Clim. Past Discuss., 11, C2756–C2769, 2015
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Interactive Comment

Interactive comment on "The biogeophysical climatic impacts of anthropogenic land use change during the Holocene" *by* M. C. Smith et al.

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Received and published: 24 December 2015

Thank you very much for taking the time and trouble to review our manuscript and for your helpful comments and suggested references.

Our responses to your comments/queries are as follows:

COMMENT: Abstract Maybe the authors already can add some numbers how large global and regional changes are in degrees centigrade – it's trivial to achieve a statistically significant result when the number of samples is high enough. The physical significance might however be irrelevant then.

RESPONSE: Will add global mean temperature changes and maximum regional change for 7ka BP, 2ka BP and PI. The comment on statistical significance is ad-

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dressed below in response to the comments on section 2.1.

COMMENT: 1 Introduction The introduction lacks a general presentation of forcings potentially influencing Holocene climate such as orbital, solar, volcanic and GHG (for an overview refer e.g. Schmidt et al. 2011) – in the present form the reader who is not too familiar with the topic might get the impression that only changes in land use were the main driver of Holocene climatic changes

RESPONSE: This will be included.

COMMENT: 2.1 Model description: The authors state the model does not include an interactive carbon module – which effect might the change in land use have on the carbon cycle ? In their introduction they note that besides the biogeophysical effects there are also biogeochemical effects in terms of changes in CO2 that might offset parts of the albedo changes induced by land use changes.

RESPONSE: Anthropogenic land use changes normally involve deforestation thus reducing the vegetation carbon sink and releasing carbon to the atmosphere particularly if slash and burn agriculture is practised resulting in little carbon being stored in the soil. Kaplan et al (2010) estimated that by AD 1850 cumulative carbon emissions due to land use changes were 325–357 Pg. Some of this excess CO2 will be absorbed by the oceans but much will remain in the atmosphere and, as a greenhouse gas, it will contribute to an increase in global temperatures. The lack of an interactive carbon module in our model means that these atmospheric CO2 changes and resultant warming are not included in our results.

COMMENT: In the last paragraph of the section authors state that changes in land use are very small and localized and therefore one needs to integrate very long times to find a small albeit statistically significant result – I find this strategy a bit unfavorable because a priori this will most likely result in a statistically significant difference independent to the physical significance of the signal (see also von Storch and Zwiers, 1999).

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RESPONSE: As climate data demonstrates variability on a range of timescales it was felt that a longer averaging period would encompass as many modes of variability as possible and thus give a more robust result. There is the potential to get the wrong results if short averaging periods are used. There were effectively 500 samples in our statistical analysis which, for temperature, gives an effect size of about 0.1°C, the minimum contour level used in our plots. Whilst a small difference, its inclusion does add value to the contour plots as it helps visualise the patterns of anomalies in the contour plots and thus to understand the dynamics of the climatic changes. It is worth noting that when the test is run with 50 samples (Figure 1) the results over the major land masses were still found to be statistically significant.

COMMENT: 3 Results Given the effect of changes in RF due to changes in land use, especially in the earlier periods, temperature changes seem to be quite large – According to Fig. 2, the change amounts to 2-3 K in the pre-industrial period over parts of Europe and North America. The temperature increase over these regions is approximately 1-1.5 K in the last 150 years (cf. Supplement of PAGES2k reconstructions). Given this strong impact of land use changes, the temperatures should even decrease over these regions due to the presence of the land use changes. Earlier modelling studies with constant land cover also show temperature evolutions that are comparable to proxy reconstructions using only changes in solar, volcanic and GHG concentrations – how do the authors explain such large impact of land use change?

RESPONSE: The cooling effect of the biogeophysical impacts of ALCC is countered by the biogeochemical effects (increased methane and CO2 production) which increase temperatures. On a global average scale and in most individual regions the overall effect of ALCC when both physical and chemical effects are taken into account the net result will be a warming. As previously mentioned the lack of an interactive carbon module in our model means that we are unable to quantify these atmospheric CO2 changes. However, in a similar study that also included the biogeochemical changes, He et al, 2014 estimated that by 1850 CE the biogeophysical feedbacks of Holocene

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ALCC caused a global cooling of 0.17°C, while biogeochemical feedbacks caused a 0.90°C global warming i.e. the biogeochemical effects of land use were a factor of 5 more important than the biogeophysical effects on the global scale and the physical effects are only dominant in the regions of greatest ALCC such as Europe, N.E. America & E. Asia. In addition during the last 150 years there has been a big increase in greenhouse gas emissions from industrial sources. The cumulative CO2 & methane emissions from industrial sources between 1750 and 2010 have been about 4 times the magnitude of those from land use (IPCC, AR5, SPM, 2014). These industrial emissions would further serve to counter the cooling due to the biogeophysical impacts of land use change. Other considerations are uncertainties in the land use reconstructions. Using the HYDE 3.1 data resulted in smaller anomalies although we feel that the KK10 data is probably more realistic for the reasons outlined in Section 5 (Discussion) of the manuscript. Also, as mentioned later, the equilibrium response could be different to the response achieved when using a transient simulation. The inclusion of ALCC improved the data-model comparison for HadCM3. For a discussion of the relative merits of HadCM3 please see the following response and the response to comments on Section 4.

COMMENT: Another important point relates to the treatment of convection, soil moisture and hence cloud cover – the drying of soils would eventually lead to less convection and less cloud cover leading to increase in shortwave radiation counteracting the increase in albedo due to land cover change. How well does HadCM3 address these processes that would be important to assess the full range and implications of land use changes, especially on the local scale ?

RESPONSE: Soil moisture and the exchange of moisture between the surface and the atmosphere is calculated by MOSES II (Met Office Surface Exchange Scheme) which is coupled to HadCM3. In MOSES soil moisture is represented on four subsurface layers. The soil moisture is treated as homogeneous across a grid box. Bare-soil evaporation is drawn from the surface soil layer only. Harris et al (2004) found that

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MOSES/HadCM3 was able to simulate the observed fluxes of heat, moisture and carbon in Amazonia with reasonable accuracy. HadCM3 uses the penetrative convective scheme (Gregory and Rowntree 1990) modified to include an explicit downdraught and the direct impact of convection on momentum (Gregory et al. 1997). The large-scale precipitation and cloud scheme is formulated in terms of an explicit cloud water variable (Smith, 1990). Johns et al (2003) found that generally HadCM3 is effective at capturing the patterns of mean seasonal precipitation for DJF and JJA when judged against the CMAP (CPC Merged Analysis of Precipitation) climatology (Xie and Arkin 1997). The agreement over land, where the climatology is more reliable, was particularly good, giving confidence in the model physics. HadCM3 does however overestimate the precipitation in the eastern tropical Atlantic and the Gulf of Guinea. In general, HadCM3 ranked highly in CMIP 2 & 3 over a range of climate variables compared to other models (Reichler and Kim (2008) compared an aggregate score for 14 climate variables) and it was one of the major models used in the IPCC Third and Fourth Assessments and contributed to the Fifth Assessment.

COMMENT: How do results quantitatively compare to other studies (e.g. Pongratz et al. 2010 and Betts et al. 2007, Brovkin et al. 2004) suggesting considerable less impact of changes in land use change on regional and global temperatures. Might therefore part of the results be a specific model-dependent issue ?

RESPONSE: In the discussion (Section 5) we compare our results to those from He et al, 2014 and Pongratz et al 2010. We found similarities in the distribution of the temperature anomalies with those found by He et al (2014) for 1850 CE and Pongratz et al (2010) for the 20th century although the temperature changes found in this study were greater e.g. a pre-industrial global annual mean temperature anomaly of -0.23°C as opposed to the -0.17°C estimated by He et al (2014). Not all the other studies use comparable time slices and so a direct quantitative comparison is not always possible.

COMMENT: Please also consult the study of Boisier et al. 2012 for a more thorough discussion of potential effects of changes in other properties related to changes in land use and the dependence on specific model and model configuration. An example for a time slice, preferably the PI vs present day concerning a separation into different components (albedo, latent and turbulent heat fluxes) as carried out in the study of Boisier et al. 2012 would also help to assess the model-specific response on land use changes.

RESPONSE: Will do for PI.

COMMENT: 3.1.2 Remote impacts of land use I wonder why the authors did not carry out in parallel a transient simulation with continuous changes in land use including changes in orbital parameters – The reason it that the equilibrium response could be different to the response one achieves when using a transient simulation – although this kind of simulation would lie outside the scope of the present manuscript at least some words addressing potential implications would be helpful to put results obtained with the multi-centennial long-time slice experiments into perspective.

RESPONSE: We agree that it would be very interesting to run a transient simulation but it was not practical to do so within the already wide scope of this manuscript. We are building on snap-shot simulations that are previously published for the last glacial cycle (Singarayer and Valdes, 2010; Singarayer et al., 2011) and these land-use time slices expand our work using this methodology. In addition, with the speed of the model and HPC queuing times it would have taken more than two years to complete a Holocene transient simulation and so was not possible within this particular project time frame, although we would very much like to be able to do this in future. We have mentioned the advantages of running a transient simulation within the discussion but will add more emphasis to that statement.

COMMENT: 3.2 Atmospheric dynamics How can low-level surface winds advect changes into remote regions ? I would rather expect a mid-to-high altitude mechanism driving low levels wind. Also the still coarse resolution of the global climate model will not properly simulate a realistic pattern of low-level winds, especially over regions

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characterized by a complex land-sea mask and regions with complex topography.

RESPONSE: Will rephrase to state that the surface winds will advect changes into adjacent (rather than remote) regions and change the order of the sections as suggested below. We agree that in most regions there won't be a recognisable or predictable pattern of advection but where there is a prevailing wind direction advection of temperature anomalies can be seen.

COMMENT: 3.2.2 Mean sea level pressure I suggest to change the order of the sections starting with upper tropospheric dynamics, to mslp and eventually low-level dynamics. Changes in mslp will change the surface wind pattern In general I have some reservations with the purely thermal explanations of wind changes in the extratropics excluding dynamical reasoning for instance related to changes in baroclinicity due to changes in the overall meridional temperature gradient also affecting the upper-tropospheric circulation

RESPONSE: Will include dyamical reasoning as suggested.

COMMENT: 3.3 Hydroclimate Analyzing hydroclimate changes from GCM output is afflicted with high uncertainties – this should be noted somewhere because results based on only one model can lead to false or not robust conclusions given the high degree of uncertainty even the current generation of GCM/ESM shows for the hydrological cycle.

RESPONSE: We agree that there are uncertainties in hydroclimate analysis by GCMs. We will emphasise this in our text. Some aspects such as the movement of the ITCZ away from a cooling hemisphere are reasonably robust and are seen in other studies (e.g. Kang et al, 2008).

COMMENT: 4 Temporal evolution of Holocene climate Can you explain why especially the NH temperatures show such a strong temperature increase – the summer insolation decreases and winter insolation north of 30 âŮęN has not a pronounced effect. Most reconstructions and simulations point to a decrease in NH temperatures during the Holocene (cf. also Wanner et al. 2008).

RESPONSE: We have previously done sensitivity experiments where the model has been forced solely with orbital configuration changes, then with greenhouse gas (GHG) variations in addition, and then with ice-sheet and sea level changes (e.g. Singarayer et al., 2011). In HadCM3, the simulations with orbit-only variations produce a slight temperature decrease through the Holocene for the northern hemisphere (30-90N). The cooling from mid-Holocene to pre-industrial is largest over the Arctic region. The impact of including increasing greenhouse gases on temperature outweighs the orbital influence and results in an overall warming over 30-90N. There are still regions over the Arctic and north Atlantic where the cooling remains, however. Seasonally, we find that cooling through the Holocene still occurs in northern hemisphere summer, when forced with orbit and GHG variations, but is not as pronounced as when only forced by orbital variations. In winter, when HadCM3 is forced with orbit-only variation there is little change in temperature, but when GHG increases are included this becomes a warming through the Holocene, which then outweighs the reduced summer cooling. While the annual mean warming signal is in apparent disagreement with some of the palaeodata records, including the recent Marcott et al (2013) record, it is within the range of other climate model responses when compared with the PMIP3 (Paleoclimate Model Intercomparison Project) model mid-Holocene to pre-industrial temperature anomalies. Figure 2 is a plot of the available PMIP3 model global annual mean temperature anomalies for mid-Holocene with our HadCM3 time slices for the Holocene. 11 of 13 PMIP3 models demonstrate little change or warming from 6ka to 0ka, rather than cooling. HadCM3 has a relatively large warming, although not the largest of all the models. The warming in our version of HadCM3 is amplified by the coupled vegetation scheme (which the majority of the PMIP3 models still do not include). The increase in modelled forest cover through the Holocene, facilitated by CO2 increase in terms of favourable climate as well as CO2 fertilization, decreases albedo and increases temperatures further. When the multi-model mean temperature anomaly map is plotted (Figure 3; taken from the PMIP3 website for expediency), the same pattern as for HadCM3 is observed

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in that the mid-Holocene is warmer than pre-industrial over the Arctic, with little change or cooler temperatures over mid- and low latitude land, similar to the HadCM3 spatial pattern. Palaeodata syntheses such as Bartlein et al (2013), as shown in our paper Figure 13, display regionally variable mid-Holocene temperature anomalies. There are a number of points over Eurasia, central N America, and the Mediterranean where their data suggest a regionally cooler mid-Holocene, while Scandinavia, eastern N America, and some Arctic regions are inferred to have a warmer mid-Holocene. This is similar to the discussion section of Wanner et al. (2008, section 6.1), and their figure 18, where the cooling is most evident over the N Atlantic and higher latitude northern hemisphere, and in some cases is thought to be mainly in summer. In summary, in HadCM3 the temperature response to increasing Holocene GHGs is larger than the seasonal decrease in temperatures resulting from decline in summer insolation. This overall response is not unusual when compared to other PMIP models. There are regional variations in the response of models with a tendency for cooling at high latitudes but warming at lower latitudes. While palaeodata syntheses may suggest a cooling of northern hemisphere temperatures, there also appear to be regional and seasonal variations in the data. The temperature anomalies are fairly small in both models and data and in addition, with a lack of data in some areas (particularly outside Europe), there is perhaps significant uncertainty in both models and data as to what the average northern hemisphere annual mean temperature response is. We will add a small discussion to the text about why we get a strong temperature increase in the model and discuss our comparison with data and other models in section 4.

COMMENT: 5 Discussion In general I liked the discussion section as useful to put results into perspective – However, I don't know if it's wise to criticize studies addressing results for regional climate change based on a regional climate model, when the GCM of the present study shows potential shortcomings, i.e. the overall temperature change between MHPI is at odds with many other studies, the biogeochemical effect and the overall coarse resolution of the HadCM3 model neglecting specific regional details.

RESPONSE: We did not intend our text to read as a criticism of regional models and accept that no model including HadCM3 is without shortcomings. We have tried to stress that our results are the results from only one model. For the land use change scenario however we did feel that it was necessary to point out that an additional issue for regional models would be that the remote atmospheric changes would not be included. Although the advantages of regional models might outweigh this disadvantage we believe that this knowledge of these remote influences could be helpful for others planning model studies in the future. We will however make the comment more general and also mention the advantages of regional models such as higher resolution.

COMMENT: Technical comments: p 4603, l 12. Why is the abbreviation anthropogenic land use change “ALCC” rather than “ALUC” ? Section 2.2.: I suggest including a table where the experimental setup is summarized with according abbreviations. p 4612, l 24: the weblinks should be replaced by citations from the peer-reviewed literature In Figure 2 and 3 it would be helpful to include the global average of the temperature change and also reproduce changes in the annual mean

RESPONSE: Will amend/add the above. ALCC should have been Anthropogenic Land Cover Change.

ADDITIONAL REFERENCES:
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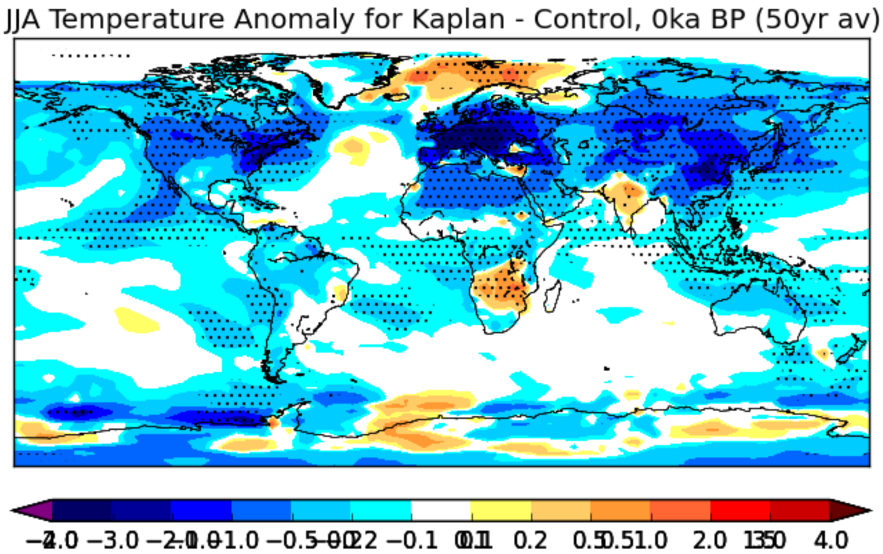

Fig. 1. Example of 50 year averaged temperature anomalies for 1850 showing statistical significance

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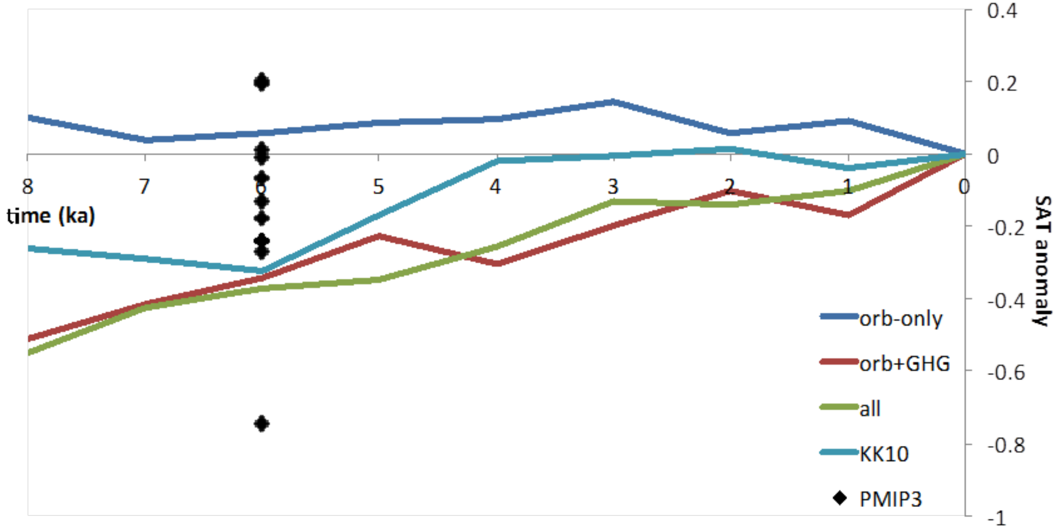

Fig. 2. PMIP3 model global annual mean temperature anomalies for mid-Holocene plus HadCM3 time slices for the Holocene.

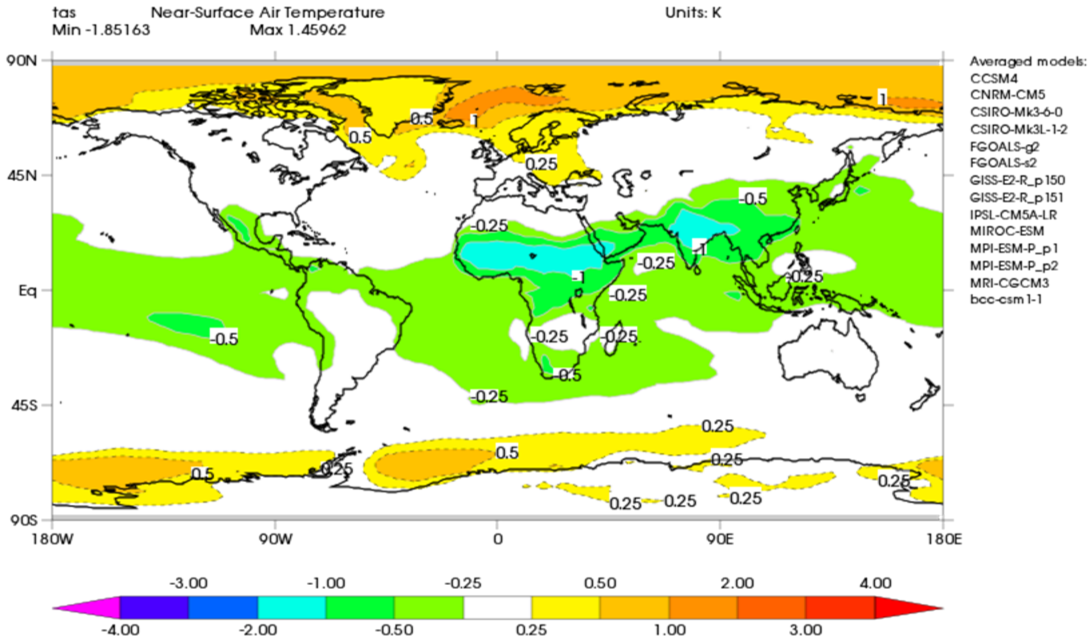

Fig. 3. PMIP3 multi-model mean temperature anomalies

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