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Interactive comment on "The Global Monsoon across Time Scales: is there coherent variability of regional monsoons?" *by* P. X. Wang et al.

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We appreciate the thoughtful and constructive comments by Dr. Clemens. Here is our response to the raised questions:

General comments:

(1)"…the title of the paper would likely be phrased as a statement, as opposed to a question (The Global Monsoon across Time Scales: coherent variability of regional monsoons)."

Agree. The suggested title will be used in the revised version.

(2) "…it is truly difficult to decide on whether a qualified 'no' or a qualified 'yes' is more

appropriate in answer to the question posed in the title. "

Following the reviewer's comment, the revised subtitle reads "coherent variability of regional monsoons", but it does not exclude regional difference. In response to the annual variation of insolation, the global monsoon system is intrinsically anti-symmetric about the equator: In the summer hemisphere is enhanced rainfall (ascending motion, upper-level divergence and low-level convergence and associated upper-level anticyclone and low-level cyclone systems), whereas in the winter hemisphere are precipitation and circulation patterns with opposite signs. Similarly, the coherent variability of the GM under change of orbital forcing does not mean the monsoon rainfall or circulation at various regions have the same signs of anomalies. Rather, it may feature hemispheric anti-phased patterns depending on the spatial-temporal structure of the insolation. So a dynamically coherent GM response pattern can vary from region to region.

(3) "…the manuscript is slightly biased toward the GM paradigm at the expense of the regional differences, at least at the orbital scale." We double checked the related paragraphs and slightly revised the text.

Specific comments:

(2178) "the Cariaco Basin for the North American monsoon (Haug et al., 2001) and elsewhere". The reviewer comments: ".South American Monsoon. . .?"

No, Cariaco Basin is located north of the equator and in the extension of the North American monsoon region. Please see Figs.2 and 3.

(2179) "The 8-ka'delay' relative to precession minima is interpreted as a response to multiple forcing mechanisms, only one of which is latent hear export from the SH. The other two are glacial boundary conditions and NH summer insolation."

Agree. The 8-kyr delayed response of Asian monsoon to insolation has been speculated to be contributed significantly by the latent heat transport from the South Indian

Ocean (Liu et al, 2006). Since the Southern Indian SST response to the SH insolation, which is out of phase with the NH insolation (∼10 kyr delay), the latent heat associated with the SST change in the South Indian Ocean is transported into the Asian monsoon region also with a 10-kyr delay. This delayed remote impact, when superimposed on the effects of the local (NH) insolation (in phase) and ice volume effect (4.5-kyr delay), may have generated a 8-kyr delay inferred from the multi-proxy stack Asian monsoon record. Although the mechanism of SH latent transport is confirmed by a modeling study (Liu et al., 2006), the final response of the Asian monsoon depends on the relative contribution from the local insolation, ice volume and the remote latent heat transport. This relative contribution remains to be further assessed.

“ Appropriate reference to these two diverging views should include both views, Ruddiman 2006 as well as Clemens and Prell, 2007 (Quaternary Science Reviews, 26, 2007, 275–278, Viewpoint: The timing of orbital-scale Indian monsoon changes).”

Done.

“ (Table 1) Speleothem d18O, to my knowledge, has not been put forth as a proxy for Precipitation Rate (e.g. mm/d). I don’t think that any proxy has been so boldly interpreted.”

The word “rate” deleted from the Table.

(2181) “If Ruddiman 2006 is referenced here then Clemens and Prell 2007 should also be included at this location (Quaternary Science Reviews, 26, (2007), 275–278, Viewpoint: The timing of orbital-scale Indian monsoon changes).”

Already cited above (2179).

(2182) “In the geological records, the surface precipitation isotope signal recorded in speleothem calcite can be induced by processes other than local summer monsoon rainfall, including Spring- Winter- and Fall-season rainfall, changes in the isotopic composition of the vapor source, changes in evaporation and precipitation along the transport path, changes in the local temperature of atmospheric condensation, residence time and exchange with extant groundwaters, and evaporation in the epikarst and/or within the cave itself (Fairchild 2006, Earth-Science Reviews 75, 105–153; Baker 2010, Global and Planetary Change 71, 201–206; Dayem, 2010, Earth and Planetary Science Letters 295, 219–230; McDermott 2004, Quaternary Science Reviews 23, 901–918)”.

It is generally true that the causes of the speleothem carbonate (calcite and aragonite) ïĄď18O values are complex and these values are difficult to interpret, because many factors may be potentially involved which are difficult to quantify. Regarding most speleothem works, however, the replication test (Hendy 1971 GCA 35, 801–824) were commonly used to rule out possible impacts from local effects such as those listed in the comment. For example, the Hulu and Dongge cave d18O records from the East Asian monsoon region are essentially the same over contemporary periods, not only among different stalagmites from the same cave, but also between the two caves that are more than 1200 km away from each other with quite different cave settings (e.g., Yuan et al., 2004 Science 304, 575–578; Cheng et al., 2012 Climate Dynamics 39, 1045–1062). Indeed, most published speleothem d18O records from monsoon regions reflect d18O values of mean annual precipitations based on the replication test. Another notable aspect of the speleothem d18O records is their broadly similar signatures within each monsoon domain regardless of seasonality difference, resulted possibly from the broad change in atmospheric circulation, which shift moisture sources and rainfall patterns across a whole monsoon system, for example, in the Asian or South American monsoon regions (Cruz et al., 2005 Nature 434, 63–66; Wang et al., 2007 GRL 34, L23701, doi:10.1029/2007GL031149; Cheng et al., 2012 Climate Dynamics 39, 1045–1062; Liu et al., 2014 QSR 83, 115–128). As such, the d18O records most likely indicate monsoon intensity as a whole, rather than the local precipitation amount in most cases. This interpretation is widely supported by a series of modeling works (e.g., Schmidt et al., 2007 JGR 112, D10103, doi:10.1029/2006JD007781; LeGrande and Schmidt 2009, CP 5, 441–455; Pausata et al., 2011 Nature Geoscience 4, 474–

480; Zhao and Harrison 2012 Climate Dynamics 39, 1457–1487; Liu et al., 2014 QSR 83, 115–128; Battisti et al., 2014, JGR in review). The simulation studies demonstrate a tempo-spatial pattern of precipitation d18O and associated overall monsoon intensity change (and/or wind strength), which is broadly consistent with those observed through many speleothem records in monsoon regions (e.g., Liu et al., 2014 QSR 83, 115–128; Battisti et al., 2014, JGR in review).

(2183) "This manuscript defines monsoon regions on the basis of having local summer precipitation exceed 55% of the annual total. . . .in the cave region of SE China, 45% to 50% of the total annual precipitation falls outside the summer monsoon season, with very distinct isotopic compositions. Hence, in this region, cave d18O cannot be interpreted as a summer-season monsoon proxy"

Based on modern instrumental observation, the southeastern China (centered at 25°N, 115°E) has a rainy season from April to June (Fig. 3c of Wang and LinHo 2002). However, the amount of May-through- September rainfall remains over 55% of the annual total except a tiny spot, so that this region still fits in the monsoon definition (see Fig. 4c of Wang and LinHo 2002). [Wang, B. and LinHo, 2002: Rainy seasons of the Asian-Pacific monsoon. J. Climate, 15, 386-398.]

(2187) ". . .it is not clear why the Dole effect and inorganic d13c rise to the top of potential GM proxy candidates. Both are described as having remaining obstacles that seem no less to overcome than the difficulties of the other proxies discussed."

Not all proxies can record the global monsoon variability, the two proxies mentioned above are most promising in providing global signals. The ice core bubble provides the unique archive of "fossil air". The Earth's Dole effect describes the isotopic 18O/16O-enrichment of atmospheric oxygen in ice bubbles with respect to ocean water which is most sensitive to variability of the hydrological cycle dominated by the global monsoon (Severinghaus et al., 2009, Science, 324: 1431-1434; Landais et al., 2010, QSR, 29: 235–246). The long eccentricity cycle in oceanic carbon reservoir was recognized as

"the Heartbeat of the Oligocene Climate System" because of its global nature (Pälike et al.,2006, Science, 314, 1894–1898), and this applies to all geological period. At the long-eccentricity maximum, summer insolation maximizes at low latitudes and regional and global seasonality increase. This results in an intensified global monsoon and enhanced precipitation, which boosts both chemical weathering on land and river runoff, increasing nutrient input to the ocean. In the nutrient-excited ocean, eukaryote large phytoplankton is stimulated and surface productivity increases, which in turn raises the POC/DOC ratio and diminishes δ13C in the global ocean (Wang et al., 2014, National Science Review, 1: 119–143).

(2202-2212) "This section is oddly constructed. . . .. . .Holocene records with total lengths less than 1/2 that of the shortest orbital cycle. The response to one half of one precession cycle is insufficient to understand the GM response to orbital forcing. . .. . . Discussion of Holocene records should be limited to Section 5."

True the Holocene covers only "one half of one precession cycle", but it was the starting point how orbital forcing was recognized in the paleoclimate records. The very first paper on precessional forcing of monsoon climate was "Monsoon climate of the early Holocene: climate experiment with the earth's orbital parameters for 9000 years ago" (J.Kutzbach, Science, 1981). Because the gradual changes of monsoon in the Holocene is typical of the orbital-scale, we preferred to leave this sub-section in Section 6.

"Figures 14, 15 and 16 (and associated text) discuss records that span only 120 to 200 kyrs,. . .. . .For the purposes of considering orbital-scale variability in this type of paper, records out to 500 kyrs might be more appropriate."

We agree that 500 kyrs data would be more convincing than 120 to 200 kyr. However, figures 14-16 are used to demonstrate the anti-phasing between the Northern and Southern Hemisphere. Since the Southern Hemisphere data up-to-now remain relatively short, the time duration of the figures are limited by the availability of the SH records.

“The GM publication of Caley and others (2011) should also be referenced and discussed”

This paper and its view was cited and discussed in the paper. Because of the page limitation, we tried our best to avoid repetition and redundancy in the text as a review paper.

(2207) “ Russon 2010 may not be an appropriate reference here as it makes no mention of monsoons in the explanation of the global ocean d13C cyclicity. Rather, it focuses on changes in global-scale carbonate and silica production.”

Indeed, the paper used numerical modeling to orbital eccentricity cycle leading to changes in seasonality and hence carbon cycling in the ocean . Their modeling results, however, provide support to the notion that the strong imprint of the 400-kyr cyclicity in the oceanic proxy records is a response to the low-latitude insolation changes and hence monsoon variability (Wang et al., 2010, EPSL, 290: 319–330).

(2179) “ In this context the correct Ziegler et al., 2010 reference is (Ziegler et al., 2010 Precession phasing offset between Indian summer monsoon and Arabian Sea productivity linked to changes in Atlantic overturning circulation.Paleonceanography, 25, PA3213, doi:10.1029/2009PA001884, 2010), instead of the reference to the 2010 Mediterranean work.”

Corrected.

“Appropriate references to the clear distinction between which parts of the monsoon system various proxies monitor (e.g. wind, rainfall. . .) would be Clemens et al., Paleoceanography, 25, PA4207, doi:10.1029/2010PA001926, 2010. In terms of the links between winds, moisture transport, and rainfall, an appropriate reference would be Liu et al. 2006, Hemispheric insolation forcing of the Indian Ocean and Asian Monsoon:Local versus remote impacts, Journal of Climate, 19, 6195-6208.”

Accepted and revised.

In general, we appreciate very much the thoughtful comments of Dr. Clemens on our paper, particularly concerning the orbital-scale monsoon changes, which are highly helpful for improving the manuscript. The main issues raised in the comments include (1) limitation in time coverage of the used geological records; (2) the phase relationships between monsoon and the precession, and (3) the underlying mechanisms.

We agree that a comprehensive understanding of the paleomonsoon histories would require considering a much wider range of geological records that can be accurately dated. Nevertheless, accurate dating of geological records is among the major difficulties, in particular, for the chronological range beyond the ability of the radiocarbon method. This is the reason why the geological records used in the review were not extended to a longer period. As to the phase relationship and the underlying mechanism of monsoon variability, those are the major topics of our companion paper, the second synthesis of the PAGES Global Monsoon Working Group, and the related issues will be discussed there.

Interactive comment on Clim. Past Discuss., 10, 2163, 2014.