MONSOONS DURING THE MID-HOLOCENE

Northern and Southern Hemisphere responses and the role of vegetation feedbacks

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Introduction

We study the monsoon response to orbital insolation forcing by comparing Mid-Holocene (6ka) to pre-industrial (0ka) experiments, performed by the Paleoclimate Modelling Intercomparison Project (PMIP). During the Mid-Holocene (6ka) the Northern Hemisphere (NH) received more insolation during summer, whereas the Southern Hemisphere (SH) had a decrease in summer insolation (**Figure 1**). This is thought to have resulted in stronger monsoons on the NH (Joussaume et al. 1999, Braconnot et al. 2007) and weaker monsoons on the SH.

This hypothesis is tested by studying precipitation from the PMIP experiments in different monsoon areas, with a focus on the expected anti-phase relationship between NH and SH monsoon strength. PMIP runs with coupled ocean-atmosphere (OA) models, with prescribed vegetation, and coupled ocean-atmosphere-vegetation (OAV) models are used to examine the role of vegetation feedbacks.

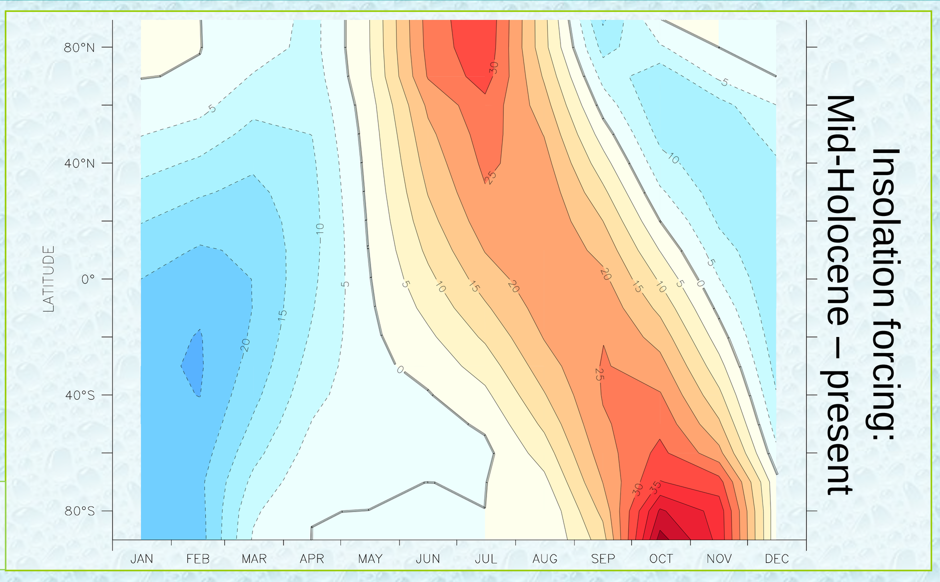


***Figure 1:** Top-of-atmosphere insolation difference 6k-0k per month and latitude (Wm^{-2}). Red (blue) indicates more (less) insolation during the Mid-Holocene than at 0k.*

Models & Methods

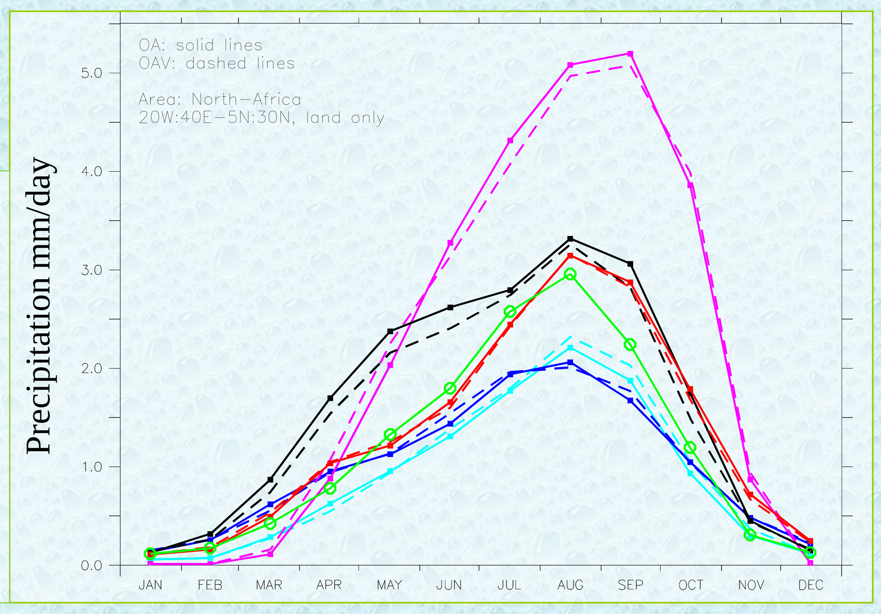
From the models used in PMIP (phase 2), five were selected that have an OA and OAV version (see Introduction) of the 0ka and 6ka experiments. See http://pmip2.lsce.ipsl.fr for details on the experimental design. **Table 1** shows these models, their resolution and also acts as a legend for Figures 2-5.

Model	Resolution	Legend
MRI-CGCM2.3.4nfa: non-flux adjusted	T42 (30)	Light-blue
MRI-CGCM2.3.4fa: flux-adjusted	T42 (30)	Blue
FOAM	R15 (18)	Purple
ECHAM53-MPOM125-LPJ	T31 (19)	Red
UBRIS-HadCM3M2	3.75°x2.5°	Black

Table 1

0 ka, control

***Figure 2:** Precipitation in North-Africa per month, see Table 1 for legend. The green circles indicate data from the CPC (Climate Prediction Centre) Merged Analysis of Precipitation, CMAP. All models reproduce the seasonal cycle, although there is some spread in the model results; in summer (the wettest period) models differ up to a factor 2. The spatial distribution of precipitation also varies between models. This also holds for the other monsoonal areas studied.*



Monsoonal precipitation in the Mid-Holocene

South-America

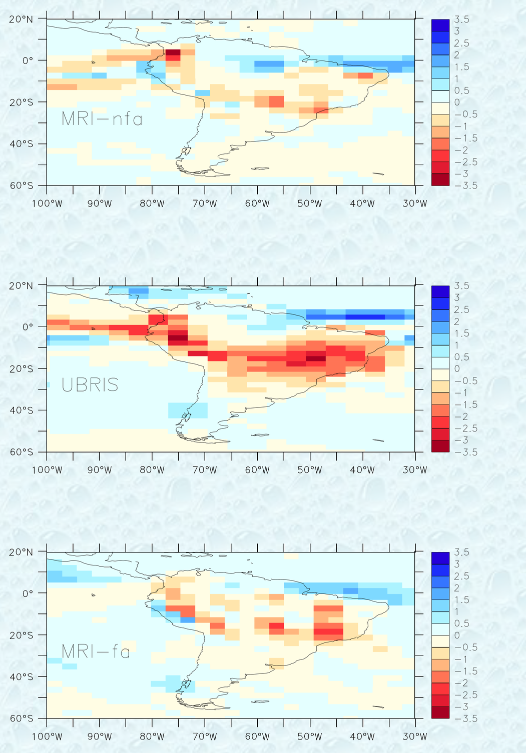


***Figure 3a:** Difference in average JFM precipitation 6k-0k in South-America, in mm/day. OAV experiments.*

North-America

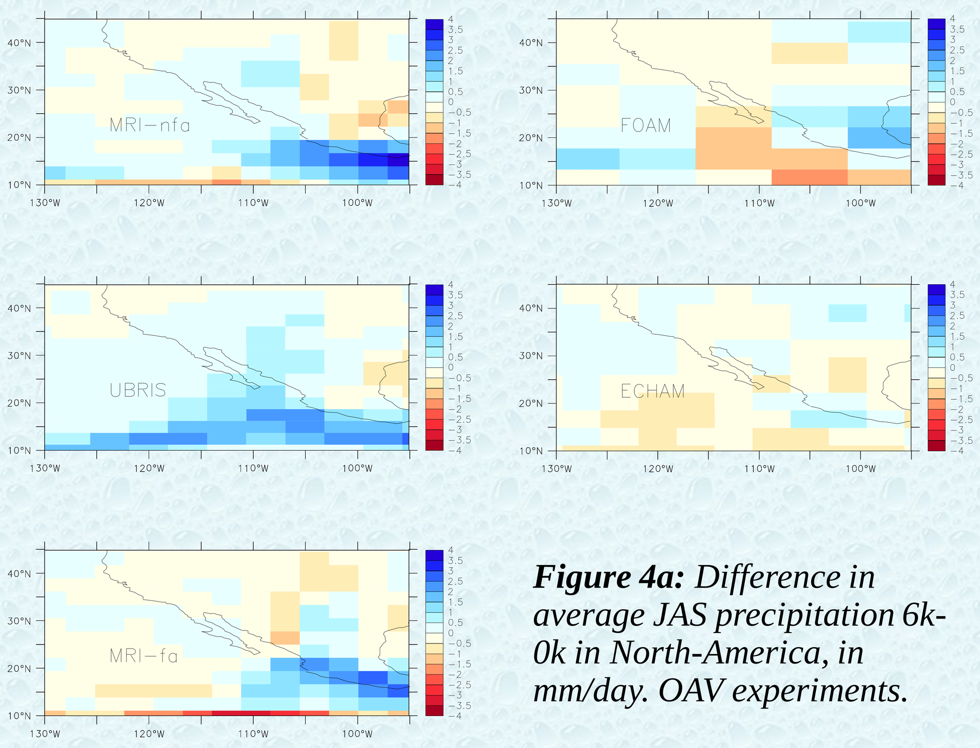


***Figure 4a:** Difference in average JAS precipitation 6k-0k in North-America, in mm/day. OAV experiments.*

North-Africa

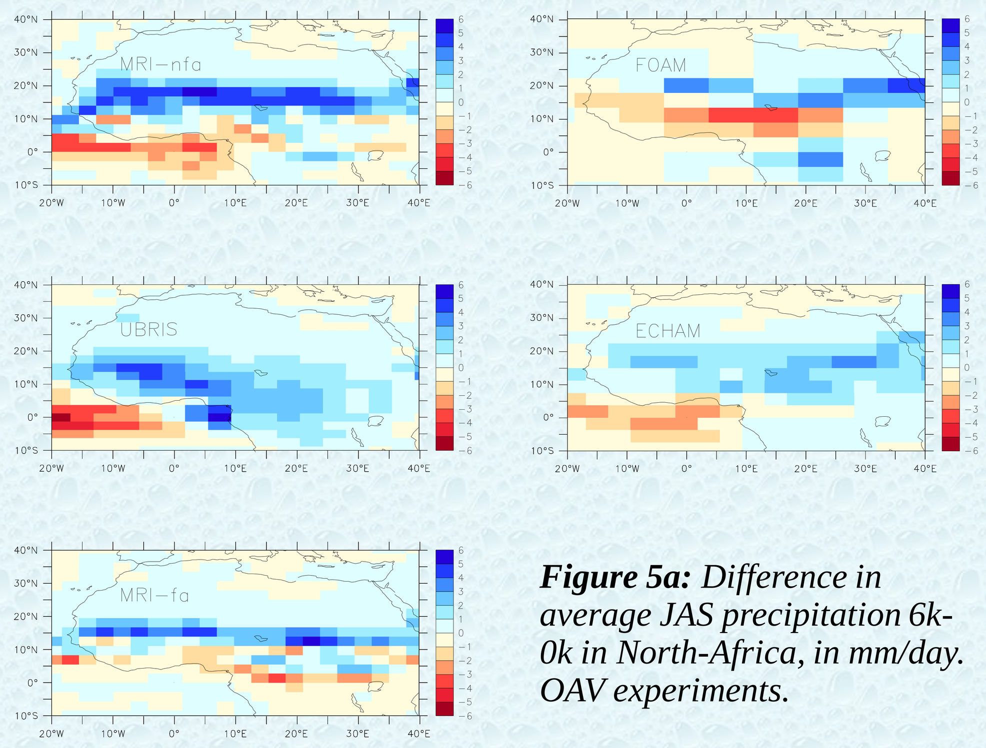


***Figure 5a:** Difference in average JAS precipitation 6k-0k in North-Africa, in mm/day. OAV experiments.*

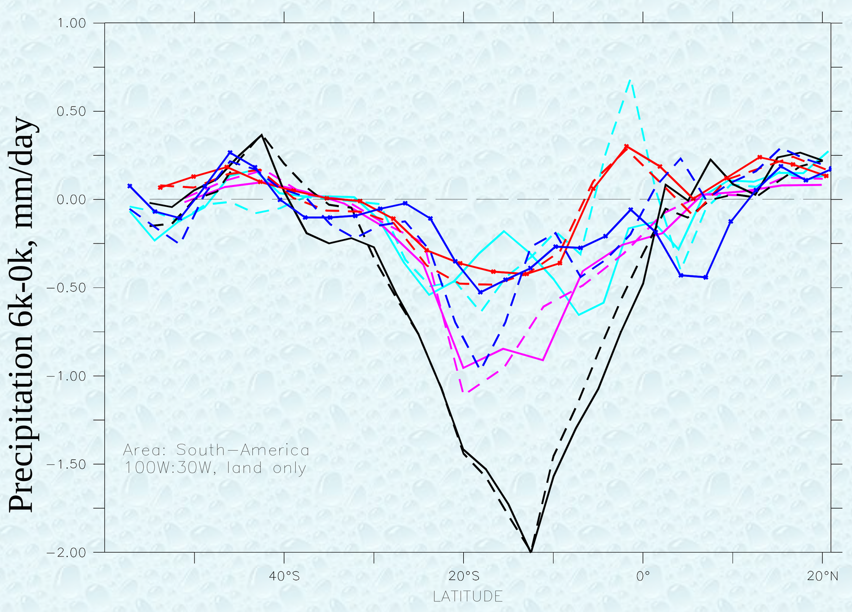


***Figure 3b:** Zonally averaged JFM precipitation difference 6k-0k in South-America. See Table 1 for a legend.*

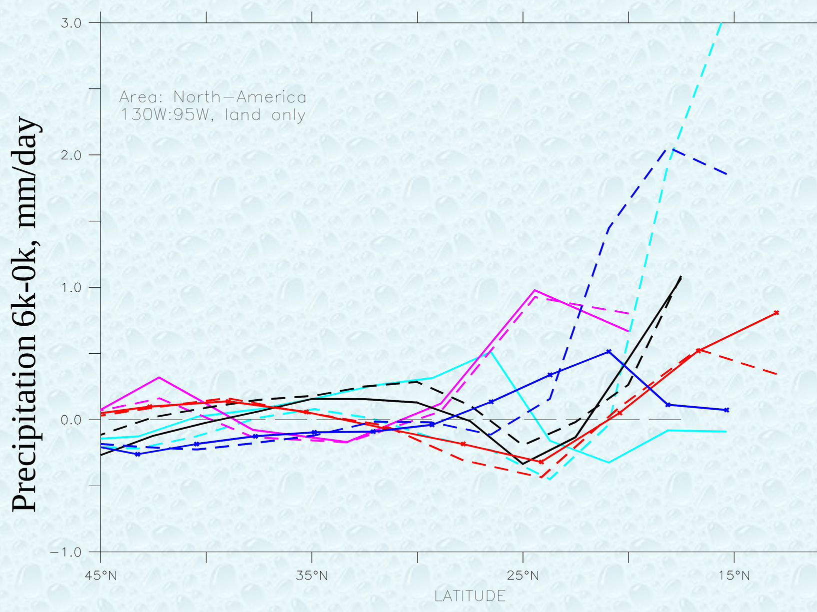


***Figure 4b:** Zonally averaged JAS precipitation difference 6k-0k in North-America. See Table 1 for a legend.*

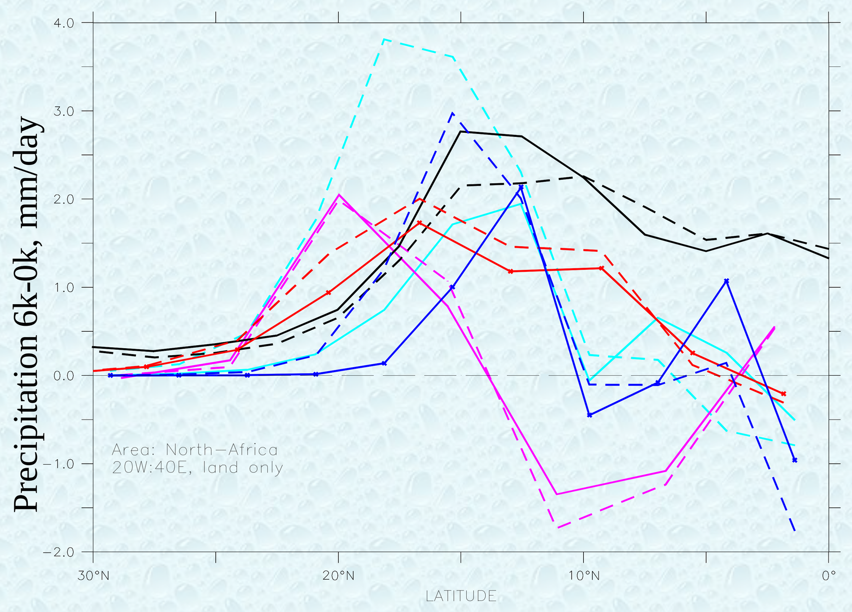


***Figure 5b:** Zonally averaged JAS precipitation difference 6k-0k in North-Africa. See Table 1 for a legend.*

Precipitation differences between the Mid-Holocene and 0ka, from the PMIP experiments, are shown in **Figures 3-5**. For South-America, all experiments show a reduction in monsoonal precipitation around 10-20°S (**Figure 3a,b**), although the strength of this reduction varies per model. On the NH, the North-American monsoon is enhanced around 15-20°N (**Figure 4a,b**). In North-Africa, the precipitation increase is most pronounced at 10-25°N (**Figure 5a,b**). An increase and northward shift in precipitation is also found in India (not shown). However, comparison to pollen data has shown that all models underestimate the northward shift in North-Africa (Joussaume et al, 1999). Nonetheless, the expected opposed behavior of the monsoons on the NH and SH (see Introduction) is produced consistently by all models.

Vegetation feedbacks are expected to enhance the effect of insolation forcing (see for instance IPCC TAR). Not all experiments produce this enhancement (see **Figures 3b, 4b** and **5b**); especially the FOAM and UBRIS models fail to produce an increase and a more northward shift in precipitation in the OAV experiments.

Conclusions & Outlook

We have shown, using PMIP experiments, that the increase in summer insolation on the NH resulted in stronger monsoons while less summer insolation on the SH resulted in weaker monsoons. Model results differ due to different parameterizations and resolutions, but they all reproduce the monsoon increase/decrease. Most models produce a stronger increase/decrease when vegetation feedbacks are taken into account.

This study provides a frame of reference for the next step: performing a Mid-Holocene experiment using EC-Earth. This is a new AO climate model based on the ECMWF operational weather-forecast model, which is expected to result in more realistic simulations of monsoon systems. It is developed and coordinated by KNMI (http://ecearth.knmi.nl/).

The experiment with EC-Earth will be done in the framework of PMIP (phase 3, http://pmip3.lsce.ipsl.fr/). It will also be used to examine the role of monsoons and mid-latitude storms as linkages between the astronomical target curve and sedimentary cycles (see for instance Tuenter et al, 2003 and 2004).

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