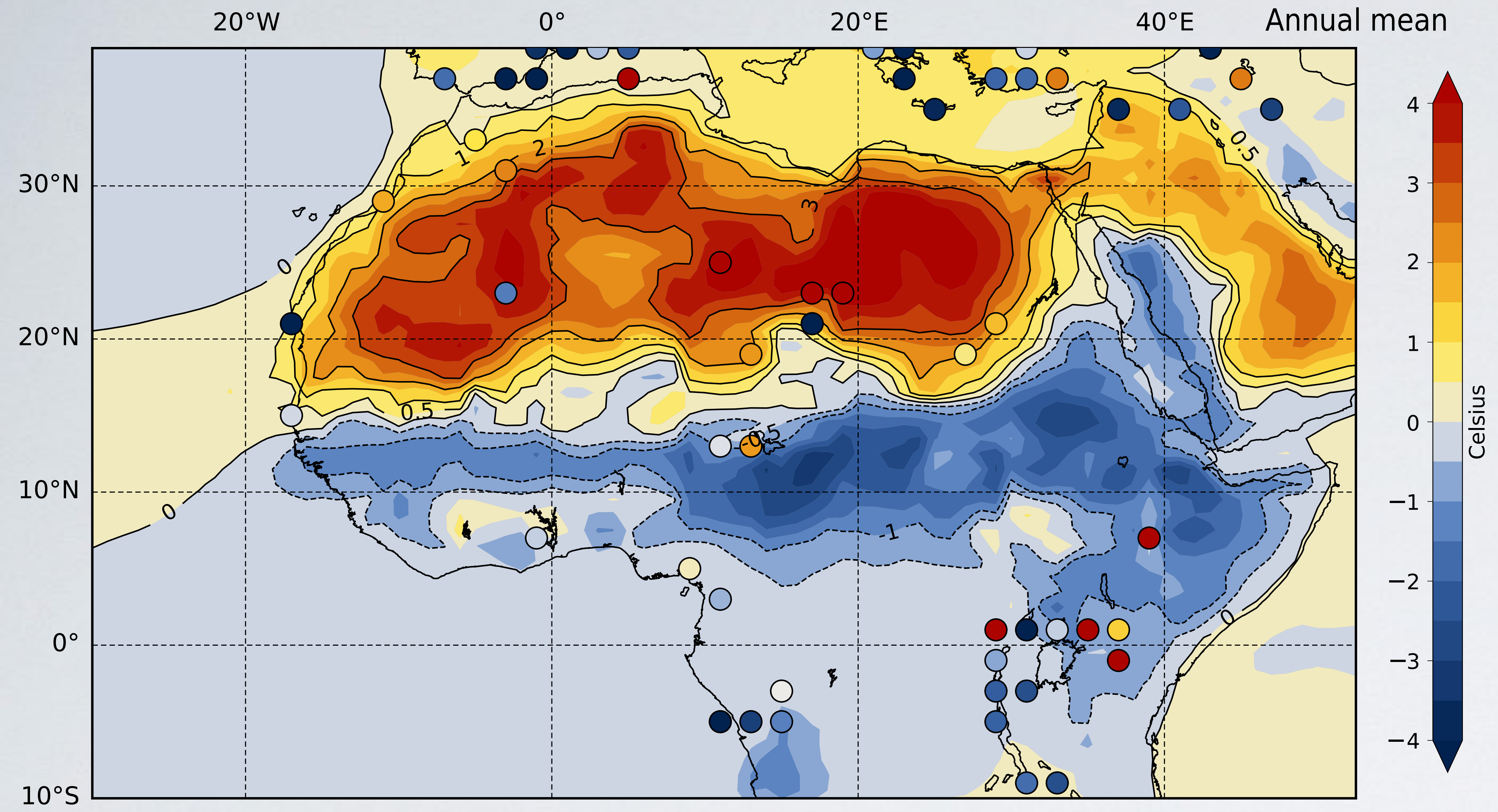
Orbital + Veg + Soil (MH_{VS})

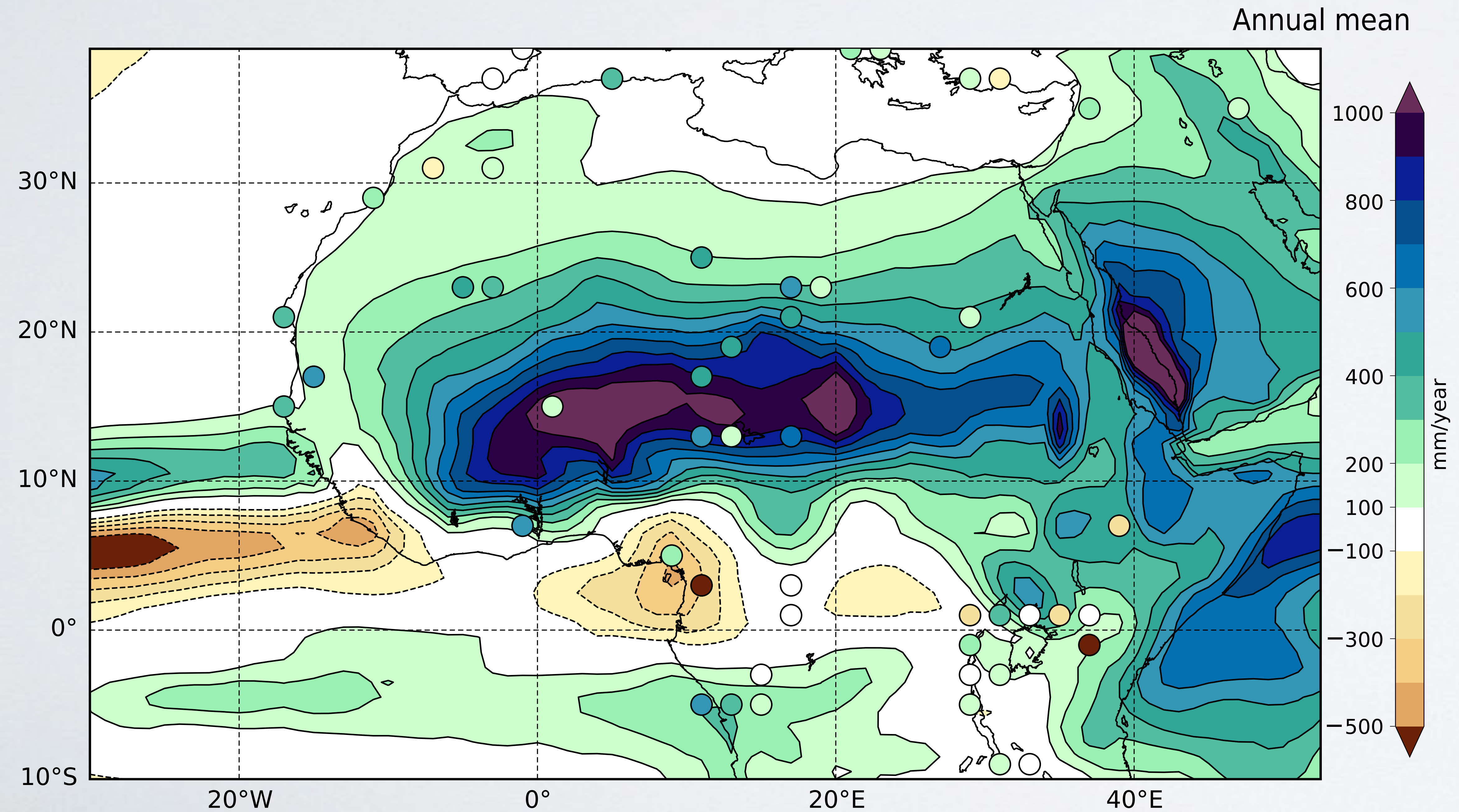
Solar insolation changes from the mid-Holocene orbit AND prescribed mid-Holocene vegetation AND changes to soil texture and composition

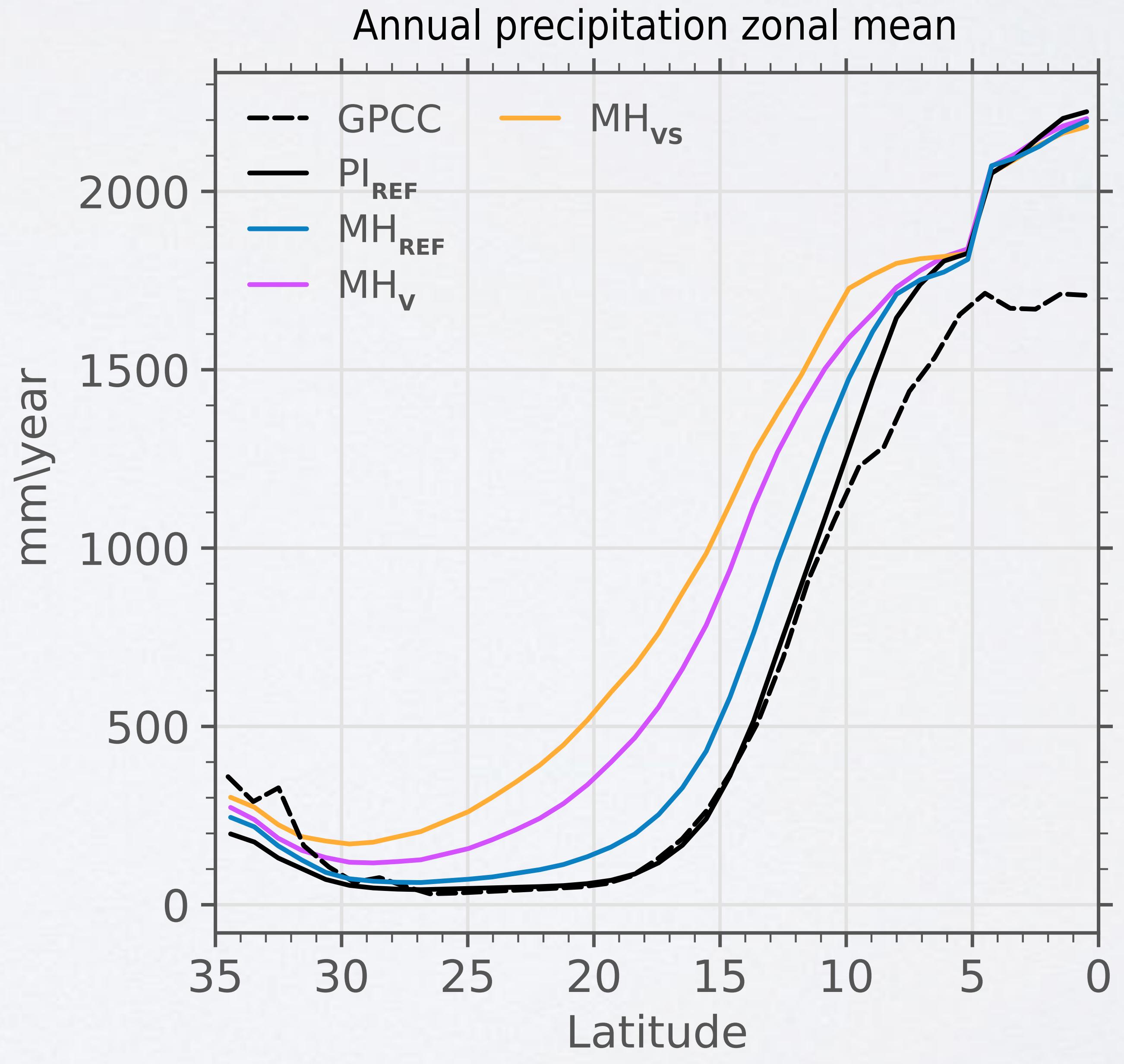
Further increase to summer monsoon driven precipitation

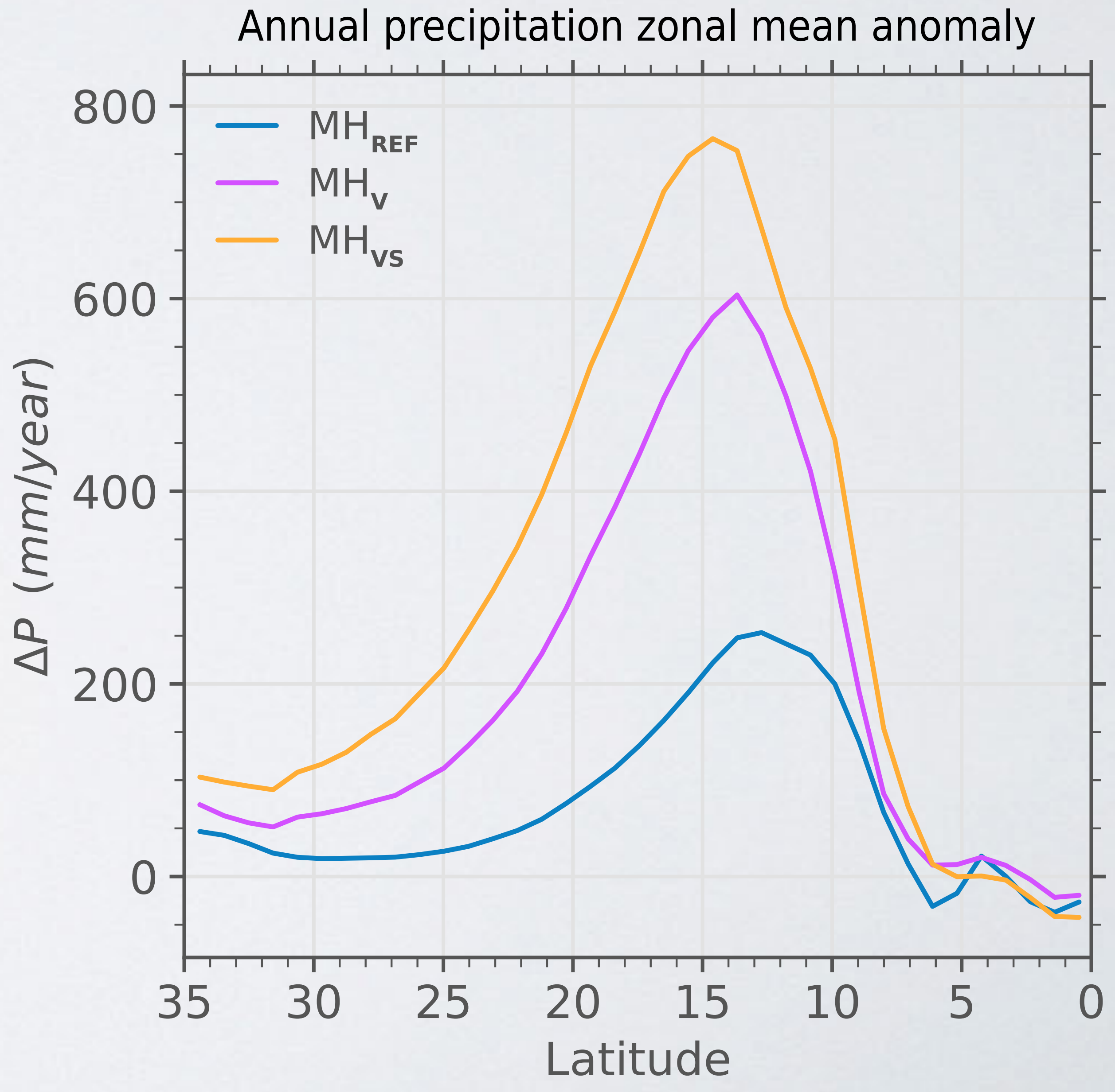
Sahara much warmer than today

Precipitation extends deeper into Sahara









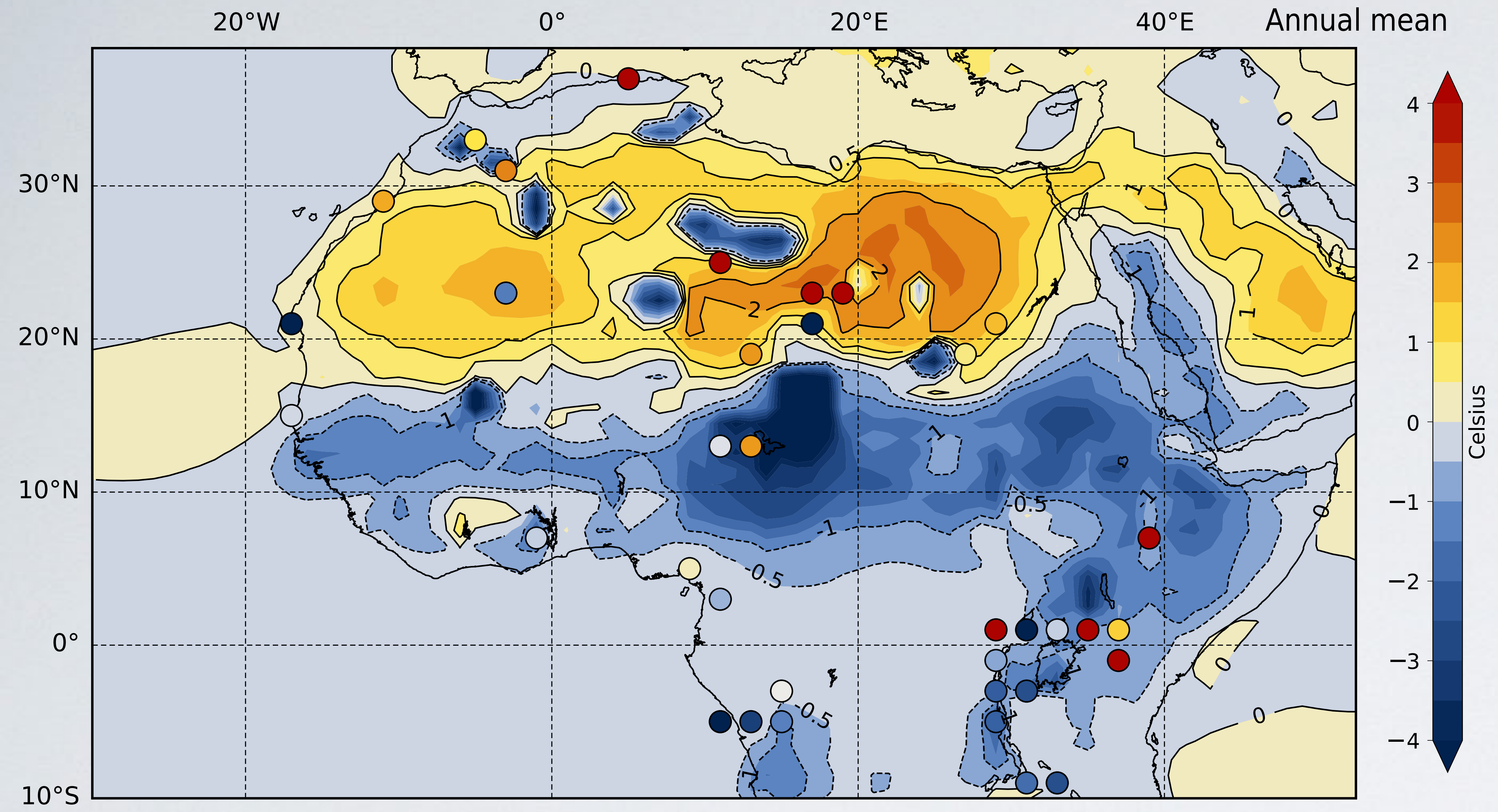
Orbital + Veg + Lake (MH_{VL})

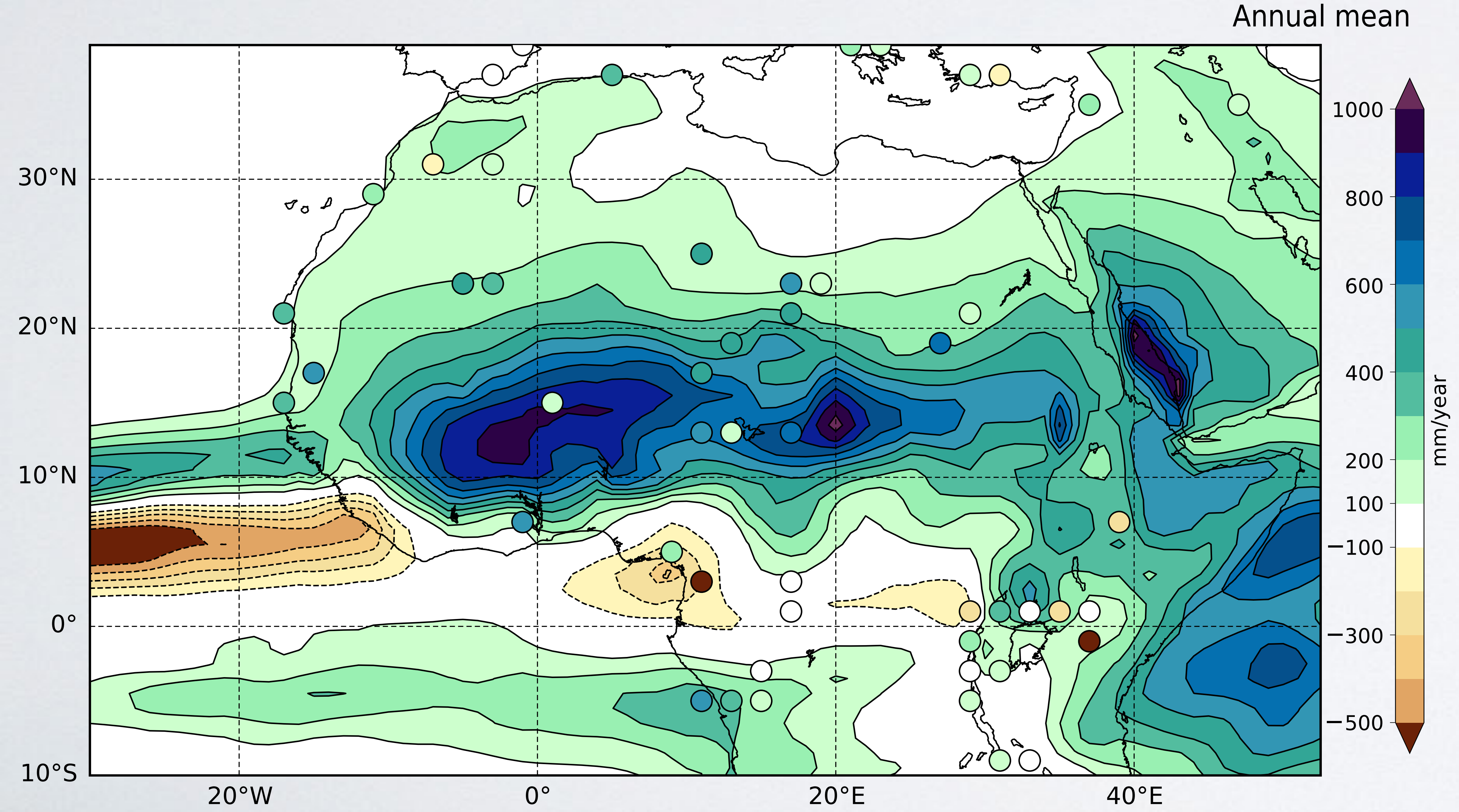
Solar insolation changes from the mid-Holocene orbit AND prescribed mid-Holocene vegetation AND mid-Holocene lakes

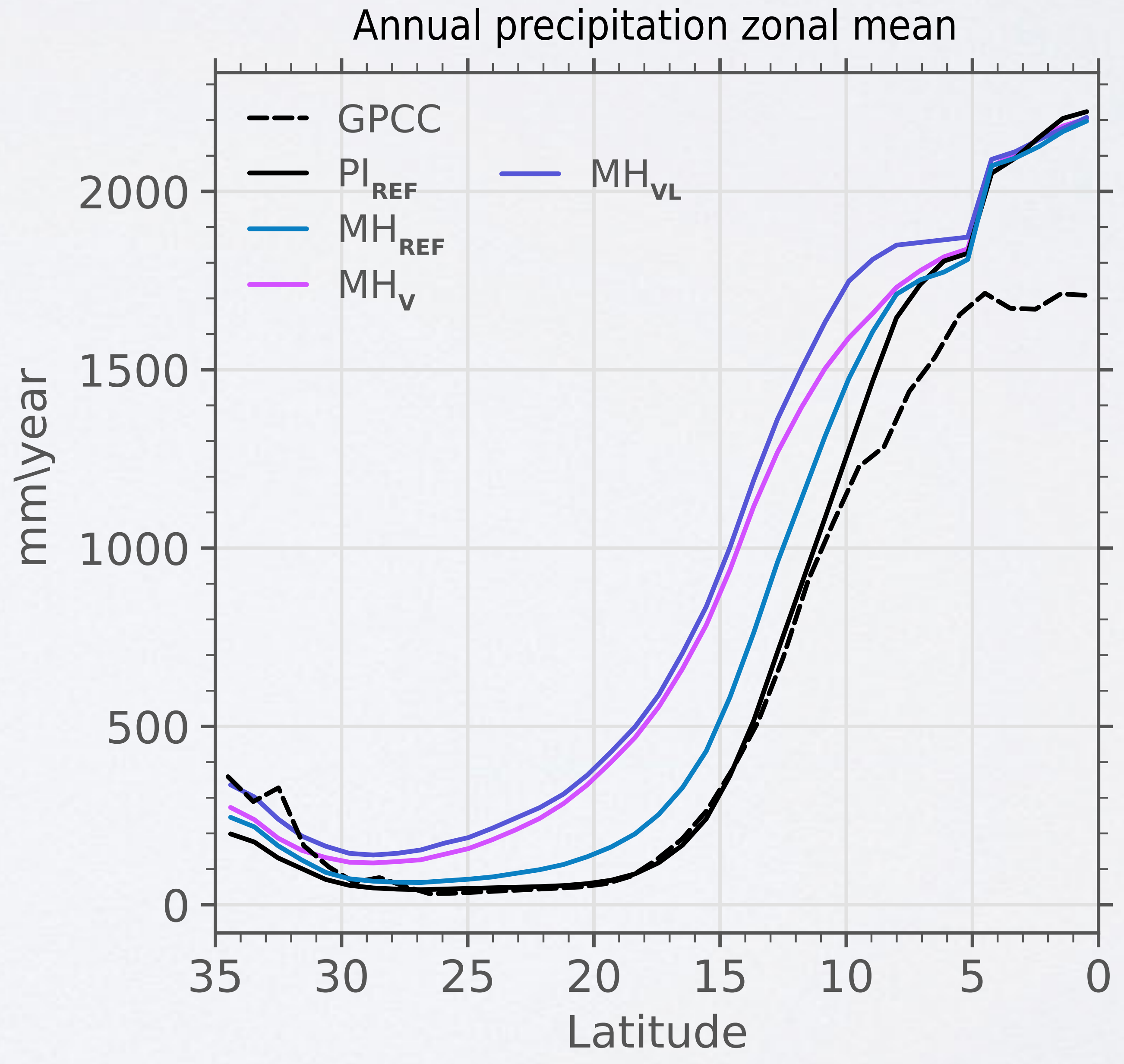
Further increase to summer monsoon driven precipitation

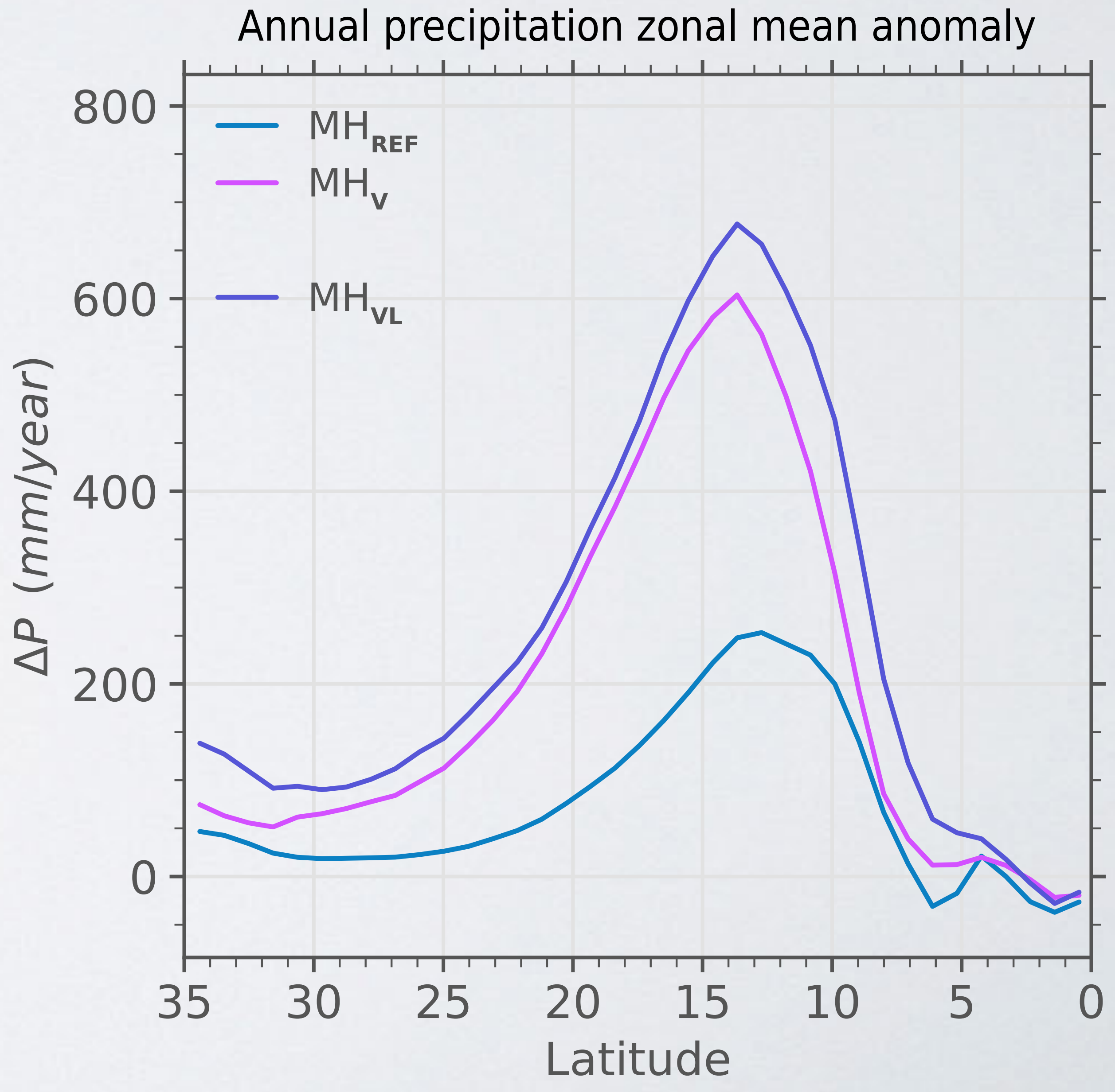
Heterogeneity in temperature field somewhat resembling proxies

Slight impact on precipitation amplitude and latitudinal extent





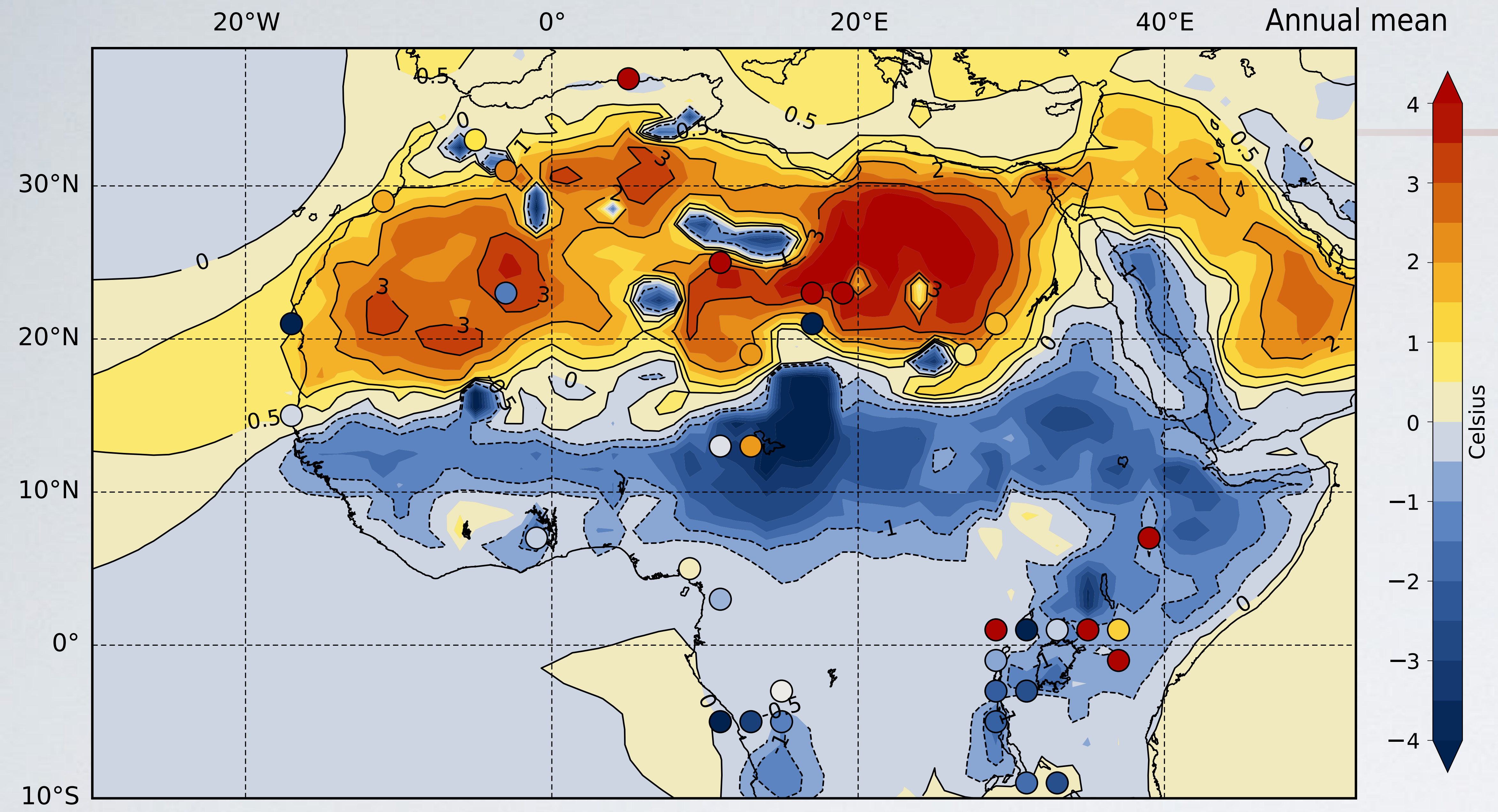


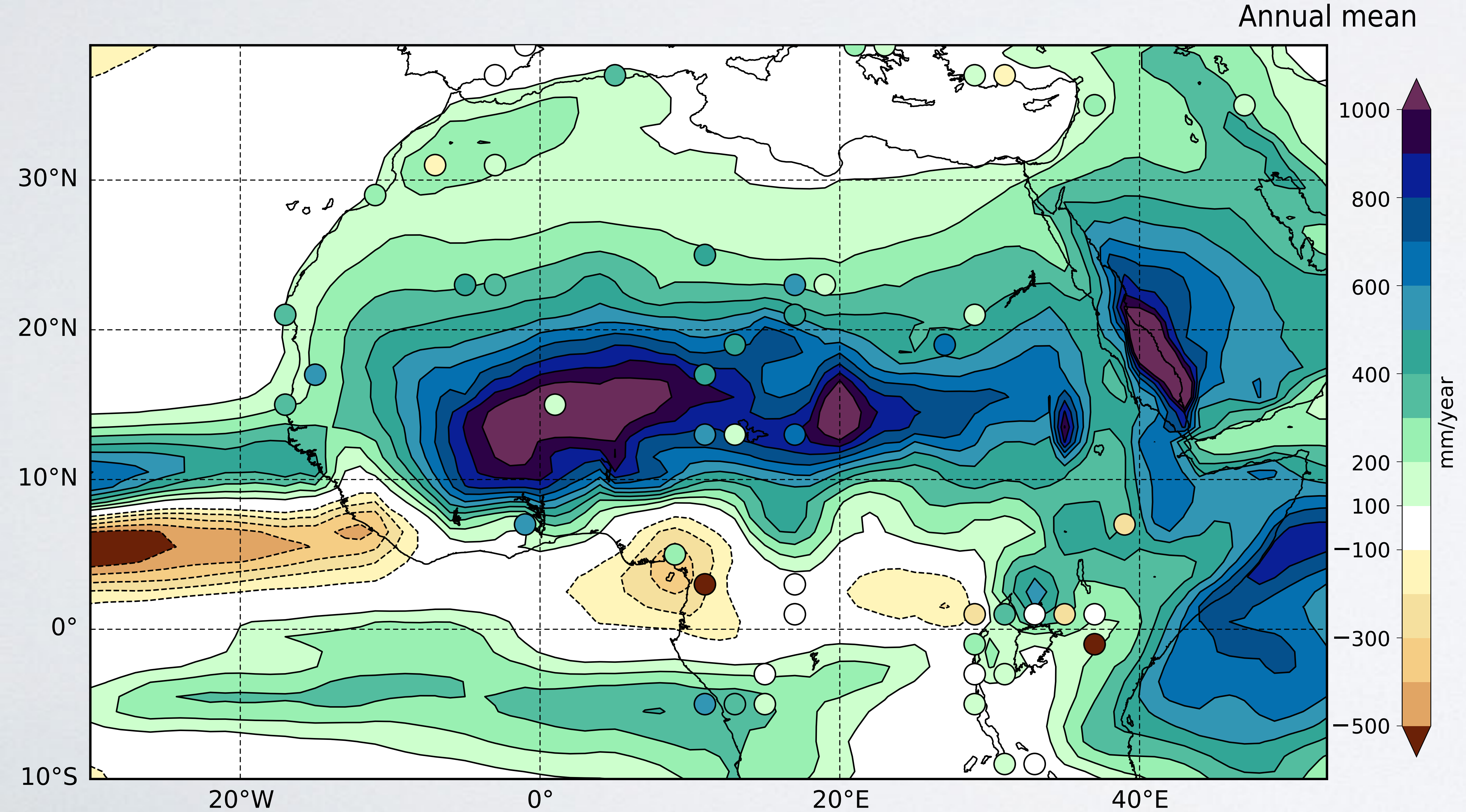


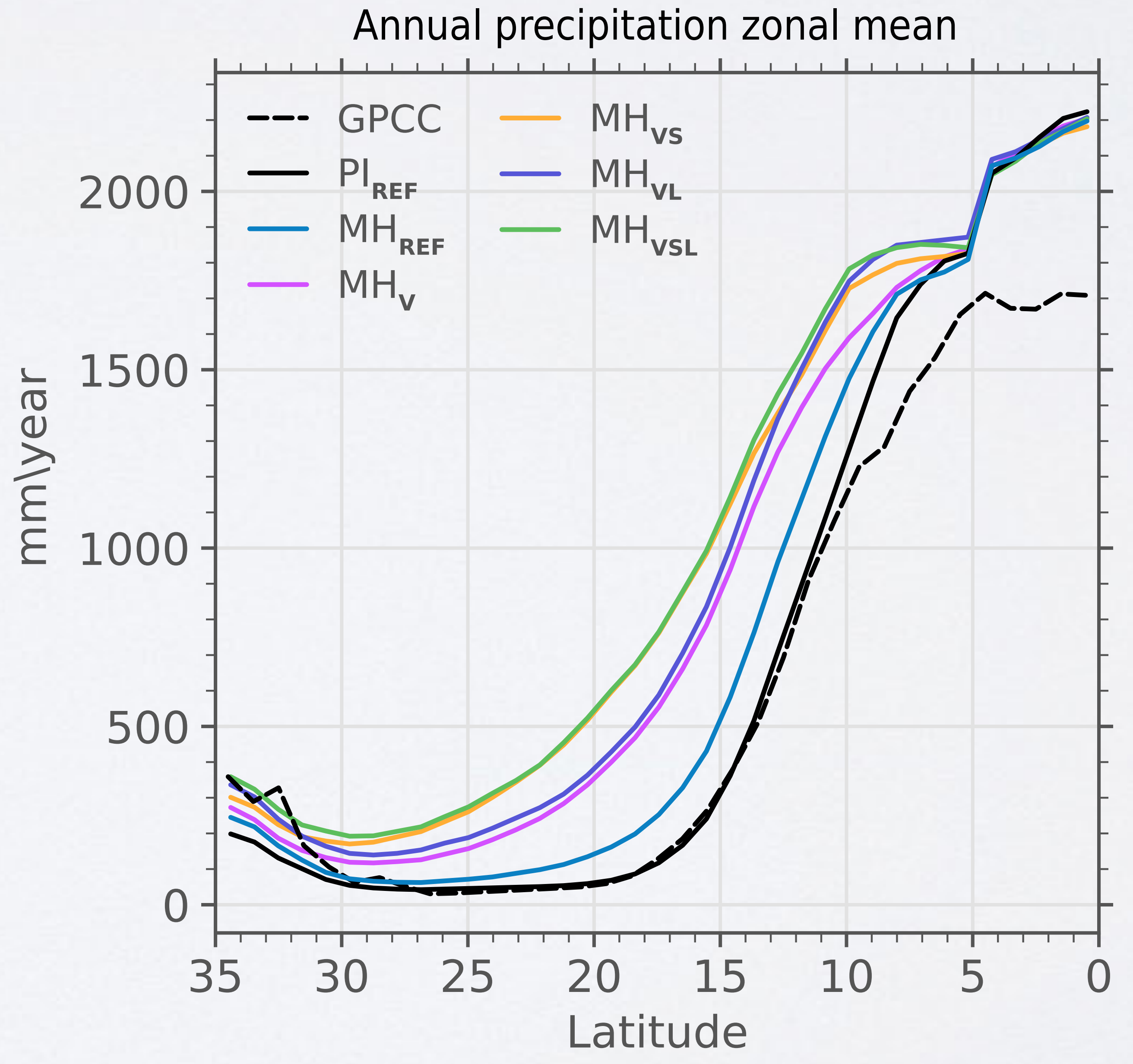
Orbital + Veg + Soil + Lake (MH_{VSL})

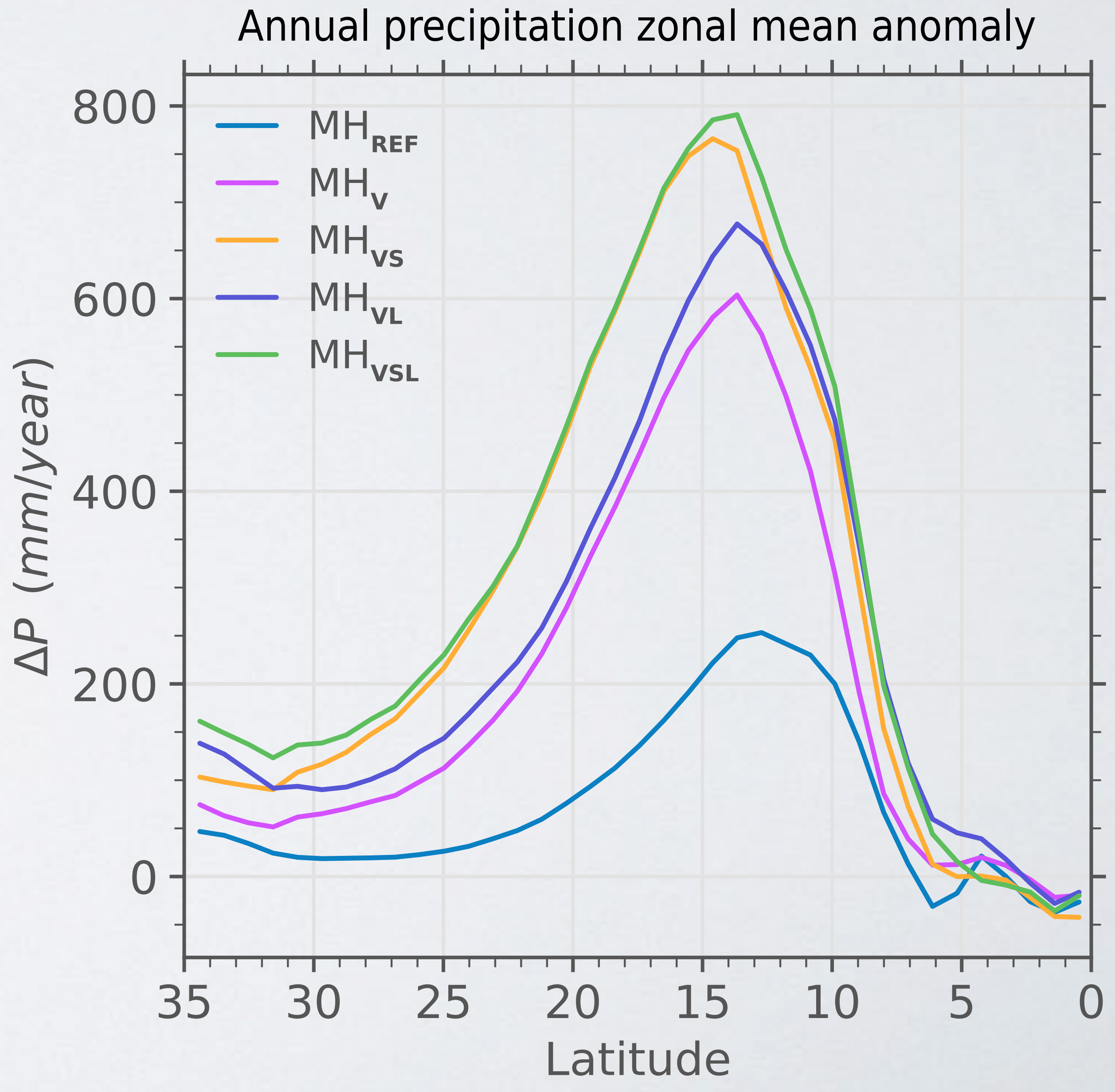
Solar insolation changes from the mid-Holocene orbit AND prescribed mid-Holocene vegetation AND changes to soil texture and composition AND mid-Holocene lake

Small further increase in precipitation compare to MH_{VS}

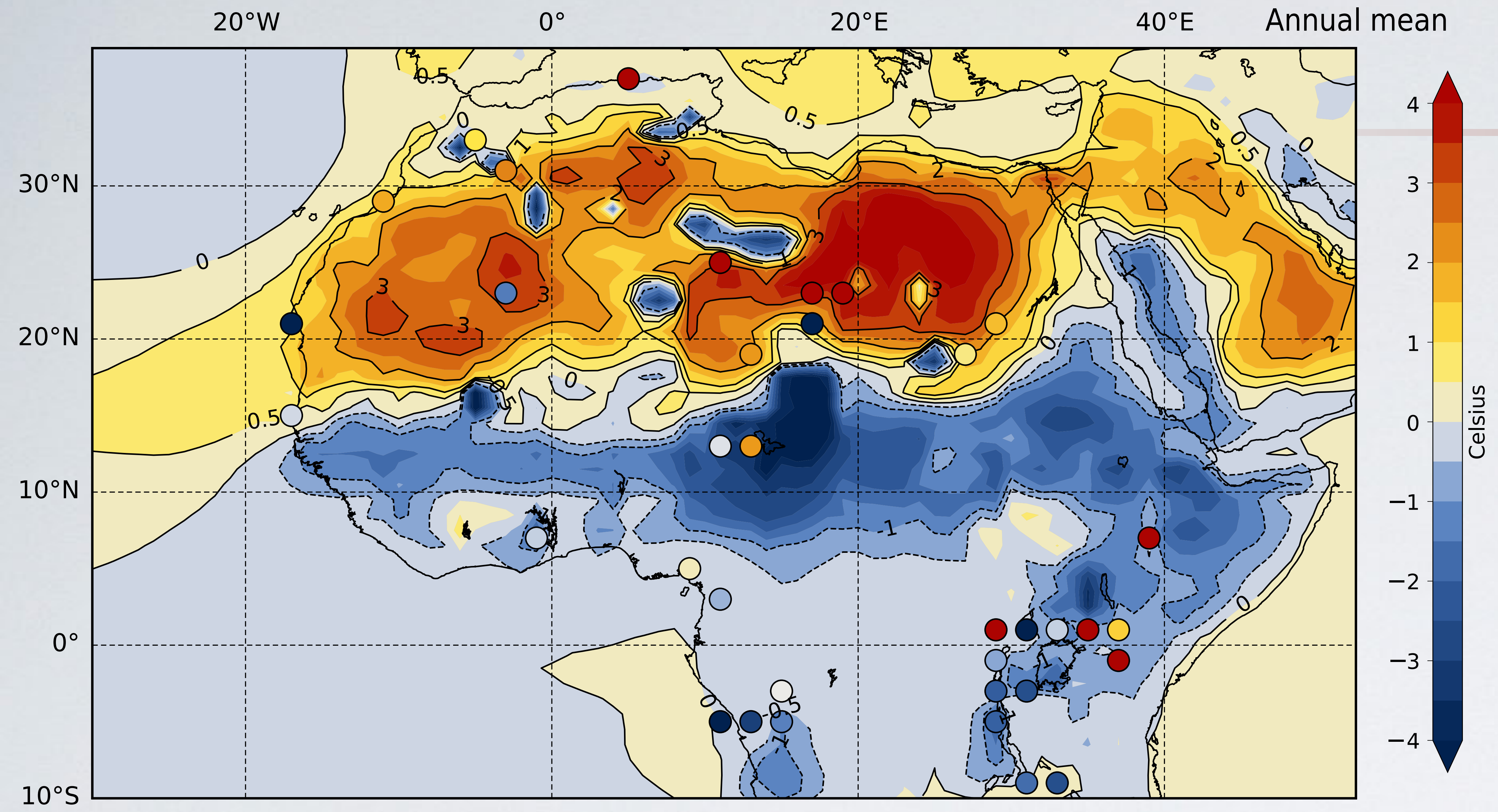


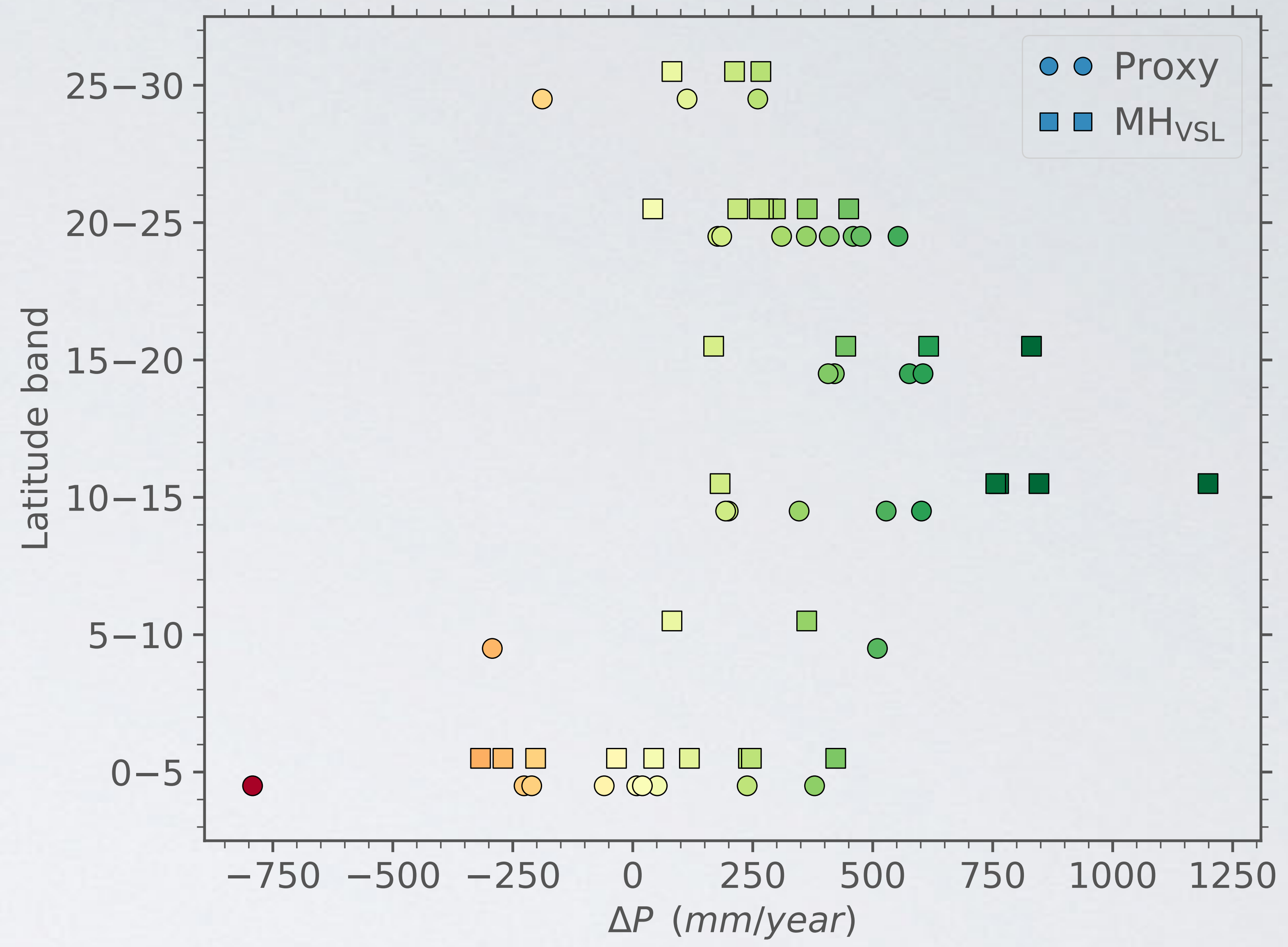


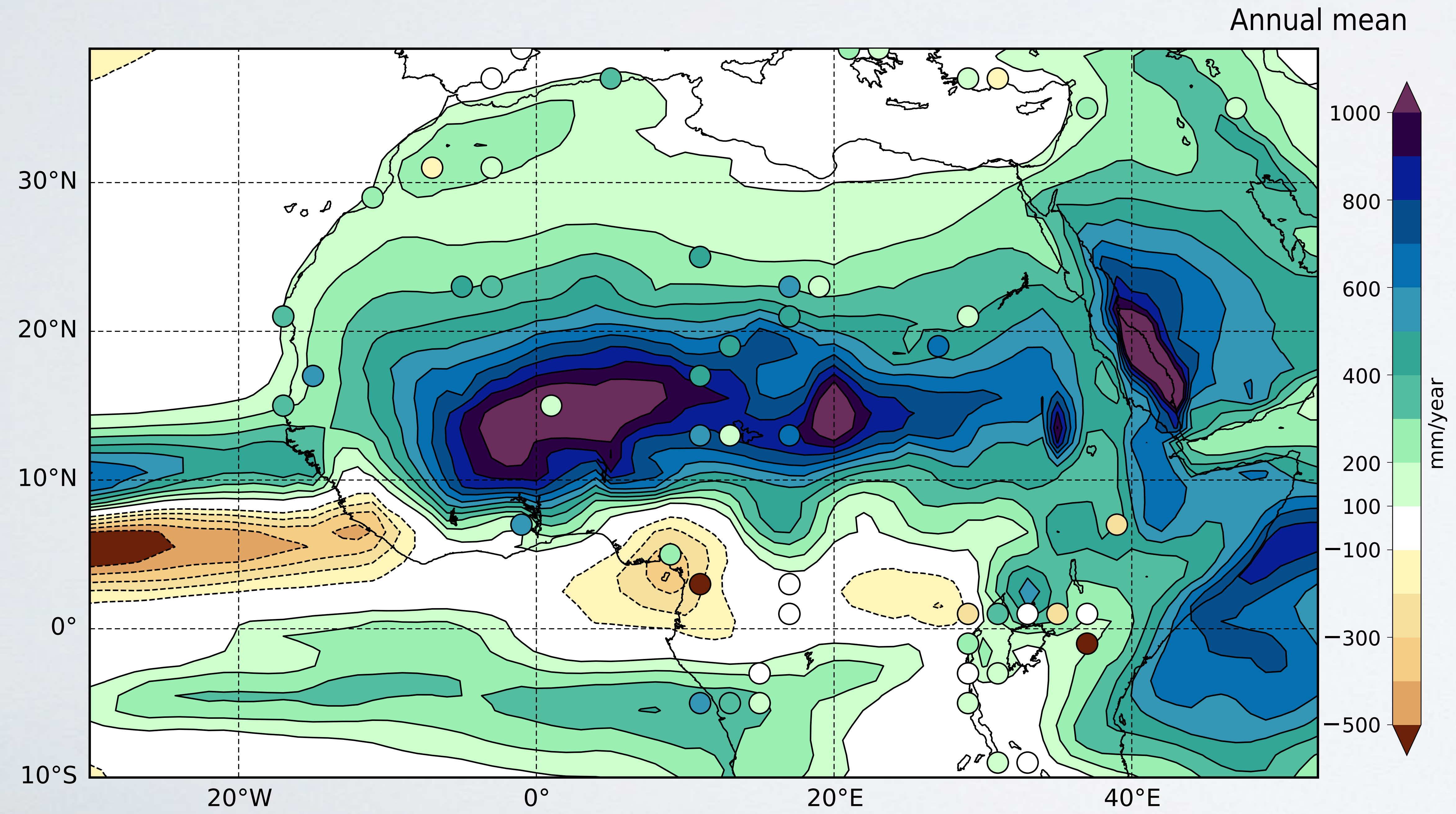


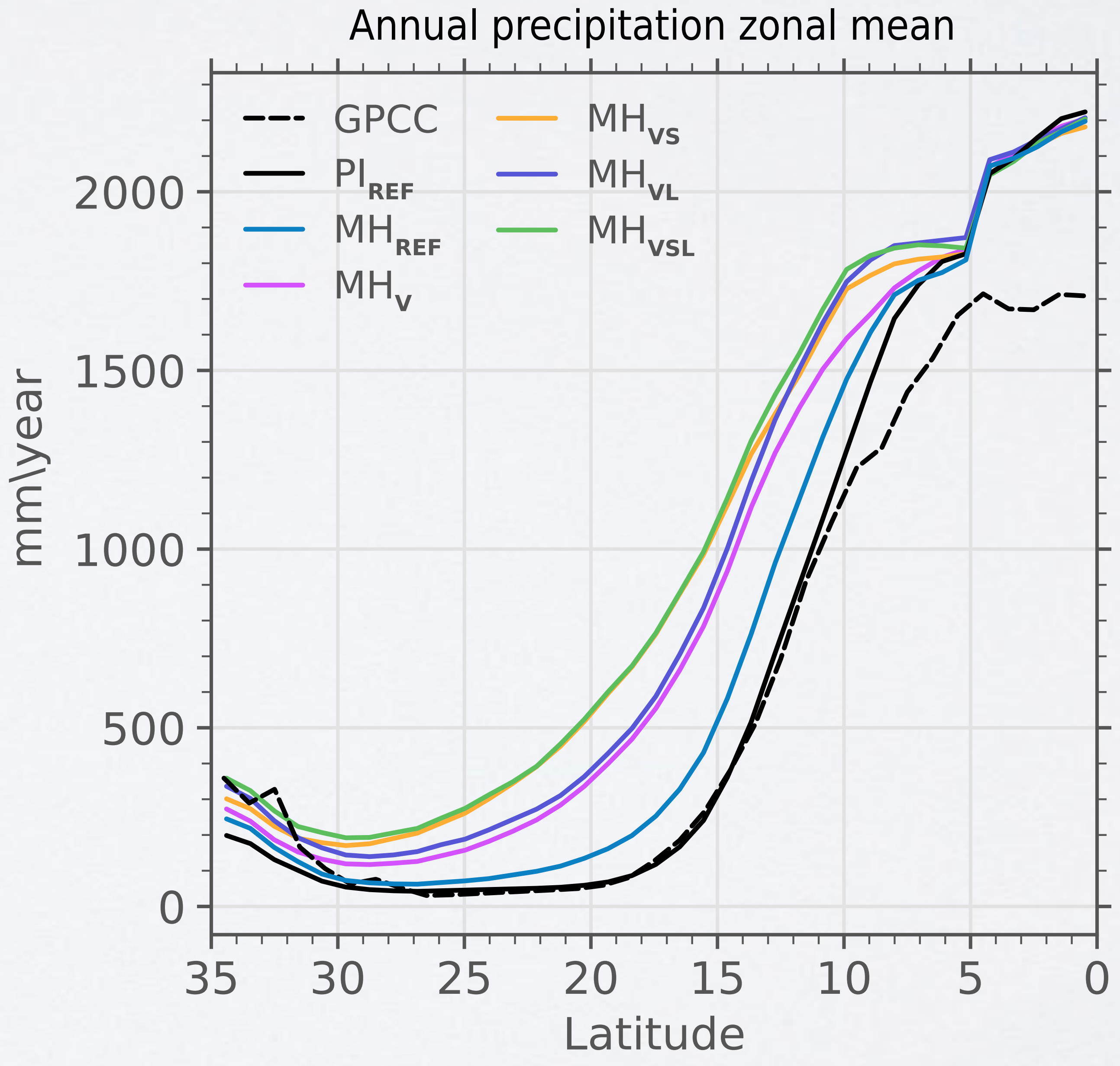


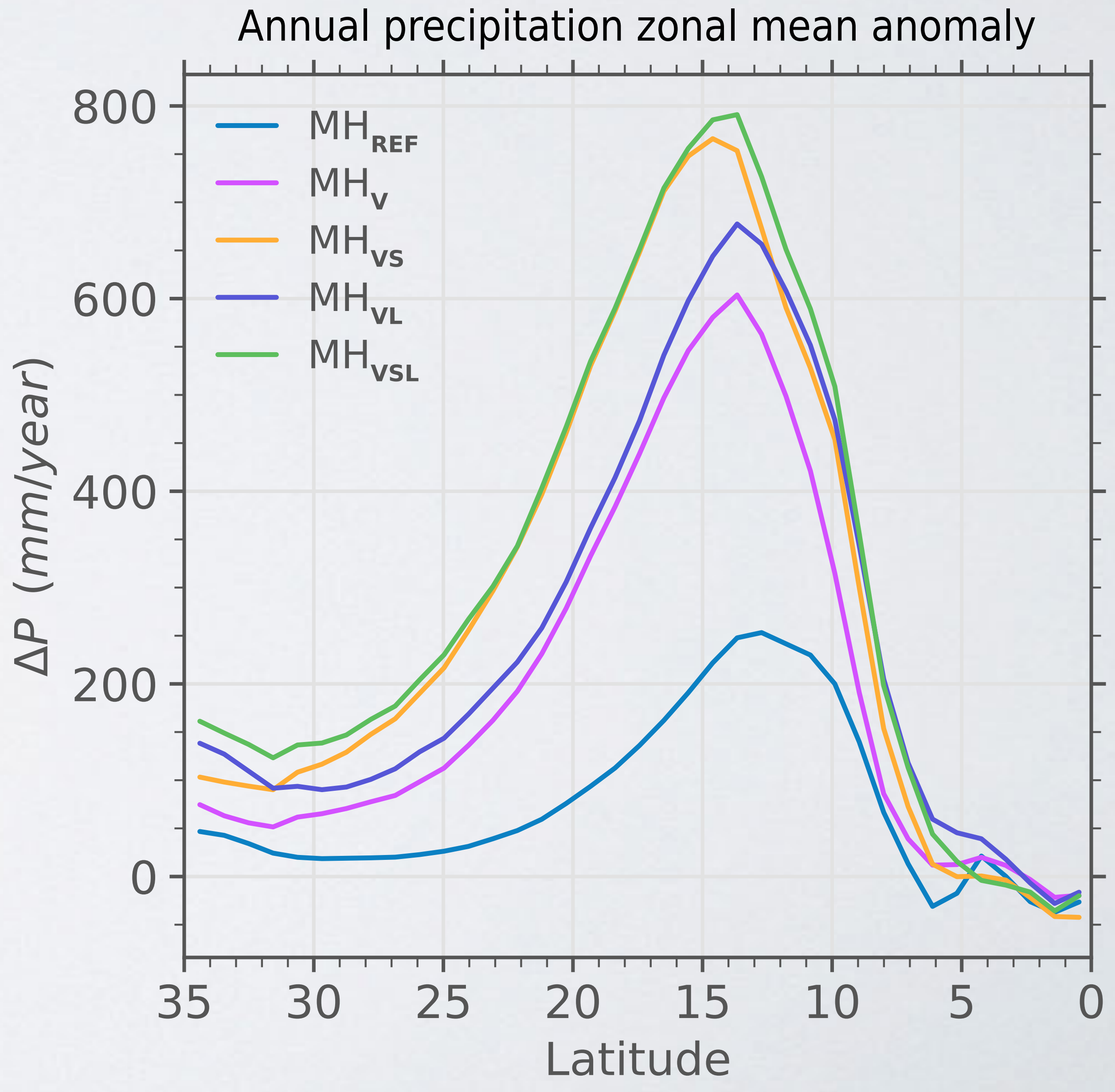
Orbital + Veg + Soil + Lake (MH$_{VSL}$)











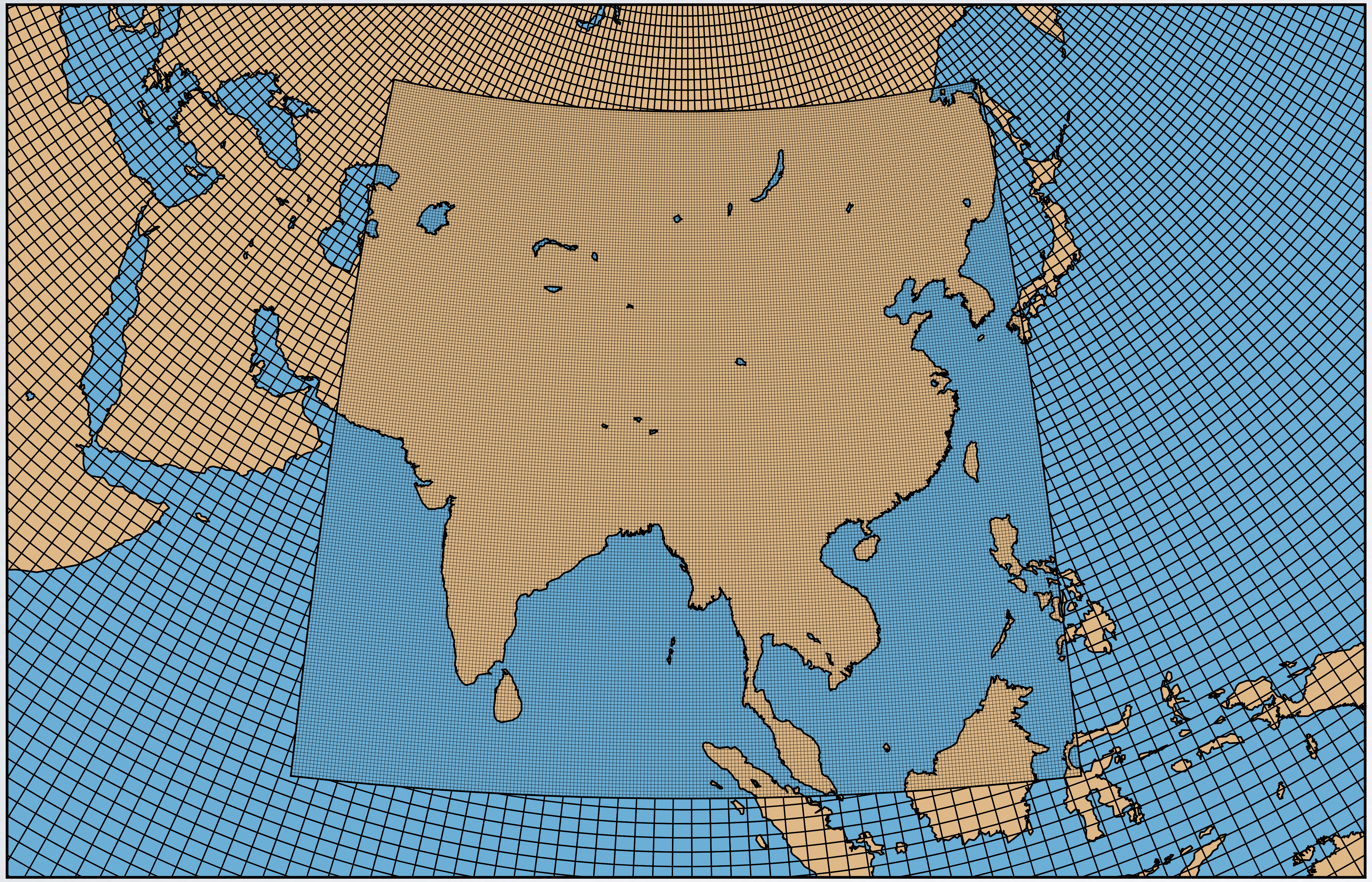
Ongoing work

- Refinements of the Green Sahara land surface. East-west vegetation asymmetry, more appropriate land surface for Arabian Peninsula
- Northern hemisphere vegetation change
- Impact of Green Sahara on Indian Monsoon
- Dynamical downscaling over Africa and the Mediterranean – connection to early human settlements

Dynamical Downscaling over Asia

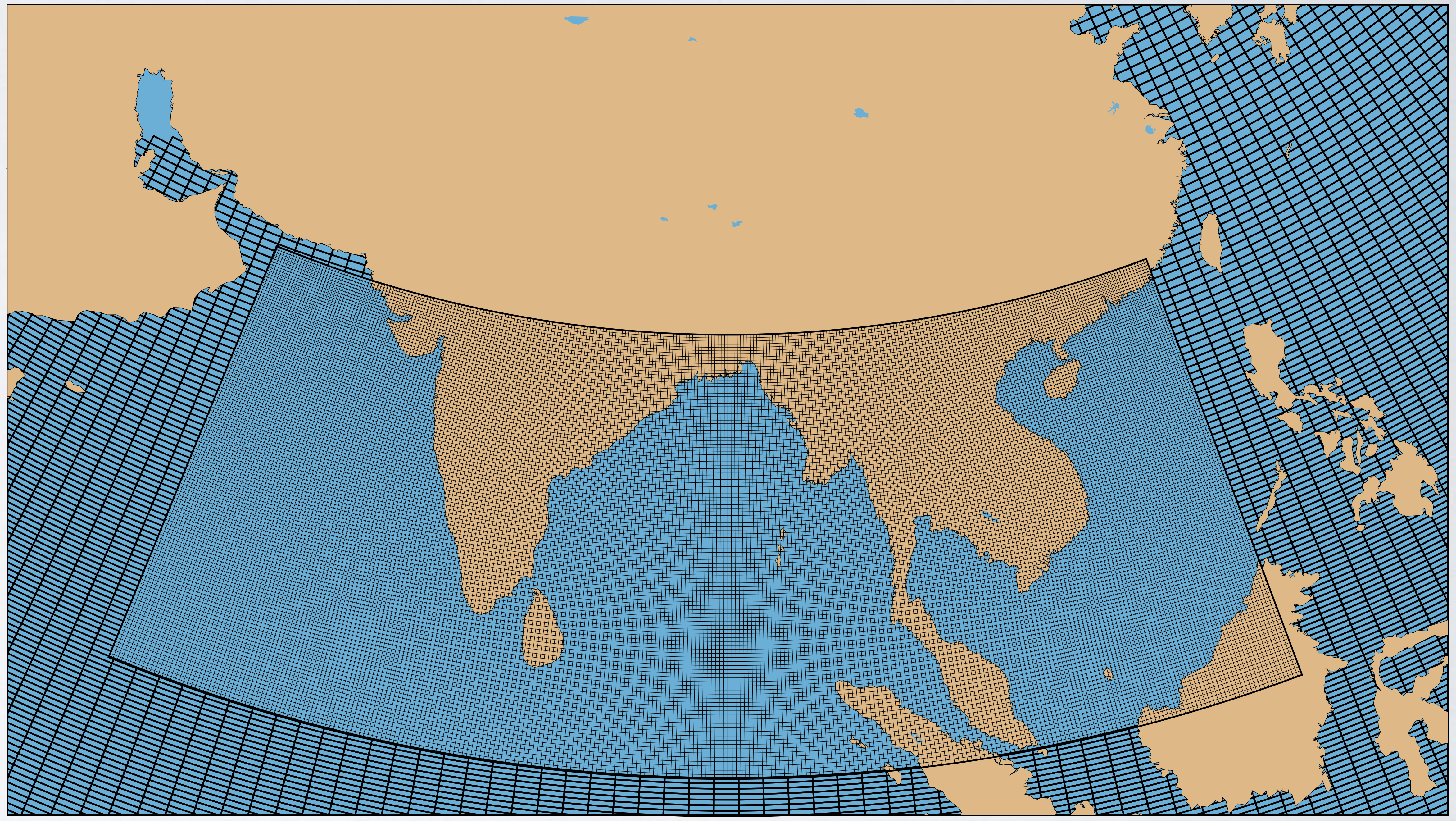
CAM grid with high-resolution WRF grid

CAM resolution ~100 km
WRF resolution ~30 km

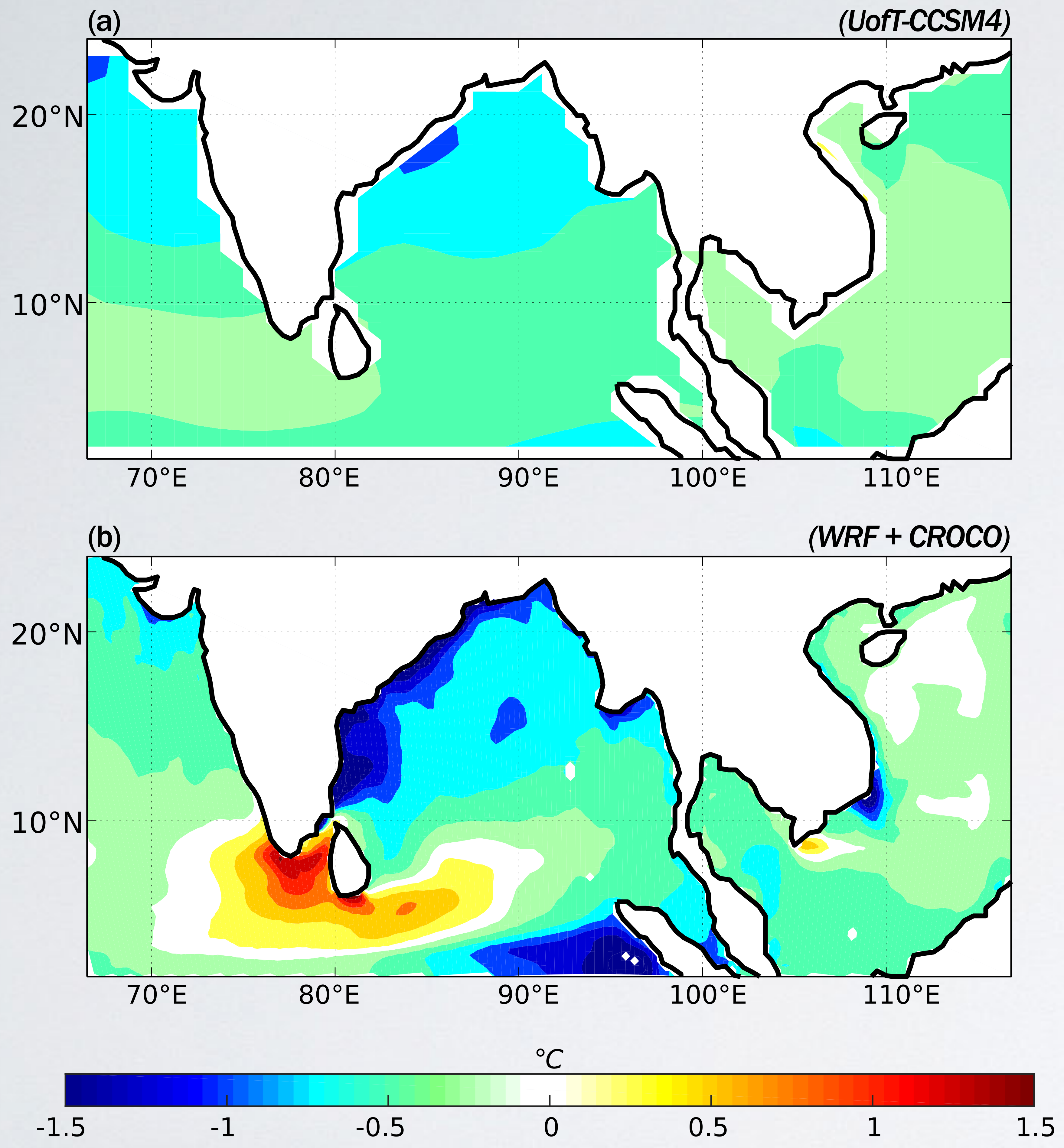


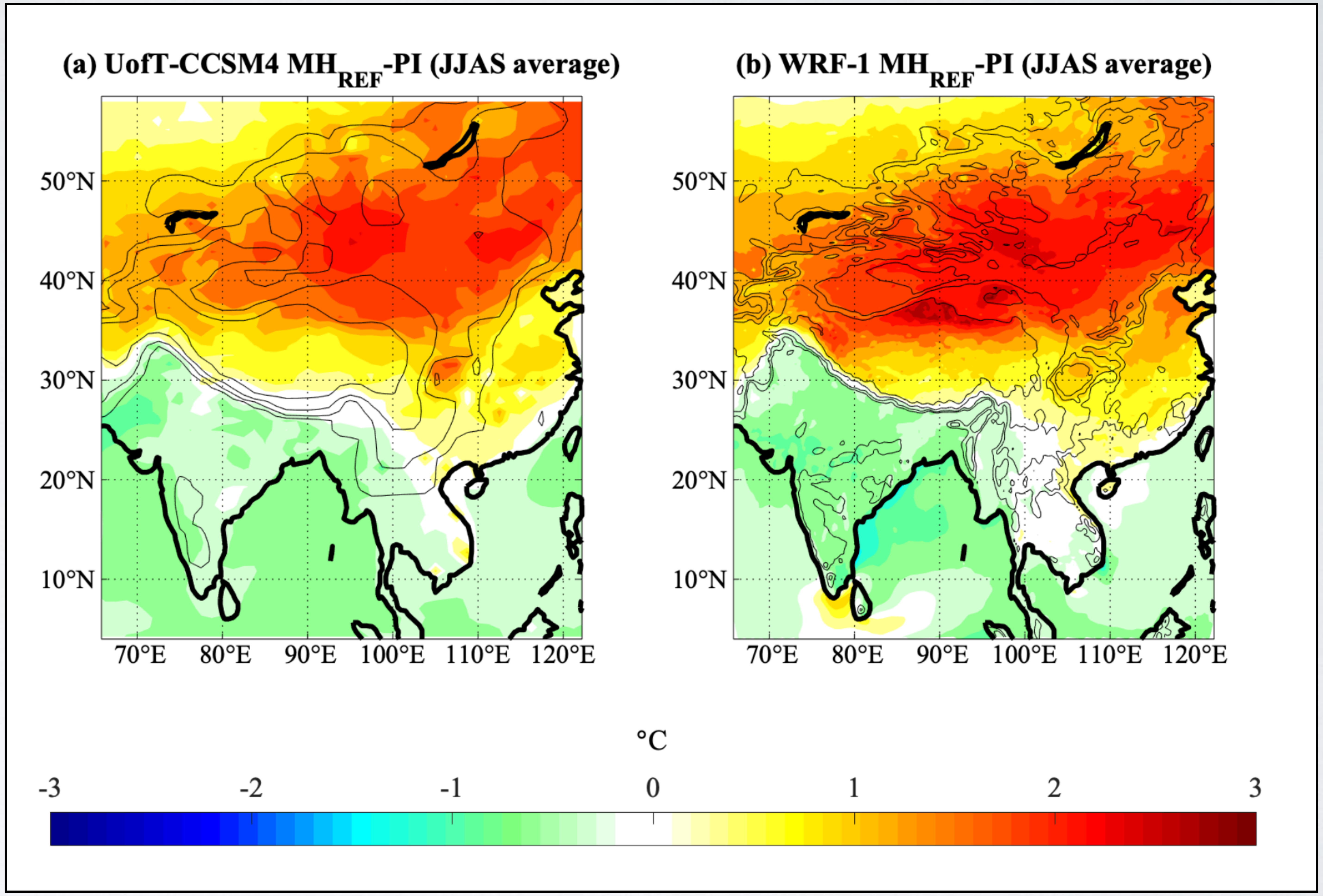
POP ocean grid with high-resolution ROMS grid

POP resolution ~100 km
ROMS resolution ~20 km



SST & SAT Anomalies (MH_{REF})

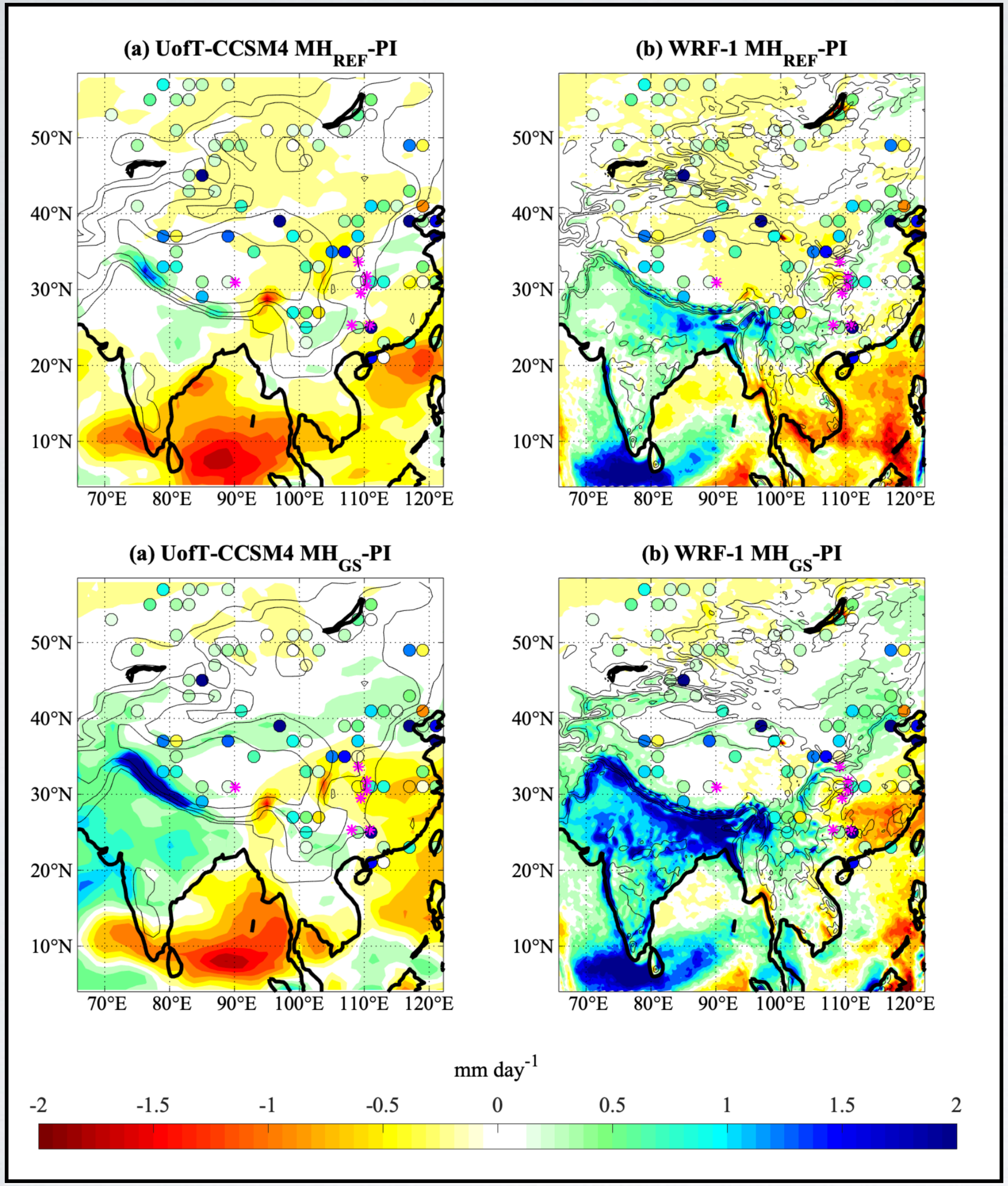




Yiling Huo, *Chandan & Peltier (about to be submitted to CP)*

Huo and Peltier 2018, 2020, 2021

Precipitation anomalies

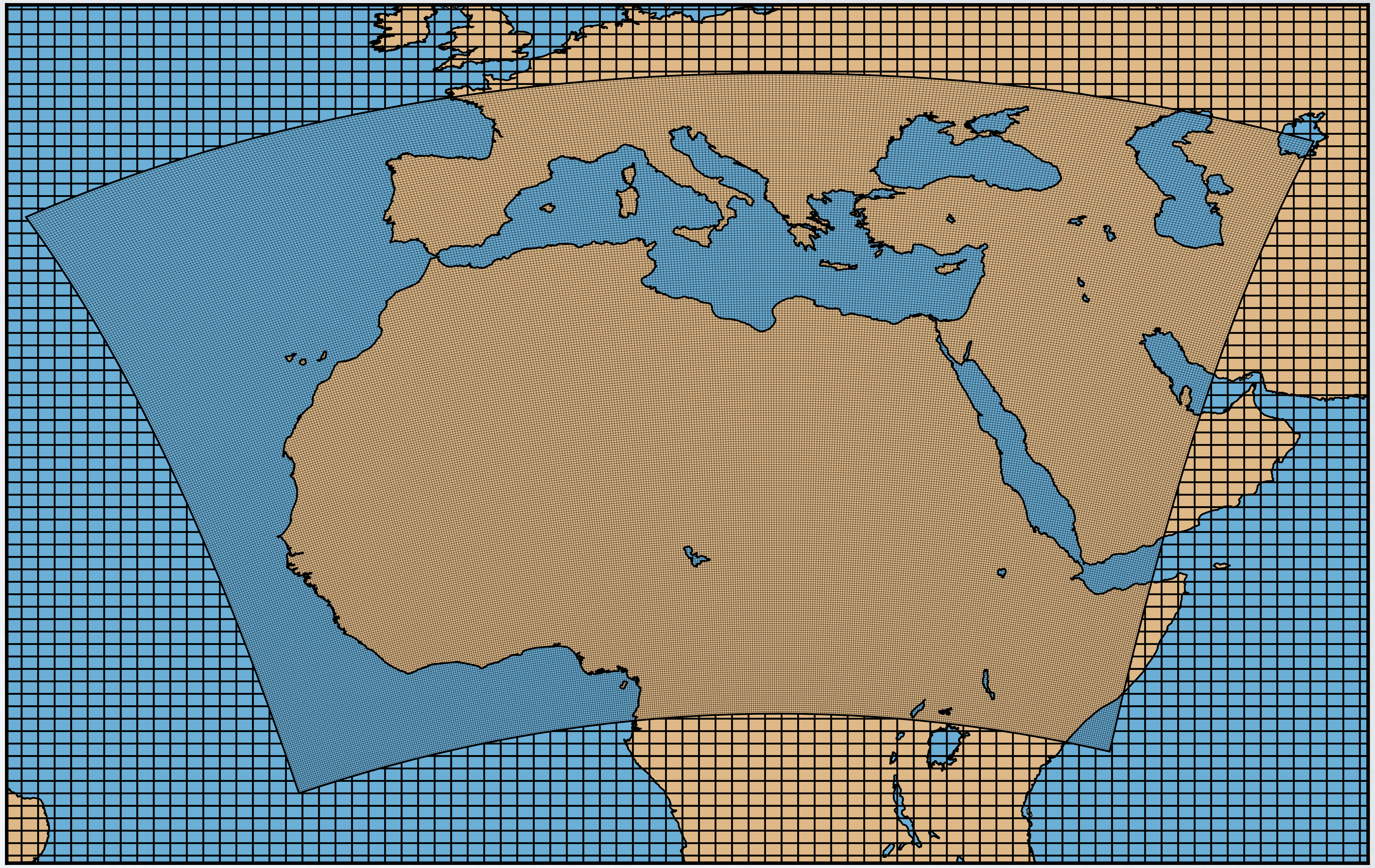


with reference simulation

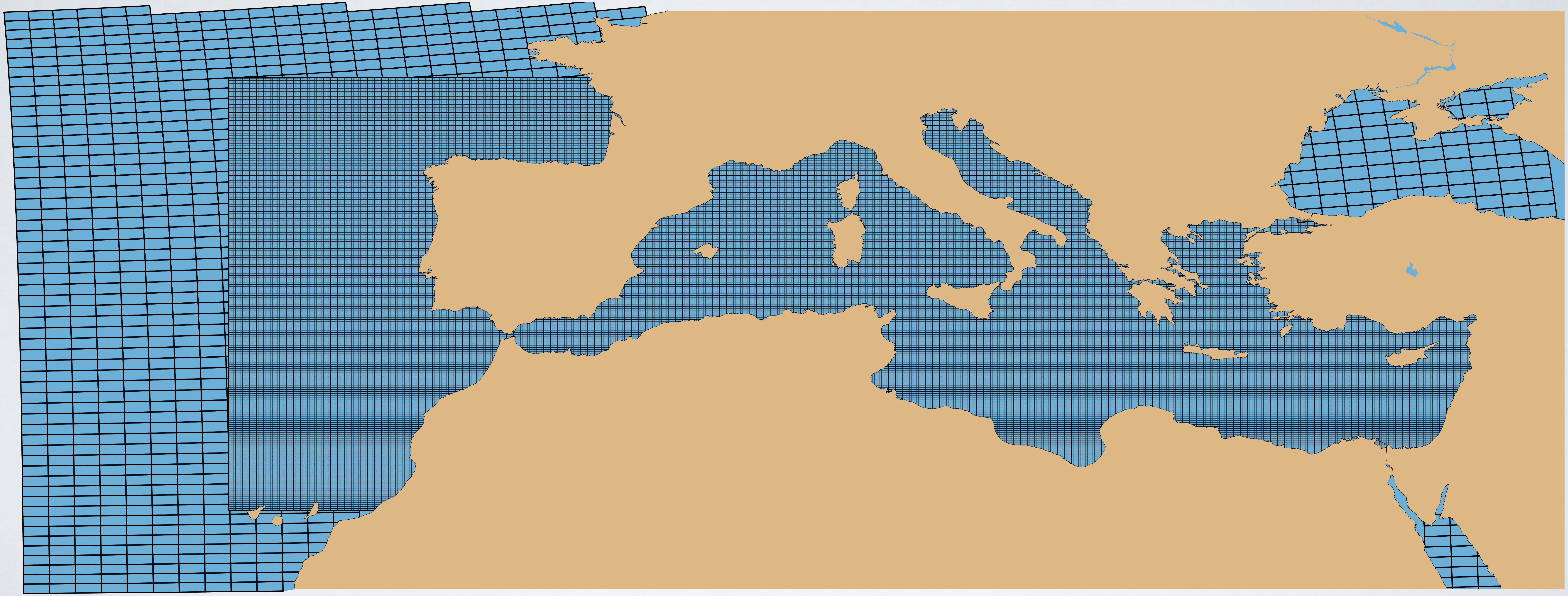
with Green Sahara simulation

Dynamical Downscaling over Africa

- Mini physics ensemble: > 18 members
- Atmosphere only and atmosphere-ocean configuration



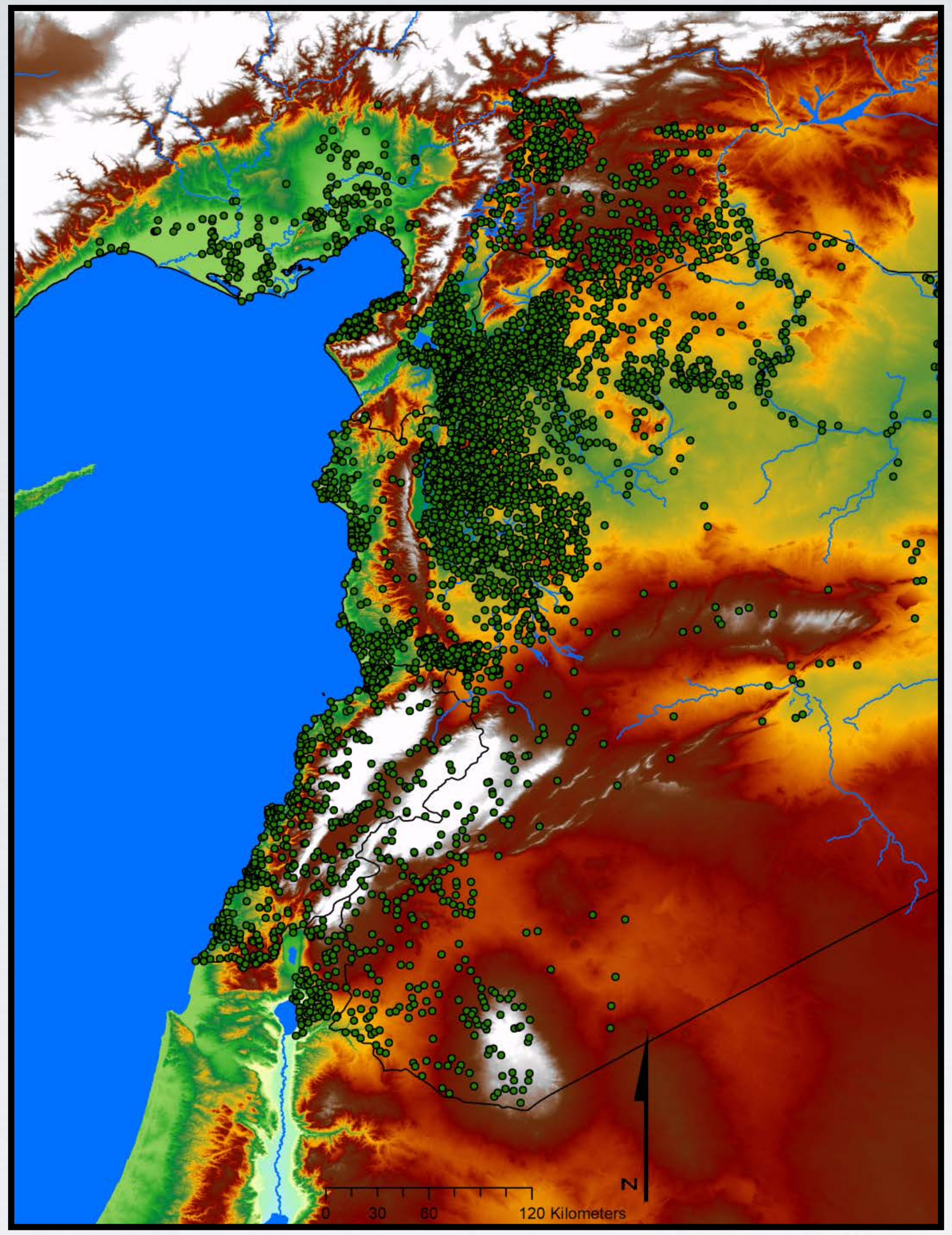
Dynamical Downscaling over Africa



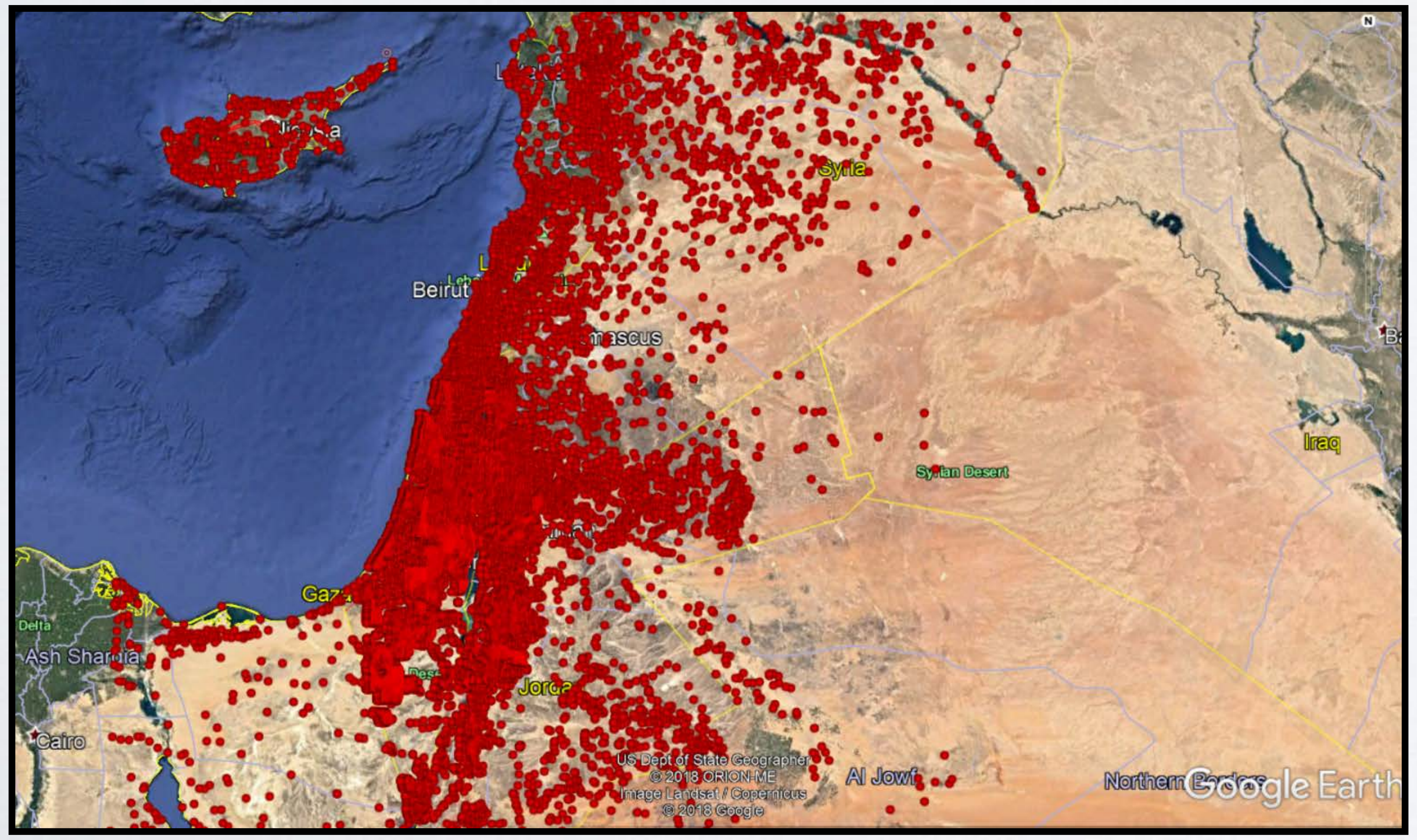
***Fengyi Xie**, Chandan & Peltier (in-prep)*

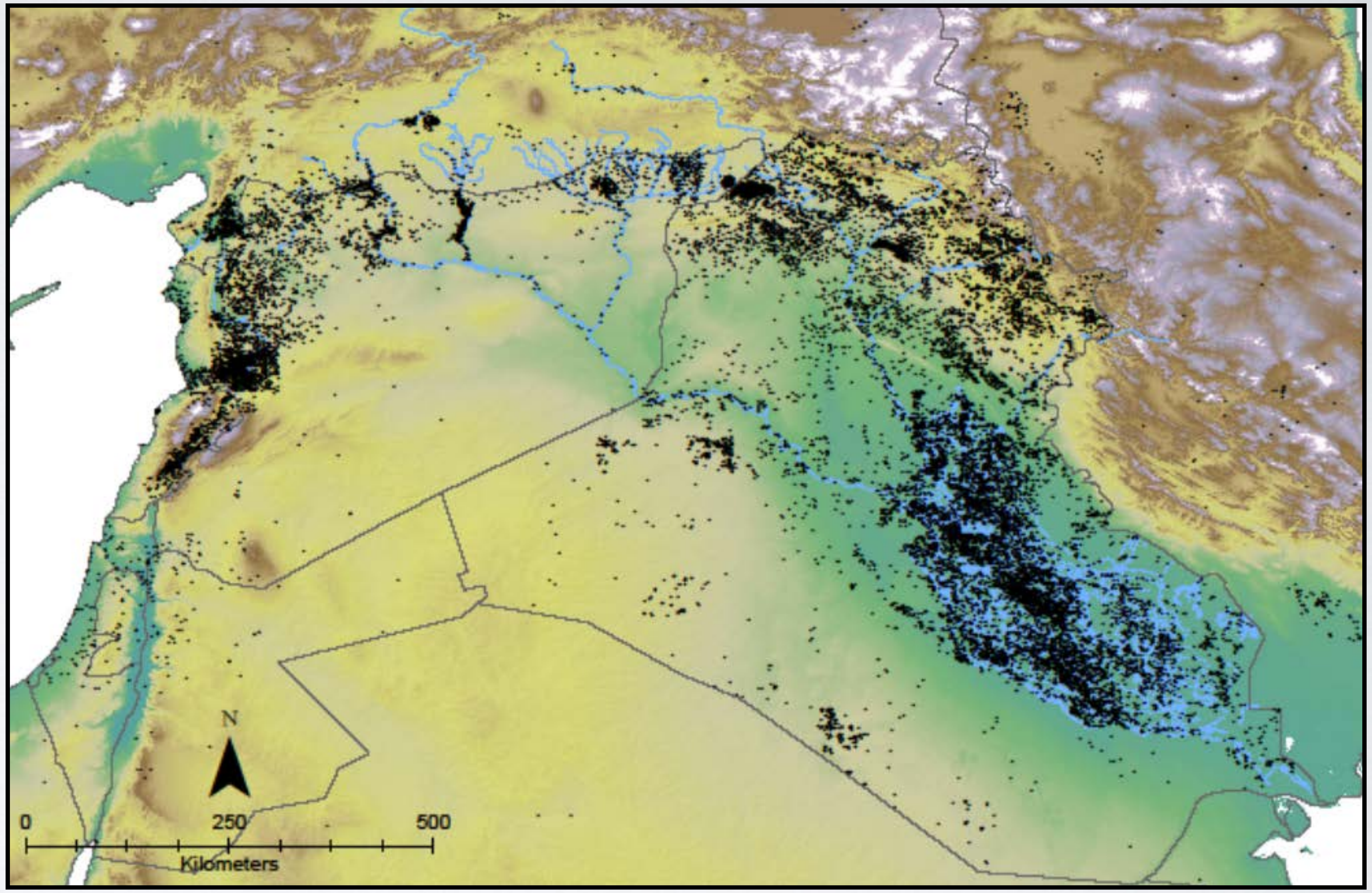
Holocene settlement data

CRANE Project



DAAHL





The CLaSS Project

Summary

- Likely cause of Green Sahara was the increased precipitation driven by the West African Monsoon that was initiated by the larger northern hemisphere summer insolation, but amplified by interaction with the land surface and atmospheric dust
- We have systematically examined the impact of feedback from various land surfaces on the precipitation over mid-Holocene northern Africa with a state-of-the-art coupled climate model
- With all feedbacks included, modeled precipitation agrees well with proxy inferences while the modeled precipitation is sufficient to sustain applied vegetation over most of Africa.
- Green Sahara leads to strengthening of the Indian Monsoon
- Green Sahara conditions lead to better data-model comparison Asia
- Dynamical downscaling very very important for Asia and significantly improves data-model comparison