Dear Dr. Luke Skinner,

Please find the reply to the comments concerning our manuscript "A reconstruction of radiocarbon production and total solar irradiance from the Holocene ^{14}C and CO_2 records: implications of data and model uncertainties".
We thank you and all reviewers for the careful reading of the manuscript and the helpful comments. The original reviews and our responses to the individual comments are appended to this cover letter. We have clarified the text in response to the various comments. We agree with your conclusion "*that a discussion of simulated radiocarbon production prior to the Holocene must indeed be reserved for another paper.*". Accordingly, the structure of the manuscript, main conclusions and results remain unchanged compared to the previous version.
We slightly revised the calculation of errors during the revision. As it turned out, there was an inconsistency in how the statistical error in the 14C forcing was translated into an error in the production rate. More precisely, the smoothing of the data was not taken into account when calculating the error band. This has now been corrected in the revised manuscript, leading to smaller statistical errors in Q. For the solar activity reconstruction, this correction has only very minor influence and the conclusions of the paper remain unchanged. Still, some numbers stated in the text in the figures had to be slightly adjusted.
In addition to changes suggested by you and the reviewers, we provide the following additional information. (i) Changes in Total Solar Irradiance are estimated following Steinhilber et al. Recently, Shapiro and co-workers suggested an alternative approach to estimate TSI from solar proxies. We now provide also results for the approach by Shapiro et al. in terms of changes in TSI (Figure 14) and in global mean surface air temperature (Figure 16). (ii) The reconstructed TSI record is extended into the future using an autoregressive (AR) model (Figure 15). Results of additional AR simulations are given to better demonstrate reliability and uncertainties associated with the approach. (iii) The radiocarbon production, solar modulation, and TSI data are provided as time series in the attachment to the manuscript. We believe that these additional information and resources are useful for the readers of Climate of the Past.

We thank you for your editorial work and are looking forward to your further decisions.
Yours sincerely,

Raphael Roth and Fortunat Joos

Response to comments by the editor
Original comments are given in normal fonts, the reply is set in bold. New revised text in red.

The issue that I perceive is that, although the BIO and CIRC experiments are seen as crude "bounding" cases that might represent a range of processes for making CO2 increase across the last deglaciation, it is not clear (to me at least) how consistent these "bounding" cases need to be with the atmospheric D14C forcing. The latter is a forcing in the model, such that the production/total inventory of radiocarbon is diagnosed so as to maintain consistency between the atmospheric D14C forcing and the physical changes that are implemented in CIRC and BIO. In other words, the accuracy of the inferred radiocarbon production changes across the last deglaciation hinge entirely on whether or not CIRC and/or BIO are in any way meaningful representations of how the marine carbon cycle changed across the last deglaciation. Presumably this issue is complex enough, and the uncertainties in the deglacial marine carbon cycle are large enough, that a discussion of simulated radiocarbon production prior to the Holocene must indeed be reserved for another paper.
The main point in your paper is that whatever happened across the last deglaciation, it did not matter for Holocene radiocarbon dynamics; am I correct?

An important point of our paper is that uncertainties in the evolution of the carbon cycle during the glacial termination have a small influence on reconstructed radiocarbon production during the Holocene. Nevertheless, the evolution of the system over the termination must be taken into account due to the long residence time of radiocarbon in the Earth System. The text on page 1196, line 15 of the original MS are slightly revised to better reflect this:

"We show that uncertainties in the processes responsible for the reconstructed CO_2 and $\Delta^{14}C$ variations over the glacial termination translate into an uncertainty of order 5% in the absolute magnitude of the production in the early Holocene, but only to small uncertainties in decadal-to-centennial production variations. This uncertainty in millennial average production due to the memory of the system to earlier changes vanishes over the Holocene and becomes very small (<1 %) in recent millennia. Although a detailed process understanding of the termination is not required to reconstruct radiocarbon production in the Holocene, the decreasing trend in atmospheric radiocarbon over the glacial termination must be taken into account."

As noted by the editor, it is outside the scope of this paper to discuss radiocarbon production over the termination. A reconstruction of the radiocarbon production rate over the termination would require model simulations that start well before 20 ka BP to account for memory effects. Uncertainties in our understanding of the climate and carbon cycle evolution over the transition would then also become important. As also noted by the editor the quality of the inferred 14C production over the glacial termination would hinge on whether or not CIRC and/or BIO are in any way meaningful representations of how the marine carbon cycle changed across the last termination. The following text is

added on page 1177, line 10 (original MS) to clarify this point:

"As noted, the transient evolution of atmospheric CO_2 and $\Delta^{14}C$ over the glacial termination is prescribed in all three setups (CTRL, CIRC, BIO). Thus, the influence of changing conditions over the last glacial termination on Holocene ^{14}C dynamics is taken into account, at least to a first order, in each of the three setups.

One other query I would like to add, as something of a curiosity perhaps, is with regard to the so-called "8.2 kyr event", when the North Atlantic overturning circulation is proposed to have been significantly perturbed (e.g. Ellison et al., 2006). Is it possible that changes in the ocean circulation such as this, that were forced by processes that are not included in your Holocene forcings, might be misconstrued as changes in radiocarbon production (as for the deglaciation)? Or conversely might it be possible to provide an argument that such changes can be ruled out on the basis of the inferred radiocarbon production changes and their statistical properties for example?

It is indeed the case that events, such as the "8.2k event" may leave an imprint in the $\Delta^{14}C$ curve. The driving forcings of this event and the event itself are not represented in our model. A corresponding 14C signal may then be misinterpreted as a production signal. We added the following text on page 1196, line 28 in the Summary and Discussion section:

"A prominent excursion in early Holocene Northern Hemisphere climate is the 8.2 kyr BP event with a decrease in Greenland air temperature by about 3 K within a few decades (Kobashi et al., 2007). A reduction in North Atlantic Deep Water formation related to a spike in melt water input is associated with this event. This 8.2 kyr event is not represented in our model setup and a possible atmospheric radiocarbon signal from changing ocean circulation would be erroneously attributed to a change in production. Vonmoos et al. (2006) compared solar modulation estimated from ^{10}Be versus ^{14}C. Deviations between the two reconstructions are not larger during the 8.2 kyr event than during other early Holocene periods. Similarly, the different reconstructions shown in Figure 7 do not point to an exceptional large imprint of the 8.2 kyr event on inferred solar modulation and thus on radiocarbon production.

References:

Kobashi, T., Severinghaus, J. P., Brook, E. J., Barnola, J.-M., Grachev, A. M., 2007. Precise timing and characterization of abrupt climate change 8200 years ago from air trapped in polar ice. Quaternary Science Reviews 26 (9–10), 1212–1222. 10.1016/j.quascirev.2007.01.009

Shapiro, A. I., Schmutz, W., Rozanov, E., Schoell, M., Haberreiter, M., Shapiro, A. V., and Nyeki, S.: A new approach to the long-term reconstruction of the solar irradiance leads to large historical solar forcing, Astron. Astrophys., 529, A67, doi:10.1051/0004-

6361/201016173, 2011.