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Climate of the Past
Discussions

Interactive comment on "The evolution of sub-monsoon systems in the Afro-Asian monsoon region during the Holocene – comparison of different transient climate model simulations" *by* A. Dallmeyer et al.

A. Dallmeyer et al.

anne.dallmeyer@mpimet.mpg.de

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Major Points:

R1: "My major points mainly concern the test of the global monsoon concept using the AOGCM data in general.

"Evaluation of the global monsoon concept using pre-industrial AOGCM results: The major aim of section 3.4 is to prove the global monsoon hypothesis on interannual time scales, which is done by correlating rainfall time series from different sub-monsoon

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systems with each other. The authors conclude on page 2324 that “rainfall variations are only partly correlated”. I miss an evaluation of the global monsoon hypothesis under pre-industrial climate conditions. As this work aims to investigate if this hypothesis is still true for millennial time scales, it is crucial to investigate the relationship of rainfall between the sub-monsoon regions. The main question are:

i) Is rainfall over the sub-monsoon regions positively correlated if using annual rainfall amounts for, e.g. the last 120 years from the simulation?

ii) Does this dependency change during the time period from 6ka BP until present.”

“Time dependent correlation: (related to #1 and #2) To test the global monsoon concept, I suggest to calculate sliding correlations using different window sizes. This would help to investigate if regional monsoon teleconnections weakened or strengthened under varying orbital parameters”

“Interannual Variability of rainfall over the sub-monsoon regions Yearly rainfall amounts are used in section 3.4 to calculate the correlations between the different regions. The authors find only weak correlations between the North African monsoon and the Indian monsoon. This is in line with the study from Feudale and Kucharski, 2013, who also found that West Asian monsoon and Indian monsoon are only weakly correlated on the interannual time-scale but found high correlations on the decadal time scale. Thus, I suggest computing correlations also for decadal to multi-decadal time-scales to compare with the results from Feudale and Kucharski, 2013 for the ISM-NAM connection.”

A: These are indeed very interesting questions and we addressed all points, but we add them only partly to the manuscript, because the focus of the study is on multi-decadal to centennial precipitation variations. The correlation calculations have been performed on time-series smoothed by a 100-year running mean to filter out interannual and decadal variability. We furthermore detrended the time-series by a 500-year running mean to avoid spurious correlations that might be caused for instance by changes in orbital forcing. In the revised version, we stress this more strongly.

Regarding the pre-industrial correlations and the sliding window correlations: For most regions the correlations (based on the annual and decadal mean precipitation) at pre-industrial times are very weak and therefore changes using different sliding windows. They remain mostly statistical non-significant. The only exception is the COSMOS simulation – here correlations are relatively strong between the North African monsoon and the Indian monsoon regions and Southern Arabia as well as between these regions and the northern part of the East Asian monsoon region (cf. attached Table 1). The correlations stay on the high levels throughout the entire period.

We add to the method part:

“To test, whether the different monsoon sub-systems are connected during pre-industrial times, we calculate the Pearson’s correlation coefficient based on the last 150 years of the annual mean precipitation time-series (for interannual variability). For this purpose, the time-series have been detrended by a 30-year running mean. In addition, we calculate the Pearson’s correlation coefficients for decadal timescales based on the last 1000 years of the simulations. For this calculation, the time-series have been filtered by a 10-year running mean and have been detrended by a 500-year running mean. Only the non-accelerated simulations are considered. Sliding correlations are performed for annual and decadal time-series to assess, if the teleconnections among the sub-systems are stable and if regional monsoon teleconnections weakened or strengthened under varying orbital parameters.”

And add to the result section:

“ 3.1.3 Connectivity of the different sub-monsoon systems Tab.3 shows the Pearson’s correlation coefficients for the annual and decadal (in brackets) precipitation time-series of the different here considered sub-regions. Overall, only the COSMOS model shows a strong positive correlation among annual and decadal mean precipitation in the Indian and the North African monsoon and the Southern Arabian region (r>0.8). In COSMOS, precipitation variability over these regions is also moderately correlated with precipitation over the northern part of the East Asian monsoon (annual: r>0.6 and decadal: r>0.5). These correlations stay on high levels throughout the entire period (not shown). For the other regions and in the other models correlations are very weak and therefore change using different sliding windows. They remain mostly statistical non-significant (not shown)."

And add to the discussion:

"With the exception of COSMOS, all models reveal no significant link between interannual and decadal rainfall variations in the sub-monsoon regions at pre-industrial times. The strong connection of the North African, Indian and northern East Asian monsoon region may be related to the ENSO variability, that is very prominent in the COSMOS model"

And add to the summary:

"COSMOS is the only model showing a link between the interannual and decadal rainfall variations in the Indian and North African monsoon region as well as the northern part of the East Asian monsoon region. This correlation is nearly constant throughout the Holocene revealing that these teleconnection is not affected by orbital variations in the model.“

R1: "Additionally, I would recommend to "streamline" the manuscript even more by highlighting the important points and reduce the paragraphs with redundant information".

A: We deleted the sections 3.1.3 and 3.2.2. as they are not relevant for the discussion. We furthermore shorten different parts of the paper.

R1: "Figure 1 shows the sub-monsoon regions used in this study, but only four regions are discussed in the manuscript (NAM,ISM,EASM,NEASM). For regions "SARAB" only the rainfall trend during the Holocene is investigated, but no validation has been performed in section 3.1.“

A: We fully agree, this is misleading. We have not clarified this in the first manuscript. The region SARAB is no monsoon region at present-day, since the annual rainfall amount is very low. This region is only characterized by a high summer to annual precipitation ratio. We included this region in the trend discussion, since we expect a strongly increased precipitation during mid-Holocene related with a stronger Indian summer monsoon. We explain it in the revised version: "The sub-region in Southern Arabia is not a monsoon region as the annual rainfall is very low. We therefore only include this region in the discussion of the rainfall trend, because we expect a strong connectivity to the Indian monsoon which circulation could have reached this region during mid-Holocene."

And in the caption of Fig.1: "Fig. 1: Definition of the different monsoon sub-regions used in this study (shaded), the Southern Arabian region included for the trend analysis, and the locations of caves. . ."

Minor Points:

R1: "section 3.1 Which time period has been used regarding ERA-40 and GPCP data? Please clarify how many years are used to calculate the average for figure 2,3,4,5."

A: We used the time period 1979-2008 for the GPCP data, and 1961-1990 for the ERA40-data. We add this information in the text and also in the Figure captions.

R1: "Figure 2: I suggest performing a significance test and shade only those areas where the differences are statistically significant (as in Figure 6)"

A: This is also a possible way to present the differences. We decided to show all data since we assume that the differences are nearly everywhere significant.

R1: "Figure 3 and p. 2305: Is the Taylor diagram showing spatial correlation, spatial standard deviation and normalized RMSE from the spatial data? It is difficult to follow the conclusions drawn in section 3.1.1 about the temporal variability. It seems, that only the average of 120 (12) model years of 0k is used."

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“ p. 2305, l.1 How is “the entire monsoon region of North Africa and Asia” defined? Is it the whole region in figure 1?”

“p. 2305, l.5 Which standard deviation is summed up over all grid-boxes? Sentence is difficult to understand.”

“p. 2305, l.13 Again: how can temporal correlation be assessed. Is standard deviation calculated from 120 years (unaccelerated) and 12 model-years accelerated?”

A: In these parts, we are indeed not precise enough. The Taylor diagram is based on monthly mean values (calculated from 120 years in case of the non-accelerated simulations and 12 years in case of the accelerated simulations) and shows the pattern correlation, the centred root-mean-square error and the standard deviation, i.e. the amplitude of the variation of the pattern in the field and within the year. This is what we describe with the term ‘spatial and temporal variability”. In the revised version of the manuscript, we avoid this term. We define the monsoon regions in the simulations based on the 55% isoline of the summer-to-annual precipitation ratio. For better comparison, we use in this calculation the monsoon region calculated on the ensemble mean of the simulated precipitation (c.f. old Fig.7, now Fig.2). As simple measure of the bias between the models, we calculated the “mean bias” using the formula of the standard deviation. We skip this bias calculation as the Taylor diagram includes similar information.

We now write:

“Averaged over the entire ensemble mean monsoon region of North Africa and Asia (including oceanic areas, c.f. Fig.2), COSMOS, COSMOSacc and KCM simulate too much precipitation, PLASIM too little precipitation. ECHO-G simulates similar rainfall as observed (c.f.Tab.2). To further quantify the biases between simulated and observed precipitation (here GPCP data), we chose a Taylor diagram (Fig. 3). This diagram is based on the climatological monthly mean precipitation values of each simulation and shows the pattern correlation of the simulated and observed precipitation and the centred root-mean-square difference of each simulation to the observation. In addition, it displays the standard deviation in each data-set comparing the amplitude of the temporal and spatial pattern variations. Overall, ECHO-G has a similar spatial and temporal variation as observed precipitation and agrees best with the observed precipitation pattern. PLASIM underestimates the variation slightly and shows the lowest correlation. KCM, COSMOSacc, and COSMOS demonstrate a very similar skill to simulate the North African and Asian monsoon precipitation. Those models slightly overestimate the amplitude in pattern variation, but show a good pattern correlation. The ensemble mean reveals the best pattern correlation and also the highest agreement in terms of spatial and temporal variation."

R1: "Figure 4: Both plots in the bottom row have the same title ("EASM")"

A: Thank you, this is indeed a mistake.

R1: "Figure 5: Maybe it is a good idea to show anomaly plots to highlight the regions with the largest differences?"

A: In this figure, our main aim is to display the monsoon flows, in particular the strong Somali jet. In an anomaly plot, the differences to the reanalysis data are more visible, but it is not so easy to identify the different branches of the monsoon systems. We therefore preferred showing the absolute values and not anomalies. However, we use also the anomaly plot to draw our conclusions. This part is now in the Appendix, because it is not important for the main conclusions of the manuscript.

R1: "Figure 6: Is the legend also valid for the reconstructions data (dots)?"

A: Yes it is. We add this information in the figure caption.

R1: "Figure 7: How large is the monsoon region for pre-industrial climate using GPCP data? Which models performs best?"

A: To reduce the text of our manuscript, we skip this paragraph as it is not important for our main conclusions.

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R1: "Figure 11: What about ERA-40, and the other model simulations? Which model captures the observed moisture flux best?"

A: Unfortunately, we do not have the relevant ERA40-data. In comparison with the ERA-40 Atlas, COSMOS agrees most with the vertically integrated moisture flux convergence and divergence pattern. The flux within the East Asian monsoon is underestimated in all models. (http://old.ecmwf.int/research/era/ERA-40/ERA 40_Atlas/docs/section_C/parameter_cifowvwtc.html#)

R1:" p. 2305, l. 26 "Thus, with respect to precipitation PLASIM does not identify the North African monsoon as "monsoon region". This contradicts with p. 2309, l. 25 and figure 7. In figure 7 monsoonal regions over Africa are well present also in PLASIM, using the ratio between summer and annual precipitation. Thus, for figure 7 PLASIM identifies this area as monsoonal and the index is also based on precipitation."

A: We agree, this is really misleading. We now write: "Thus, with respect to maximum precipitation PLASIM does not identify the North African monsoon as monsoon region."

R1: "p. 2307, l.15 It's difficult to compare the results of the models with ERA just using figure 5. Is it possible to calculate spatial correlations, maybe also for special regions?"

A: We agree that it is difficult to compare the figures, but calculating spatial correlations for the complex monsoon wind field makes no sense. Since comparing the present-day monsoon in the different models is not the main aim of our manuscript, therefore we perform no further calculation. We put this section in the Appendix.

R1:" p. 2314, l. 2 Where do you show the climatological interannual variability?"

A: We deleted this term.

R1:" p. 2316, l. 20 Which time-scale are you talking about when writing "temporal variability" ?"

A: This term has indeed to be specified. We now use 'centennial variability'.

R1: “p. 2316, l.18-28 This complete paragraph is also mentioned in the Summary section.”

A: We do not understand this point. In the summary, we refer to these results, but only very shortly and more concise.

R1: “section 4.3 and section 4.3.1 How is the onset and withdrawal defined? I am not convinced that it is possible to conclude differences of the onset date in 9ka, 6ka, 3ka, 0ka using monthly mean precipitation data as used in section 4.3.1. Furthermore this analysis might be difficult as only 12 model years are used for each time-slice to calculate climatological mean rainfall amounts.”

A: This is indeed not explained in the manuscript. For the CMAP-data (i.e. reference for present-day), we calculated the onset, peak and withdrawal based on pentad mean precipitation by using the definition of Wang and Linho, 2002. For the model results, we only compare the differences in the seasonal cycle between the different time-slices based on monthly mean values. Here we take as onset the month in which rainfall rate increases drastically, the exact onset pentad is not relevant for our conclusions.

We now write: “Fig. 10 displays the pentad of monsoon onset and withdrawal as well as the month of rainfall peak in the Afro-Asian monsoon region based on the observational dataset of the Climate Prediction Centre (CMAP, 1979-2008, Xie and Arkin, 1997). Both has been calculated according to Wang and Linho (2002), on the basis of the relative pentad mean rainfall, i.e. the difference between the pentad mean rainfall rate and the January mean rainfall rate. The period in which the relative mean pentad rainfall exceeds 5mm/day is defined as monsoon season.”

. . . “In the following, these hypotheses are discussed based on the transient climate simulation performed in the Kiel Climate Model (KCM), because this is the sole simulation in the here considered transient simulations that covers the early-Holocene and have been undertaken in a comprehensive global climate model. Since we only analyse monthly precipitation data, we define the onset of the summer monsoon in the model by the month in which rainfall rate increases strongly. Accordingly, we define the end of the monsoon season by the last month in which the rainfall decreases drastically. We are aware of the impreciseness of this definition, but it does not effect the conclusions drawn in this section."

"... This insolation gradient anomaly is positive during spring and strongly increases in March at 9k and in April at 6k leading to an earlier onset of the monsoon season over northern Africa during early-Holocene than at mid-Holocene, taking the month of strongly increasing precipitation as onset of the rainy season."

R1: "I can't find the link between section 4.3.1 and section 4.3.2. In section 4.3.1 the authors analyse the seasonal cycle of rainfall during 9ka, 6ka, 3ka and 0ka. Section 4.3.2 discusses the start, mid-point and end of the wettest period derived from proxy data. Could you please highlight the linkage between the output from this analysis and the model data?"

A: The analysis of the model results and the proxy data is independent, but they both are methods to assess, whether the differences in the seasonality of the monsoon sub-systems lead to differences in the strength of the rainfall response to the orbital forcing.

We further specify this:

"...In the following, these hypotheses are discussed based on the transient climate simulation performed in the Kiel Climate Model (KCM), because this is the sole simulation in the here considered transient simulations that covers the early-Holocene and have been undertaken in a comprehensive global climate model. Reconstructions are rather indicative of annual accumulated precipitation; seasonal variations can not be resolved. Therefore we can not directly utilize reconstructions to prove these hypotheses. We assume that differences in the seasonality among the sub-monsoon systems may affect the strength of the rainfall response to the orbital variations and may therefore lead to systematic differences in the Holocene rainfall maximum. This

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would underline the third hypothesis. For this purpose, the synthesis of reconstruction drawn by Wang et al. (2010) is analysed regarding the timing of wettest period during the Holocene. . ..”

Please also note the supplement to this comment:
http://www.clim-past-discuss.net/10/C1606/2014/cpd-10-C1606-2014-supplement.pdf

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