Responses to Reviewer 2

At the outset, we would like to thank the reviewer for her useful and encouraging comments, which have improved the standard of the manuscript.

Specific Comments:

(1) Paleoclimate reconstructions from proxy data suggest that during the MWP, a cooler tropical eastern Pacific, referred to as a La Niña-like background state, is reconstructed. However, this is not evident in the PMIP3 model simulations. Almost all the models except one consistently simulate more El Niños as compared to La Niñas during the MWP compared to the LIA.

In P.14, the authors state that "It is known that the El Niños (La Niñas) cause anomalous increase (decrease) in global temperature. Therefore, a predominant presence of higher number of simulated El Niños as compared to La Niñas in almost all the models is the reason why the simulated MWP is warmer as compared to the LIA. Given this agreement across the models, we can surmise that, in real world too, the MWP is likely due to the occurrence of a relatively higher frequency of El Niños as compared to the La Niñas".

I think this statement is not reasonable. The reconstruction exhibits a La Niña-like pattern in the tropical Pacific during the MCA (Cobb et al. 2003; Graham et al. 2007; Mann et al. 2009). Besides, the La Niña-like condition is reproduced in simulations employing the simplified Zebiak-Cane model of the tropical Pacific coupled oceanatmosphere system (Mann et al. 2005), which exhibits a stronger dynamical feedback than most global models. Thus, it is not correct to say that in real world, the MWP is likely due to the occurrence of a relatively higher frequency of El Niños as compared to the La Niñas" just from the perspective of model results. The global temperature changes may have been driven by the effective radiative forcing during the past millennium. However, there is little evidence for globally synchronized MCA and LIA intervals, with the specific timing of these intervals varying regionally, which may have been dominated by the internal variability.

Cobb, K., C. Charles, H. Cheng, and R. Edwards, 2003: El Nino/Southern Oscillation and tropical Pacific climate during the last millennium. Nature, 424, 271- 276.

Graham, N. E., and Coauthors, 2007: Tropical Pacific-mid-latitude teleconnections in medieval times, Climatic Change, 83, 241-285.

Mann, M. E., M. A. Cane, S. E. Zebiak, and A. Clement, 2005: Volcanic and solar forcing of the tropical Pacific over the past 1000 years. J. Climate, 18, 447-456.

Mann, M. E., and Coauthors, 2009: Global signatures and dynamical origins of the Little Ice Age and Medieval Climate Anomaly. Science, 326, 1256-1260.

Response:

Thank you for thought-provoking comment. Motivated by the suggestion, we checked the suggested papers out, and in the process, found another recent paper. While the papers suggested by the reviewer suggest that MCA has been a host to more La Niñas, there is at least one proxy-based paper, Conroy et al., (2008), which finds that their diatom record are not consistent on SST interpretation with that of a coral record (Cobb et al., 2003). Specifically, while the diatom record suggests warmer SST in the eastern equatorial pacific during a portion of the medieval period, the coral derived SST indicates a cooling trend. Conroy et al. (2008) suggest a more heterogeneous SST in the region.

Therefore, we temper our discussion as follows.

"Interestingly, a majority of the PMIP3 models in this study indicate more El Niños as compared to the La Niñas during the MWP. Tellingly, in the recent period, El Niños (La Niñas) have been suggested to cause anomalous increase (decrease) in global temperature (e.g. Trenberth and Stepaniak, 2001). Therefore, a predominant presence of higher number of simulated El Niños as compared to La Niñas in almost all the models is a possible reason why the simulated MWP, at least in some tropical regions, is warmer as compared to the LIA. Having said this, this needs to be verified by making some AGCM sensitivity experiments (such as forcing them with the MWP & LIA SSTs, and later repeat them by removing a few El Niño/La Niñas), which we plan to do I near future.

Importantly, a study using a Cane-Zebiak type of coupled model (Mann et al., 2005) suggests more La Niña-like conditions during the MWP. Several proxy-data studies (Cobb et al. 2003; Graham et al. 2007; Mann et al. 2009) suggest either a weak ENSO variance or more La Niñas during the MWP. Then again, a study by Conroy et al., (2008), which finds that their diatom record is not consistent on SST interpretation with that of a coral record (Cobb et al., 2003). Specifically, while the diatom record suggests warmer SST in the eastern equatorial pacific during a portion of the medieval period, the coral derived SST indicates a cooling trend. Conroy et al. (2008) suggest a more heterogeneous SST in the region. Therefore, a predominant presence of higher number of simulated El Niños as compared to La Niñas in almost all the models is the reason why the simulated MWP is warmer as compared to the LIA. Given this agreement across the models, which have a more detailed oceanic component as compared to that used in Mann et al. (2005), we can surmise that, in real world too, the possibility of occurrence of MWP due to the occurrence of a relatively higher frequency of El Niños as compared to the La Niñas cannot be ruled out completely".

Conroy et al. (2008). Unprecedented recent warming of surface temperatures in the eastern tropical Pacific Ocean. *Nature Geoscience* **2**, 46 - 50 (2009) doi:10.1038/ngeo390

(2) The simulated ISMR anomaly shows a weak decreasing trend throughout the LM. The authors also attributed the possible dynamics to the more number of El Niños during the MWP as compared to the LM. The distribution of summer velocity potential at 850 hPa suggests a westward shift in Walker circulation, and the anomalous divergence center in the west also extends into the equatorial eastern Indian Ocean, which results in an anomalous convergence zone over India and therefore excess rainfall during the MWP. It is good that the model results are inter-consistent by themselves. Proxy records also suggest that the ISMR was higher during the MWP and relatively weaker during the LIA (Yadava et al. 2005). A speleothem-based reconstruction of ISMR variability exhibits an increased summer monsoon precipitation during the MWP and a severe weakening of monsoon rainfall during the LIA, apparently associated with droughts particularly between 13th and 17th centuries. However, proxy reconstructions show opposite ENSO conditions as compared with the simulations during the MWP and LIA periods, how can we explain the ENSO-monsoon relationship and the possible dynamics from the reconstruction perspective?

Response:

Thank you for the comment. The response to the above comment provides a partial answer in relation to the uncertainties associated with the ENSO conditions. In addition, models are in confirmation with proxy studies such as Yadava et al., Ramesh et al., Thamban et al. in the sense that they simulate above normal (below) rainfall during MWP (LIA).

We have ascertained through a correlation analysis between Nino3.4 index and 850 hPa Velocity Potential that many models reproduce the typical anomalous divergence over the western pacific-through-Indian region; associated with El Niños (the figure below shows some samples). From this, it is apparent that while the interannual dynamics behind ENSO-ISMR connections are likely similar to that during the current day, the long term changes in the Walker circulation between the MWP and LIA modulate the El Niñoo impacts.

(3) Apart from the Walker circulation changes, does the land-sea thermal contrast change in the upper-troposphere also play an important role for the ISMR variability during the LM? If yes, can we further attributed to the external forcing drivers? Since the correlations between ENSO and the ISMR may differ on the multi-decadal-to centennial scales from that on the inter-annual timescales.

Response:

Thank you for the very important comment. We have checked the simulated land sea thermal gradient. Our new analysis shows a weakening land sea gradient at the 850 hPa (e.g. Sinha et al., 2015; Roxy et al., 2015) during LIA compared to MWP in five out of eight models, and also in the upper troposphere (e.g. Goswami et al., 2006; Wang et al., 2013). . Having said that, it is difficult to say whether this is related to the decadal circulation changes associated with ENSO, or independent of them. We cannot also comment whether such changes are associated with external forcings such as volcanoes, unless we conduct sensitivity experiments with AGCMs. Unfortunately, carrying out such experiments is beyond the scope of the current study. These aspects are also reflected in the revised text.

Just for information, Eurasian snow cover, land sea contrast, Atlantic variability, etc. are some of the other forcings suggested in addition to the tropical Indo-pacific drivers.

Sinha, A. *et al*. Trends and oscillations in the Indian summer monsoon rainfall over the last two millennia. *Nat. Commun.* 6:6309 doi: 10.1038/ncomms7309 (2015).

Goswami, B. N., Madhusoodanan, M. S., Neema, C. P. & Sengupta, D. A physical mechanism for North Atlantic SST influence on the Indian summer monsoon. Geophys. Res. Lett. 33, L02706 (2006).

Wang et al., 2013. Northern Hemisphere summer monsoon intensified by mega-El Nino/southern oscillation and Atlantic Multidecadal oscillation. Proc. Natl. Acad. Sci. USA 110, 5347–5352.

Typing Errors:

(1) P.16, Line 16, there are two “due to”, delete one

Thank you. Corrected it.