

## ***Interactive comment on “Individual and combined effects of ice sheets and precession on MIS-13 climate” by Q. Z. Yin et al.***

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We thank Referee1 for the helpful and constructive comments which have been taken into account in the revised version and given here in some details.

Revisions for the major concerns of Referee1:

1. In the revised version, we have added the followings important references for the Asian monsoon study: (1) An et al., Quat. Res., 36, 29-36, 1991. (2) An et al., Nature, 411, 62-66, 2001. (3) Liu et al., J. Clim., 19, 6195-6208, 2006 (4) Kutzbach et al., Clim. Dyn., 30, 567-579, 2008. (5) Wang et al., Science, 451, 1090–1093, 2008. (6) Ding and Sikka, Synoptic systems and weather, in: The Asian Monsoon, edited by: Wang, B., 131–202, 2006. (7) Barnett et al., J. Atmos. Sci., 46, 661-685, 1989. (8) Goes et

al., Science, 308(5721), 545-547, 2005. (9) Vernekar and Shukla, J. Clim., 8, 248-266, 1995. (10) Wang et al., Mar. Geol., 201, 5–21, 2003.

2. We have corrected the following references. For de Menocal (1995), we cited it only for African climate. For the reference to the East Asian summer monsoon, we replaced Ding et al (1994) by An et al (2001). The citation of Fezer et al (1996) was also corrected.

3. In the revised Abstract and also in the manuscript, we have spent more time to explain the mechanisms. In the abstract, we have added the following lines emphasizing the mechanism of the ice sheets' influence on the African and Asian summer precipitation.

“Precipitation over different monsoon regions responds differently to the size of the ice sheets. Over North Africa and India, precipitation decreases with increasing ice sheet size due to the southward shift of the Intertropical Convergence Zone (ITCZ), whatever the astronomical configuration is. However, the situation is more complicated over East Asia. The ice sheets play a role through both reducing the land/ocean thermal contrast and generating a wave train which is topographically induced by the EA ice sheet. This wave train contributes to amplify the Asian land/ocean pressure gradient in summer and finally reinforces the precipitation. The presence of this wave train depends on the combined effect of the ice sheet size and insolation. When NH summer occurs at perihelion, the EA is able to induce this wave train whatever its size is, and this wave train plays a more important role than the reduction of the land/ocean thermal contrast. Therefore, the ice sheets reinforce the summer precipitation over East China whatever their sizes are. However, when NH summer occurs at aphelion, there is a threshold in the ice volume beyond which the wave train is not induced anymore. Therefore, below this threshold, the wave train effect is dominant and the ice sheets reinforce precipitation over East China. Beyond this threshold, the ice sheets reduce the precipitation mainly through reducing the land/ocean thermal contrast.”

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4. (a). The model is discussed in the first paragraph of Section 2. And its advantages and limitations have been added as follows:

“LOVECLIM is, within the hierarchy of the Earth system models of intermediate complexity, a low-resolution general circulation model (Claussen et al., 2002). Its main advantage compared to more sophisticated general circulation models is that it is much faster, allowing to study the behavior of the coupled atmosphere-ocean-sea ice-land surface-ice sheet system over thousands of years (a run of 1000 years takes about 3 days on a workstation AMD Opteron 252/2.6 GHZ with 2 CPU dual core/4 GB RAM). The main simplification within LOVECLIM is the coarse resolution and the low level of complexity of some parameterizations. This leads to some limitations which are related, in particular to the prescribed cloudiness and the difficulty to simulate the atmospheric variability at low latitudes. Accordingly, the model results for the tropics should be treated with caution. In particular, the East Asian summer precipitation is underestimated and the low-level geopotential ridge over the North Pacific is shifted northward 10 degrees in latitude compared to observations (Yin et al., 2008). These weaknesses are most likely caused by insufficient spatial resolution and simplified convective physics. As a consequence, quantitative estimates of the effects of astronomical parameters and ice sheets on East Asian precipitation should not be interpreted too rigidly. Yet, LOVECLIM has proved to be a reasonably appropriate tool to identify teleconnections. Moreover, the synoptic systems for the East Asian monsoon region are of hybrid nature due to the existence of a very significant interaction between the monsoonal aircurrents and impacts from mid and high latitudes (Ding and Sikka, 2006). Along with its computing efficiency, this justifies using this model for a first qualitative assessment of the connections between ice sheets and sub-tropical dynamics by means of a series of sensitivity experiments. Moreover, the reliability of our results is tested on the basis of simulations with more sophisticated ocean-atmosphere general circulation models (such experiments, which confirm our results, will be discussed in companion papers). ”

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(b) In the revised version, the role of land/ocean thermal contrast on monsoon has been introduced in many places. For example, in section 5.1, the following is added:

“The fundamental driving mechanisms of monsoon include: (1) land/ocean thermal contrast and the resulting pressure gradient force between the differentially heated regions and (2) moisture-related processes that determine the strength and location of the monsoon precipitation (Webster et al., 1998). According to (1), one might expect that ice sheets, by cooling the continents, will induce a smaller land/ocean thermal contrast and so will contribute to reduce the monsoon rainfall. However, this is not the case over East China. Although the temperature gradient between the Asian land and the surrounding ocean gets indeed slightly smaller, July precipitation increases by 20% over East China relative to the no-ice-sheet case (Exp.1). Consistent with the precipitation increase, the summer low at 800-hPa deepens over a large area of Siberia-Mongolia-China, but at the same time pressure increases over a large region extending from northeastern China to Japan and up to the Pacific. These two pressure anomalies induce a westerly wind anomaly over western China and an easterly wind anomaly blowing from the sea to the land over East China, which converge over central China resulting in more convection there. At the same time, there is a significantly increase of water vapor flux convergence over East China. These intensified convection and moisture availability contribute to increase the precipitation.

These changes in precipitation, pressure and wind fields are also associated with a wave train originating from the EA ice sheet and propagating to the Southeast. This wave train is characterized by (i) an alternation of precipitation increase and decrease ending over East China with a reinforcement of precipitation (Fig. 6a), and (ii) alternating positive (subsidence) and negative (ascent) omega anomalies ending over East China with a large scale ascent (not shown here). This wave train is also remarkably present in the wind divergence field. Our sensitivity experiments using either albedo or topography as the only forcing show that this wave train is mainly generated by the EA ice-sheet topography. The existence of this wave train is consistent with the results

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of Grose and Hoskins (1979) and Hoskins and Karoly (1981) showing that wave trains can be orographically generated in barotropic or baroclinic atmospheres. The phase lock of our wave train over East China is related to the summer low there and to the Tibetan Plateau (Yin et al., 2008). The increase of land/ocean pressure gradient due to the introduction of the ice sheets, opposite to what is expected from the decrease of the land/ocean thermal contrast, is therefore tentatively attributed to the topographically induced wave train.”

In section 5.2, the following is added:

“This anticyclonic anomaly over land and cyclonic anomaly over ocean largely reduce the land/ocean pressure gradient and generate a northwesterly wind anomaly over East China (Fig. 10). At the same time, the water vapor flux divergence increases over East Asia. All these impacts eventually weaken the EASM and reduce precipitation. Therefore, the impacts of the large ice sheets at 495 ka BP are markedly different from what happens at 506 ka BP. In the 495 large-ice-sheet case, the ice sheets influence the EASM mainly through cooling the continent and reducing the land/ocean thermal contrast with no counteraction. On the other hand, in the 495-small-ice-sheet, 506-small-ice-sheet and 506-large-ice-sheet cases, the ice sheets play a role on the EASM through both reducing the land/ocean thermal contrast which tends to weaken the monsoon, and a topographically induced wave train which tends to reinforces it. In these three cases, the reduction of the land/ocean thermal contrast is too small to overcome the wave train effect on the land/ocean pressure gradient.”

5. We have read carefully the manuscript and tried to improve the English.

Revisions for the additional comments:

1. We have reduced and made clearer arrangement for the abbreviations.
2. We have deleted the citation of Felzer et al (1998) from the introduction.
3. “much larger” has been used.

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4. The last paragraph of the introduction has been modified in order to present the scientific questions better. An outline has also been given to direct the reader. The new paragraph is:

“All these results tend to show that the response of the monsoons to ice sheets depends on their size and location, on the different monsoon regions, and on the combined effects of insolation and ice sheets. It is therefore interesting to know whether at MIS-13 the strengthening of precipitation over East China due to the EA used in Yin et al. (2008) holds for other ice volumes and astronomical configurations. Is there a threshold in the ice volume beyond which the ice sheets reduce the summer precipitation? What is the exact role played by the insolation in the relationship between the ice-sheets and the monsoons? What is the response of the precipitation from other monsoon regions to the different ice sheet and astronomical forcings? These questions will be investigated in this paper, focusing mainly on the sensitivity to the NH ice sheets volumes and to the importance of the astronomical configurations. The model and experiments will be described in Sect.2. In an attempt to characterize the orbital signature of interglacials (Kukla et al., 1981), climate response to different astronomical forcings will be discussed in Sect.3. In Sect.4, the response of July temperature to different sizes of the EA and NA ice sheets will be investigated under two opposite precessional situations. In Sect.5, the response of July precipitation to different sizes of the EA and NA ice sheets under the two opposite precessional situations will be discussed for different monsoon regions. Finally, conclusion will be drawn in Sect.6.

Comments 5, 6, 7, 8, 9, 13 and 16: the revisions are done.

10. We have largely reduced the length of Section 4 where the temperature is discussed, and have increased the length of Section 5 where we focus more on the precipitation changes and their mechanisms.

About temperature, we like to stress that this is the first simulation done using ice sheets during the interglacial MIS-13. We think therefore that the results deserve to be

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presented and discussed in some details. We accept however that there are similarities with earlier studies done with NH ice sheets at the LGM for example. In our paper the ice sheets are introduced in a particular interglacial and the climate sensitivity to them is therefore assumed to be different. Moreover the sensitivity during a warm phase (NH summer at perihelion) is compared to the sensitivity during a cool phase (NH summer at aphelion) in the presence of the same ice sheets.

11. In the last paragraph of section 2, we have added the following lines to tell why we choose four ice sheet volumes for 506 ka BP, while only two volumes for 495 ka BP :

“Only two ice volumes were used for 495 ka BP because the experience gained from the 506 ka BP four simulations shows that most of the conclusions can be drawn from these two experiments only.”

12. In the revised version, we have added paragraphs to explain the mechanisms of precipitation changes, especially over Africa and Asia, as much as we can. Fig.6 and Fig.9 reproduce the wave train respective for 506 and 495 ka BP with small (Exp. 4 and 7) and large ice sheets (Exp. 5 and 8). Maps with the other small-ice-sheet sizes (Exp.2 and 3) are very similar to that of Exp.4.

14. We have discussed about the role of the land/ocean thermal contrast on the monsoon in the revised version (see our answer to the major concern 4 above).

15. The impact of the difference in solar forcing between 506 and 495 ka BP (no EA and NA ice sheet) is discussed in section 3 for temperature and precipitation (last paragraph). Actually, the impact of this difference on monsoon has been discussed in detail in Yin et al (2008). In section 5.2, following the recommendation of Referee1, we have discussed the difference when the ice sheets are introduced.

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Interactive comment on Clim. Past Discuss., 5, 557, 2009.

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