Clim. Past Discuss., 9, C1101–C1111, 2013
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Climate of the Past
Discussions



# *Interactive comment on* "Simulation of the Indian monsoon and its variability during the last millennium" *by* S. Polanski et al.

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Response to reviewer 2

We thank reviewer 2 very much for her/his helpful comments. We took her/his remarks into account and improved the manuscript accordingly.

Changes in the manuscript are highlighted with a green font according to the comments of referee 2.

Major comments:

"1. As the previous reviewer observed, the amount of variability in the AIMR calculated for the different ensemble members is quite large. For instance, mil0012 would be interpreted as a wet MCA and a dry LIA, but mil0014 would be interpreted as a dry MCA and modern period with a wet LIA, and mil0010 would depend on how MCA and LIA were defined in time. This is a remarkable amount of variability for models that I assume have the same forcing (the forcing series used here need to be described and cited, in any case). One would draw completely difference conclusions about forcing of the South Asian Monsoon if one were to examine only a single member. What explains this large amount of within-ensemble variability? And, given the observed variability, how could it be possible to justify selecting a single ensemble member (mil0014) to continue with the analysis? Why not use the ensemble mean for the high resolution runs?"

We acknowledge very much your critical and legitimate comment about the selection of ensemble member mil0014 as input for our higher resolved ECHAM5 simulation. Using the single member instead of the ensemble mean is due to different reasons, which we will describe in the following. For better clarification and justification we changed the paragraph according to the comments from you and reviewer 1 (page 7, lines 22-28).

1. AIMR variability among the ensemble members:

The remarkable large spread in the rainfall variability among the different ensemble members, which all include the same external forcing but different ocean initial conditions, is associated to a strong internal model variability (see also Jungclaus et al., 2010). The forcing series and its references are already presented in the previous draft of the revised manuscript (see changes in red font).

2. Northern temperature evolution in the last millennium and the difficult definition of warm and cold climate anomalies in space and time:

In our first guess about a realistic selection of the two prominent climate periods, we followed the approach from Jungclaus et al., 2010 and analyzed the NH temperature variations. The study points out, that the northern hemisphere reconstructions for the last millennium show a strong differentiation among each other, in which the spatial and



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temporal extent of climatic epochs as Medieval Warm Period (ca. 900-1250 AD) and Little Ice Age (ca. 1500-1850 AD) are difficult to define. We refer to this in our introduction. The large spatiotemporal heterogeneity leads many authors to express the MWP as MCA (Medieval Climate Anomaly). However we use the "MWP" term as suggested in the Millennium Experiment. The simulated northern temperature changes over the last 1200 years (Jungclaus et al., 2010) indicate a significant spread among the ensemble members from the range of internal variability defined by the control experiment. Especially strong volcanic eruptions have a long-lasting imprint on the NH climate. The simulations show the warmest preindustrial NH temperatures around 1050-1250 AD and in the late 18th century and cold periods during the 13th, 15th, 17th and early 19th centuries (see Fig. 3a in Jungclaus et al., 2010). While the global distributed data from Bradley et al., 2003 show their warmest 30-yr period between 1000 AD and 1200 AD, most reconstructed NH temperatures recommend an earlier occurrence of MWP. This underlines the discrepancies between model and reconstructions to define a realistic timing of these climate epochs. Figure 3b in Jungclaus et al., 2010 makes clear, that the ensemble spreads are of similar magnitude as the range of the internal variability in the control run verifying a good representation of internal variability in the ensemble members. During the first part of the 17th century, when the coldest part of LIA is reconstructed, a cold E1 ensemble with negative temperature anomalies is identified. Multi-century climate variations as MWP-LIA transition can be attributed to some parts of internal centennial-scale climate variability and not only to strong solar forcing. In addition, Frank et al., 2010 compared the warmest 30-yr period during the MWP with the coldest 30-yr period of LIA, in which the best estimate of MWP (1071-1100 AD) - LIA (1601-1630 AD) transition is 0.38K. The application on all ensemble members shows, that the warmest MWP periods occur between the end of the 11th century and the middle of the 12th century while the reconstructions suggest a slightly earlier temperature maximum (see Tab. B1 in Jungclaus et al., 2010).

3. Temperature and rainfall variability over AIMR domain during the last 1000 years:



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Assuming an earlier warming peak of the Medieval Warm Period in tropical Asia due to an earlier onset of increased incoming solar radiation and a lag spreading towards the northern latitudes, we focused on the analysis of the temperature evolution averaged over AIMR domain (we averaged the same domain to ensure a consistency with our precipitation region) for the different ensemble members (see Figure 1s in our response to reviewer 1). According to many proxy evidences we have chosen the earlier time period between 900 (1500) and 1200 (1750) AD to find the most robust ensemble member, which ensures the best resembling of the warm (cold) climate anomaly. Mil0014 identifies the most robust temperature signal for both MWP and LIA. Compared to the other members it is closer to the ensemble mean, which represents a more reliable signal for mil0014. Taken this into account we additionally investigated the AIMR rainfall time series and found the most robust signal for mil0014. A better millennium-scale variation in precipitation for mil0014 has been another important reason for selecting this special member. Finally the higher temporal variability has been crucial for the main aim of our study with respect to the analysis of extreme monsoonal events on centennial time scale, which are not well represented in the ensemble mean. Therefore we decided us for mil0014 as single member and not for the ensemble mean and classified the MWP from 900-1100 AD and the LIA from 1515-1715 AD. Obviously, many advantages and disadvantages for using either a single member or an ensemble mean lead to a careful interpretation of the results, which can differ among each other. Further the scope of a study has an important effect on the selection. Since a clear definition of an exact timing of the climate anomalies is still under discussion especially in accordance to many uncertainties in both modeling and reconstruction studies, we completely emphasize on the argument, that it is a great challenge among the scientist involved in past climate research to classify these anomaly periods realistically. We tried to combine the temperature and rainfall signals averaged over our region of interest with results from reconstruction studies to find the best fully coupled simulation realization from Millennium Experiment to drive our higher-resolved AGCM by using the SST/SIC data from the coarse resolved global model.

"2. There is some limited comparison to proxy records. Section 4.1 accomplishes this mostly qualitatively, and the sign of the difference between MCA and LIA indicated in Figure 6 in some cases doesn't track from the proxy records themselves or depend strongly on how LIA and MCA are defined in time. It isn't clear how these were chosen, and I'm skeptical of the ability of some of them to resolve climate variability on the timescale considered here. Dandak, for instance, only comes up to 1550, and doesn't fit any simple MCA/LIA dichotomy. The Lonar is mentioned several times, but never described, nor plotted, and the reference for it indicates the record is still not published (nor is it clear what 'geochemistry' means as a proxy type). Several of the records are from pollen, which can have lags, human influence, and multiple climate interpretations at these time scales. The Godavari core (again, it isn't clear what 'bioisotopes' means), has only a handful of measurements in the last millennium. The Pokhara Valley cave record places the Little Ice Age in the late 1500s, but one could easily place the end of MCA in the 12th century or the 1300 to 1400s (how then was the choice to assign the LIA to 1515 to 1715 in the present analysis made?). Overall, the selection of the proxies used here doesn't seem to follow any particular justification, and their interpretation is severely hampered by time uncertainty, sampling resolution, and multiple possible interpretations."

Thanks for your critical comment about the uncertainties in the proxy data. We clarified this in the manuscript and added some additional comments about their confidence level (page 8, lines 8-13). Further we updated the information for Dandak and Jhumar record and added a new site from the Himalayas (Dharamjali cave with a ~1800-yr long chronology), which is shown in Table 1 and Fig. 3. It is based on U/Th dated aragonite stalagmites using $\delta$18O and $\delta$13C proxies. The selection of MWP and LIA has been answered in 1. In order to classify the uncertainty level in the records, we introduced a 3 color-coded scaling in Table 1 (red, orange and green). In our study we selected all existing proxies from the archives in India for the interpretation regardless of the level of uncertainty. The Dandak and Jhumar sites are now updated for the last 2000 years. The Lonar record is based on geochemistry that means evaporitic mineral



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type (gaylussite and calcite) and isotopic analysis. The moisture signal from Lonar is plotted in Fig. 6a, b, c and has been recently published by Anoop et al., 2013 and Menzel et al., 2013. More Lonar publications are currently in progress: Prasad et al., 2013 (in preparation), Riedel et al., 2013 (in revision) and Sarkar et al., 2013 (in review). We updated the references in the manuscript and in Table 1. The Godavari record is based on $\delta$13C plant waxes proxies on centennial scale resolution, but the authors have used archaeological data (building of water tanks) to support their findings. The dating uncertainties in the records exist, but for the archives used here we have checked the sedimentation / growth rate (stalagmites, trees). The stalagmites are well dated. In case of the sediments, we have used changes in lithology to estimate if there were any major changes in sedimentation rate (there were no reasons for such a conclusion). In any case, the stalagmites are given higher confidence level as compared to sediments with the exception of Lonar lake, which is very well dated.

"3. A lingering question regards uncertainties both in the model representation of major teleconnection modes and the observation data used. Regarding observational data, large parts of the study domain are poorly observed and have very limited instrumental records."

Thanks a lot for your helpful comments. We agree with your arguments, that some further information about the uncertainties in model and observation data have to be added in the discussion about our results. Further we add two references for GPCC data (Becker et al., 2013 and Schneider et al., 2013) and its errors in the main manuscript to highlight the advantages and disadvantages.

"Where do we actually have confidence (or no confidence) in the APHRODITE and GPCC rainfall products? What are their uncertainties?"

APHRODITE (summarized from Yatagai et al., 2012):

The spatial density of rain-gauge stations (based on more stations than GPCC) are shown in Yatagai et al., 2012 (see Fig. 1 in the ref.). The advantages of the improved





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rainfall data set verify that heavy rainfall along the Himalayas and the narrow precipitation zone along the Western Ghats are well represented due to a denser gauge network and an improved algorithm. Strong rainfall along the rainfall patterns over South and Southeast Asia are resembled more precisely with APHRODITE. It is also mentioned, that without input data from Nepal, Bhutan and northern India the precipitation is underestimated. Finally the most important outcome of this high resolved data set is that it can be mostly used for understanding and validating of tropical monsoon precipitation in accordance to submonthly or intraseasonal oscillations. The estimate of rainfall is more reliable and avoids false penetration of wet zone's precipitation to arid regions. It is a helpful tool especially for runoff studies and climate change assessments at high altitudes and high latitudes to discriminate between snowfall and rainfall. However, for the analysis of interannual variations it is crucial to consider the change of the number of gauges, the configuration of the gauge network over many years and the spatiotemporal variation in the number of data. This data set mostly suggests an investigation of future changes in monsoon and/or extreme events and assessments of historical/future changes in hydrological flow, which rely on accurate long-term daily gridded rainfall data. This has been achieved within the APHRODITE project. Therefore, we used APHRODITE as one gridded high resolved rainfall data set for model validation.

GPCC6 Full-Data (summarized from Becker et al., 2013 and Schneider et al., 2013):

This monthly gridded data set from 1901-2010 with a spatial resolution of 0.5° is based on near-real time and non-real time rainfall data over global land surface. It shows the best accuracy for verification of model-based case studies, re-analysis and for global assessment of water resources. The data are also used for analysis of historic global precipitation and large-scale variability patterns. Further it can be used for trend analysis. Three groups of uncertainties are defined:

1. Systematic errors due to gauge-measurements 2. Stochastic sampling errors due to sparse network density 3. Residual errors due to spatial and temporal discontinuities



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The uncertainty of the best estimate for terrestrial annual precipitation has been estimated to be ±10 mm due to false correction methods of systematic gauge-measuring errors. An improved correction method considering monthly weather conditions is applied in evaluation. The next release of an enlarged and improved data base will include a better correction of systematic gauge-measuring errors, which will help to reduce the uncertainty in estimating the land surface precipitation. Since the rainfall product is one of the best accurate state-of-the-art data sets, we used it for our model evaluation.

"I'm also concerned about how realistically the models represent teleconnections between the monsoon and remote modes of variability. How well does the ECHAM model reproduce teleconnections between ENSO and the monsoon? How realistic is the coupled model's ENSO and IOD and PDO, for instance?"

We completely agree with your concern, how realistically these models can really resemble the teleconnections between the monsoon and remote climate modes. Many studies still postulate a serious problem in reproducing these interactions realistically, which is due to an insufficient understanding in the physical mechanisms of the atmosphere-ocean coupling and its parameterization in the ESM. Transient long-term simulations with fully-coupled global models in a coarse spatial resolution have been improved during the last years, but need still a further modification in accordance to changing knowledge about the air-sea dynamics. Currently, we are using one of the state-of-the-art coupled models (MPI-ESM) to simulate the coupled climate system as realistic as possible considering the remaining errors. In order to validate the ENSO signal in the MPI-ESM we compared it with observational ENSO for the last ∼130 years. Figure 1s (see below) shows the ENSO time series between the coupled MPI-ESM (we neglected the ECHAM5 model in the plot since it shows the identical signal as seen in the driving ESM) and the observed Niño 3.4 index based on HadISST data (1871-2000). The anomalies are computed by subtracting the 1950-1979 monthly mean climatology from raw SST data. Later the anomalies have been area averaged by summation over cosine latitude weighted anomalies on offset grid. The region is: 170-



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120W/5S-5N. A 5 month running mean has been applied to the area averaged time series. The fourth order low pass Butterworth filter with normalized cutoff frequency of 0.05 has been used to smooth the data. Although there is a low 1.75-yr lag-correlation of 0.32 (99%) between simulated and observed Niño 3.4 index the MPI-ESM is able to capture the same sign in the positive and negative ENSO phases as seen in the observations during most of the periods especially after 1950s. The present-day global warming signal can be captured by the model. The same approach for the DMI shows similar results. Thus we can summarize, that the correlation is low, but the signs of the phases can be well reproduced. Further the results have to be interpreted carefully with respect to the errors in the observed SST from Hadley Centre.

"One thing that appears worrying in this regard is the lack of a meaningful tropical Pacific correlation with the leading EOF of the modeled drought index (Figure 9)."

The aim of this correlation has been on the direct model-proxy-intercomparison in order to follow the algorithm of Cook et al., 2010. Therefore, we correlated the Principal Components of modeled PDSI with the observational SST indicating a lower correlation (see also our response to referee 1).

"Additionally, what are the consequences for using an atmosphere only model to simulate the monsoon? Here I'm thinking of Kumar et al. 2005, who found that coupling between ocean and atmosphere was necessary for accurately simulating teleconnections between the tropical Pacific and the monsoon. What are the consequences within this study of specifying the SSTs in atmosphere-only ECHAM5 simulations?"

That is a legitimate comment. Therefore, we added some more information about the selection of the atmosphere-only ECHAM model for our time slice experiments (page 5, lines 6-13) and added the reference from Krishna Kumar et al., 2005. We emphasized on the atmospheric response of a higher resolved monsoon circulation. In order to better understand the atmosphere-ocean imprint on the monsoon system, long-term AOGCM simulations as the transient fully-coupled Millennium experiments provide that



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essential oceanic response. Monsoon feedbacks with internal modes of the ocean as ENSO are developed within the fully coupled ESM and are later transferred to our time slice experiments by prescribed fixed SSTs (see also our comment above). High resolution time slice experiments using AOGCMs further need a long spin-up time especially for the oceanic part as well as a large amount of computing ressources, which has been beyond the scope of our study since we only focused on centennial scale long time slices.

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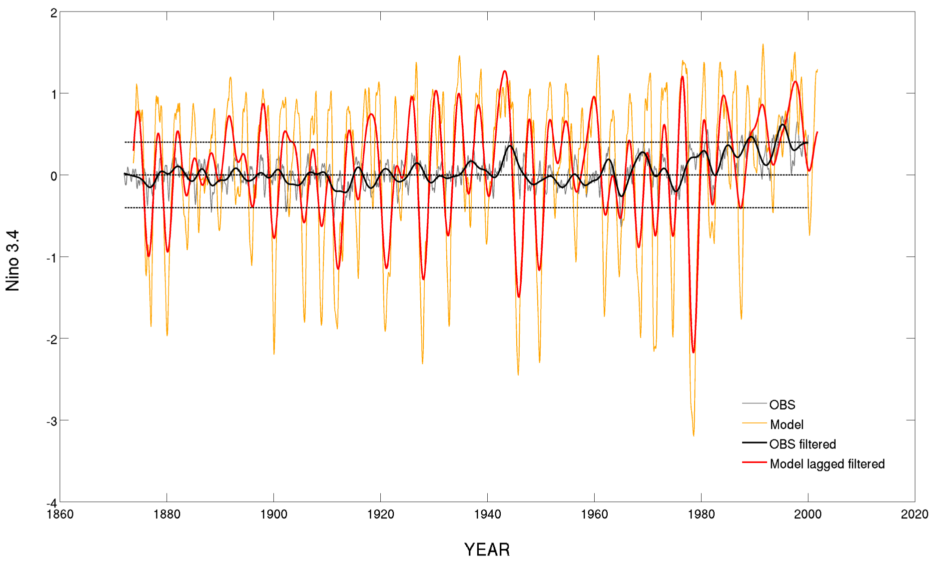


**Fig. 1.** f01s_enso_validation