“Obliquity forcing of low-latitude climate” by **J. H. C. Bosmans et al.**
Author response to anonymous referee #2

The authors performed two model experiments of obliquity extremes with the climate model EC-Earth. The results show a statistically significant climate response in the tropics. From analyzing the climate response and tropical circulation changes, they argue that the changes are caused by the changes in the cross-equatorial insolation gradient and propose that this gradient may be used to explain obliquity signals in tropical paleoclimate records.

The manuscript shows that even without considering ice-sheets, changing the obliquity results in changes in low-latitude climate. However, the mechanisms of these changes and the relevance of the simulated changes remain unclear. Thus I find the scientific value of the manuscript in its present version somehow limited and recommend major revisions.

My major concerns are the following:

Do the model experiments really prove that the orbital influence is via a low-latitude mechanism? From the presented results, the mechanism of the climate changes is unclear. The response could be caused locally caused or via teleconnections from the high latitudes etc. In principle a climate model could be used to determine this by e.g. running an experiment with changing only insolation in the tropics or in certain latitude bands but with the two simulations performed in this study, this is hard to tell. The conclusion that the simulations “suggest that these patterns arise from a direct response to changes in the cross-equatorial insolation gradient” is thus not well supported by the presented evidence.

Author's response:
Our aim is to show that obliquity-induced climate changes can occur without a lag on the orbital time scale and without any (land) ice changes. The changes that we see fit well with the SITIG hypothesis, better than with other ideas (i.e. we find no enhanced moisture transport from extratropical regions, see for instance figure 2a-d). We will change the line mentioned to "suggest that these patterns may arise..." as indeed an experiment with insolation changes only over the tropics would be needed to solidify this suggestion. Unfortunately this is not (yet) possible with the model (see also response to reviewer 1). We will suggest such an experiment in our Discussion. We will also add references stating that the present-day monsoon strength depends on the strength of the (winter hemisphere) Hadley cell (Lourens & Reichart 1996), also described as differential heating between for instance the Asian continent and the southern subtropical Indian Ocean (e.g. Clemens et al, 1996). This would strengthen the suggestion that such inter-hemispheric gradients drive monsoon strength on Milankovitch timescales as well.

Is the amplitude of the simulated changes relevant?
The relevance of the amplitude of the changes is unclear as no reference is given. Maybe changing the precession parameters would give an even stronger change (thus the problem of a stronger obliquity than precession signal would still be unsolved), or including an ice-sheet would lead to an obliquity caused climate change which is much stronger than the response found in this experiment?
Is the amplitude of the change found in the experiments relevant for proxy records? Maybe showing relative changes would help (e.g. relative precip and wind changes relative to the absolute precip amount / windspeed).

Author's response:
Concerning the amplitude of changes: it is true that the (seasonal) insolation amplitude introduced by precession is greater at the tropics, as expressed in the beginning of our introduction (lines 16-19, p 222). This is also observed in proxy records. The problem that we try to acknowledge in the beginning of our introduction is that while the precession signal in (tropical) proxy records is rather easily explained by the insolation at low latitudes, the obliquity signal is not. The latter does not show up in power spectra of tropical (summer) insolation.

Including an ice-sheet might indeed enhance the response to obliquity changes through an altered meridional temperature gradient (and thus poleward transport of heat and moisture), as discussed in the second part of Section 4.3 (see also response to reviewer 1). However such a response would be slower due to the slow response of ice sheets.
The obliquity-induced changes are relative at the 95% (using a two-sided student t-test), but the relative changes were indeed not mentioned. We have checked the relative changes in precipitation and wind speed, which are given below (figures 1 and 2). Both precipitation and wind speed can change up to, and over, 100% in both summer and winter as well as in the annual mean. This will be mentioned in the revised version (and if required by the editor / reviewer these figures could be shown as supplementary material).

Detailed comments:
Introduction, page 222:
In the introduction about insolation is missing a discussion about the seasonality of the insolation: Precession results in strong changes when looking at single seasons (or single days) but has no effect on annual mean insolation. Obliquity in contrast is the only parameter having a significant influence on the annual mean. Therefore, it is well possible that a 100W/m2 insolation anomaly only acting seasonally (and thus resetting every year) has a smaller influence than a 2W/m2 annual mean change, which persists over thousands of years. Thus I'm not very surprised that some records, even in the tropics, only show obliquity.

Author's response:
Indeed precession and obliquity differ in their effect on annual mean insolation. We will mention this in the introduction. The annual-mean effect of obliquity has been used to explain climate changes through the intrahemispheric insolation (and temperature) gradient. However, some of the proxy records that show obliquity signals in the tropics capture a monsoon signal. Monsoonal precipitation falls mainly in summer so records showing obliquity in monsoonal precipitation must somehow be affected by summer insolation. The SITIG hypothesis presented in our study provides an explanation. Also, annual mean changes show a temperature drop and weaker circulation over the tropics during maximum obliquity, which cannot explain the enhanced precipitation.
Furthermore the precession signal may result in annual mean temperature and precipitation changes because of feedbacks within the climate system or one season being more sensitive to insolation changes (Bosmans et al 2012, 2015 or Herold and Lohmann 2009).

Figures:
Figure quality is relatively poor and at least in my printouts it is hard to identify the axes labels. Please adapt the line thickness and size of axis annotations.
In Figure 6, it has to be clearly stated that these are all summer insolation values (June 21?). Maybe it would be useful to also show the spectra of annual mean insolation, which would give a completely different result.

Author's response:
When seen on A4 the figures look better; they appear smaller in CPD printouts.
Figure 6 indeed shows 21 June insolation values, which will be clarified. A new figure is now included (see comments to reviewer 1). Annual mean insolation would indeed show an obliquity peak and not a precession peak. Although this has been used to explain obliquity signals elsewhere (such as in glacial records, see Section 4.3), annual mean insolation cannot explain the full Milankovitch spectra found in (tropical) records (see remarks above). SITIG shows both a precession and obliquity peak, which fits nicely with for instance the sapropel record.

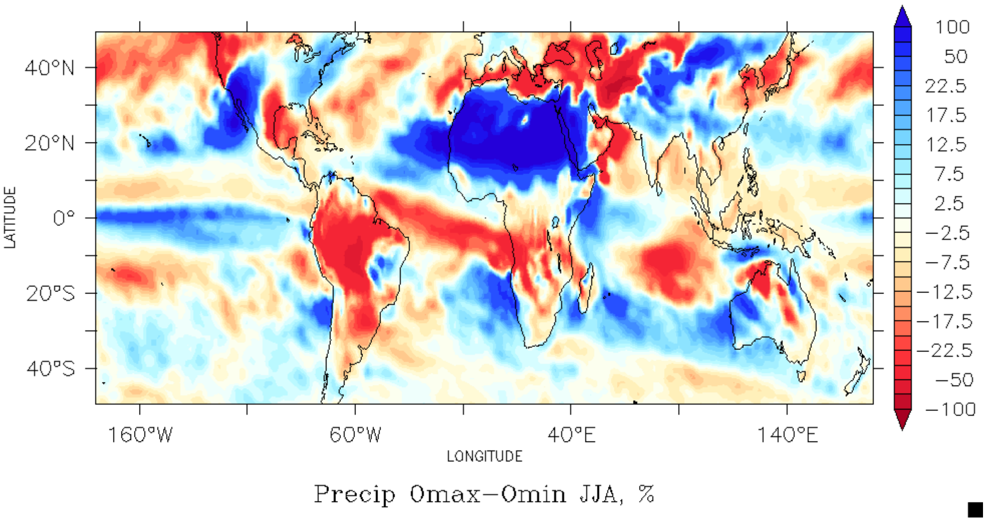

Figure 1a: relative change in summer (JJA) precipitation, percentage ((Tmax-Tmin)*100/Tmin).

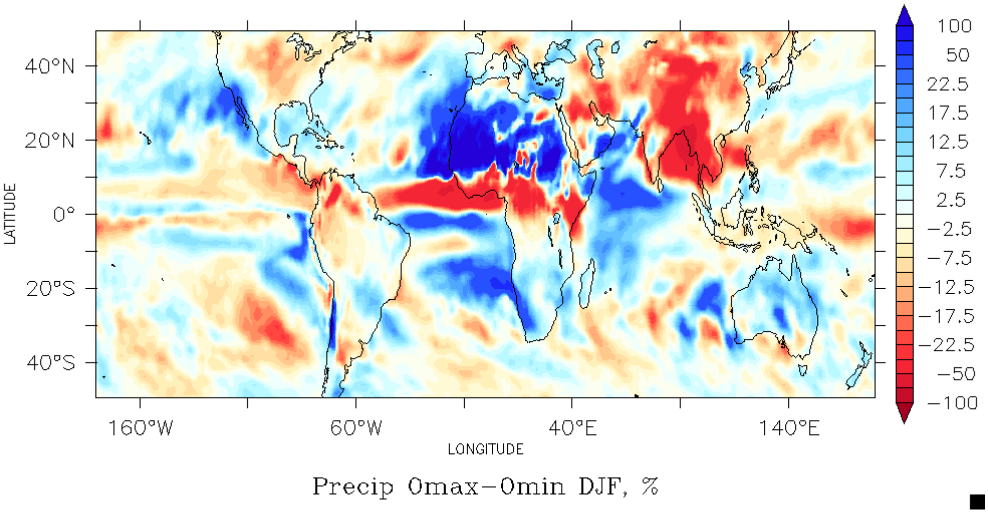

Figure 1b: relative change in winter (DJF) precipitation, percentage

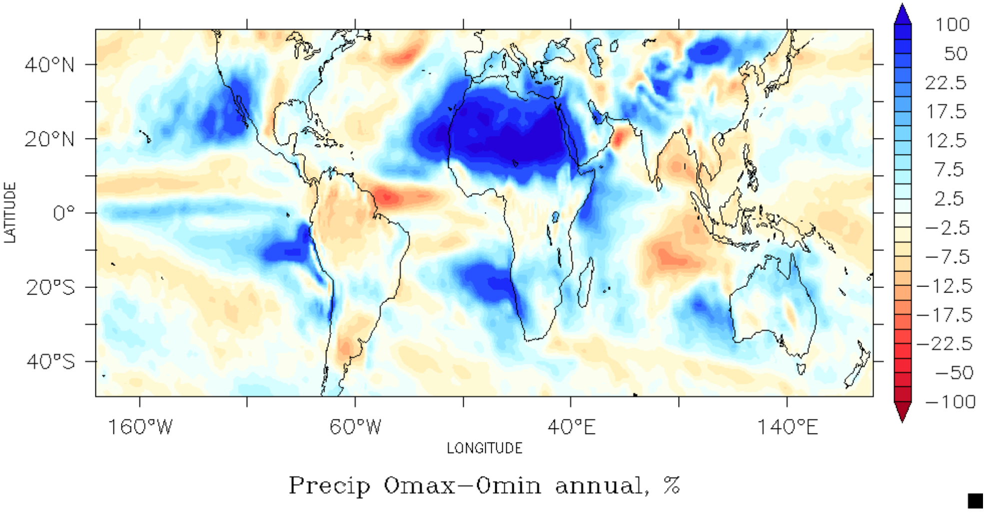

Figure 1c: relative changes in annual mean precipitation, percentage

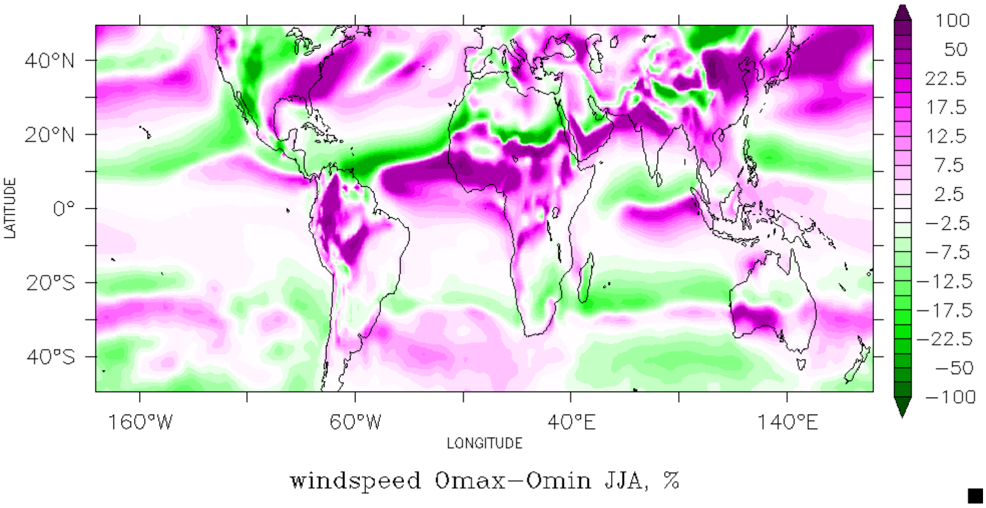

Figure 2a: relative changes in wind speed in summer (JJA), percentage

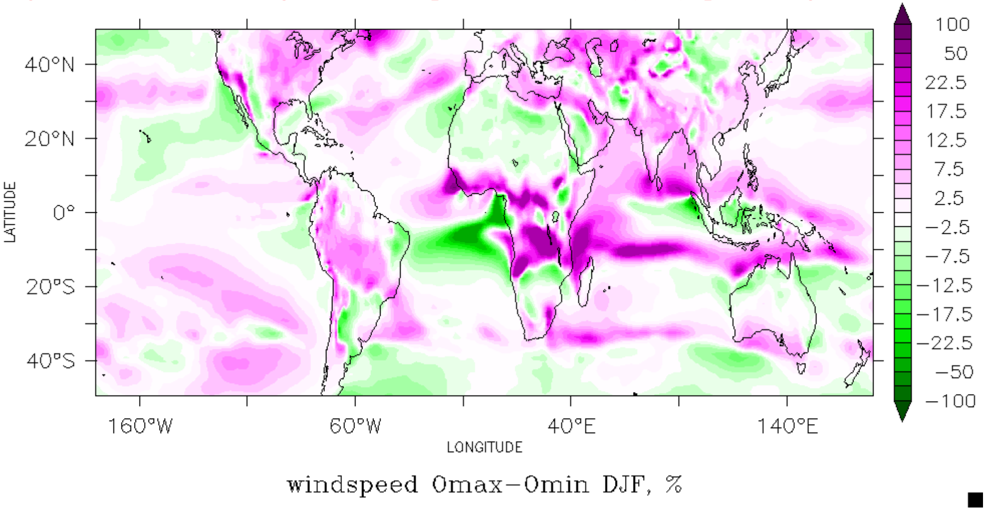

Figure 2b: relative changes in wind speed in winter (DJF), percentage

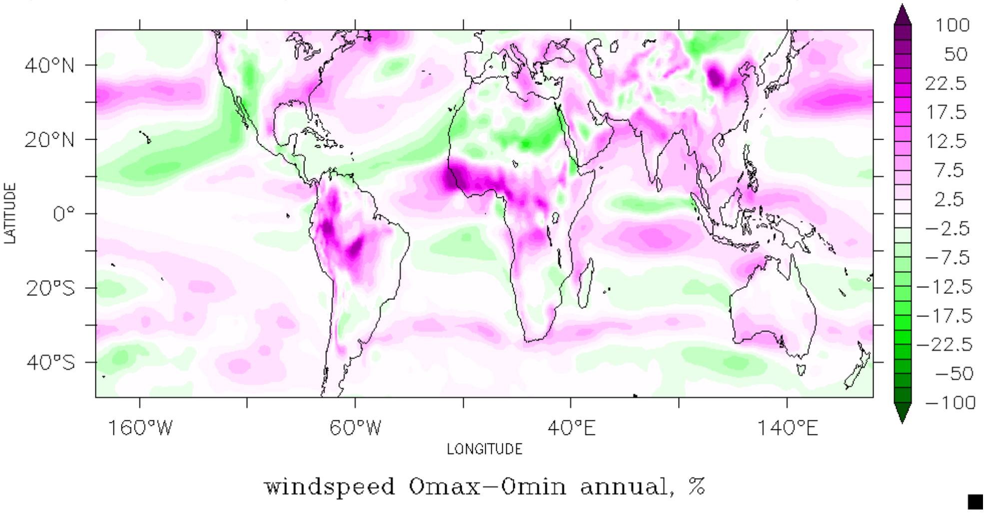

Figure 2c: relative changes in annual mean wind speed, percentage