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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Snow cover sensitivity to black carbon deposition in the Himalaya: from atmospheric and ice core measurements to regional climate simulations" *by* M. Ménégoz et al.

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We thank the referee #2 for its useful and thorough reviews. Our replies to its comments follow below, including a new Figure. In addition to this response, we will submit a revised version of our manuscript, with the main modifications underlined in yellow, that can be downloaded on the discussion website (see the response to the first referee).

Response to Anonymous Referee #2:

The second referee mentioned one general comment concerning our paper:

"The authors, unlike their predecessors, employ high resolution model, which should

be more helpful. [. . .]. However, 50km is still inadequate to represent snow-covered areas in this region. The use of a gcm rather than a ctm is still rather novel in the atmospheric chemistry/climate studies, and it would be helpful to read more details on the model. One thing that I do not see addressed and is almost as concerning as snow cover is topography. Is that improved in higher resolution? Is it at least approaching adequate at 50km? What would be adequate in that region?"

As explained in our manuscript, the stretched grid that we used for our simulations allows a more realist representation of the snow cover both over the Tibetan Plateau and in the Himalayan region. We have no doubt that using finer resolution should allow to further improve the model performance as it was shown in previous studies using regional climate models (e.g. Ménégoz et al., 2013b). However, applying a coupled model simulating interactively aerosols and atmospheric circulation still remains very expensive in terms of computing time. Moreover, the use of a large-scale model is justified here by the need to describe long-range aerosol transport, in particular the long-range transport of aerosols emitted from the Indian sub-continent towards the Himalayan region (Ramanathan et al., 2007). Using Regional Circulation Model (RCM) coupled with an aerosol model would need to consider a very large domain including the Indian sub-continent to describe correctly the aerosol transport. Considering a smaller domain with a RCM would imply to consider complicated boundaries layers in terms of aerosol transport. Therefore, the stretched grid used here for our global model appears to currently be the best tool allowing the representation of both the long-range transport of aerosols and the snow cover in the Himalayas with a tolerable computing time. Finally, in the revised version of our manuscript we point out that our simulation is representative for the seasonally snow-covered areas and not for the glaciers in high altitude areas (see the response to first reviewer and the revised version of the abstract and the conclusion). As recommended by the second referee, we added one statement referring to the resolution of models in Section 2.2: "The Himalayan Mountains located over 3000 m are poorly described with the coarse grid, whereas the stretched grid allows a more realistic representation of the topography both along the Himalayan arc

and over the Tibetan Plateau (not shown)." and in the conclusion: "Further climate simulations based on higher spatial resolution allowing the representation of permanent snow cover on current glaciated areas could be used to simulate the forcing of BC over glaciers". Supplementary Figures 1 and 2 shows the topography resolved with the coarse and the stretched grids. To our knowledge, RCMs have been applied over the whole Himalayas with resolutions around 20 km (e.g. Lucas-Picher et al., 2011; Dimri et al., 2013), which allow enhancing the model performance regarding precipitation. But these models remains still far from correcting all the biases especially concerning the correct simulation of snowfall (Ménégoz et al., 2013b). Finer resolution ($\sim$1 km) has only been applied over very small domains indicating an even better representation of the precipitation (e.g. Maussion et al., 2011).

Specifics comments:

We suggest to specify in the abstract that our study focuses on model comparisons with observations performed in Central Himalaya. (see the suggested abstract in the response to the first referee).

To explain that the Himalayan region is not year-round snow-covered we suggest to add the following sentence to the introduction: "In addition, wide areas of North Western and Eastern Himalaya are seasonally snow covered during long periods, whereas in central Himalaya the snow cover extent is rather limited (Ménégoz et al., 2013b)." Furthermore, we define how the snow cover duration is computed in our paper (see the response to the first referee).

P. 31017: We suggest to clarify in the revised version the statement concerning the nudging time step: "Each 150 seconds (i.e. with a time step 5 times longer than those used to compute wind velocities)".

Kopackz -> Kopacz

P. 31019: relatively -> rather

P 31021, l. 19-21: We suggest to indicate in the text and in the caption of Table 2 that the percentages reefer to the total annual deposition. The monsoon fluxes correspond to the period JJAS whereas the inter-monsoon fluxes represent an average flux for the period of October to May.

p31022, l. 3-14 : as explained in the text, we do not conclude that snowfall doesn't influence BC concentrations. We clarify the statement in the revised version: "The similarity of order of magnitude of the observed snow accumulation and the modelled snowfall is clearly a coincidence. Still, it indicates that the difference between modelled and observed concentration of aerosol in the snow, particularly marked for BC, cannot be explained by a difference in snow accumulation between model and observations." Besides, we add the following statement to Section 3.3 to explain how post-depositional processes (when snow is aging) affect the BC concentration: "Furthermore, melting and sublimation accumulate BC in snow surface layers. These processes more pronounced at low altitude than at high altitude explain also the difference between the observations performed at the upper parts and the lower parts of the Mera Glacier. Our model takes into account these processes, we expect the model therefore to reproduce the concentration of BC in snow observed at 5500 m and not those sampled at the top of the Himalayan glaciers."

p31022, l. 19 : hazardous -> difficult

p31022, l. 21 : analyses -> analyse ; global -> regional

p31023, l. 20 : trough -> through

Section 4: As recommended by both referees we explain in more detail the uncertainties of our study, in particular in the abstract, in Section 4, and in the conclusion (see the response to the first referee). In particular, we explain that BC in snow reduces the snow cover duration by one to five days in the Central Himalaya and by one to eight days in the Karakorum and in the Western Himalaya. We point out that our simulations are not representative of high altitude glaciated areas (> 6000 m), and may be more

representative of seasonal snow cover at low altitudes (<6000 m). The 95% significance level of the snow cover duration reduction means that the comparison between simulations performed with and without BC in snow show a signal that is clearly detectable in spite of the high inter-annual variability of snow cover duration. Such results would be different using lower BC concentrations in snow. As recommended we add a statement concerning snow-aging processes: “Note that snow aging processes, and in particular snow grain size growth is taken into account in our model. This rapid adjustment significantly enhances the BC forcing in snow.” In the model description, we refer to a previous paper describing the snow parameterisation (and in particular the description of snow aging processes): “The representation of snow grain size and BC in the snow and the snow albedo scheme implemented in our model are detailed in Ménégoz et al. (2013a).” Finally, as recommended in the revised manuscript we point out the need for using higher spatial resolution in climate models and the need for more BC observations in snow. The font will be adapted in the figures for the revised manuscript.

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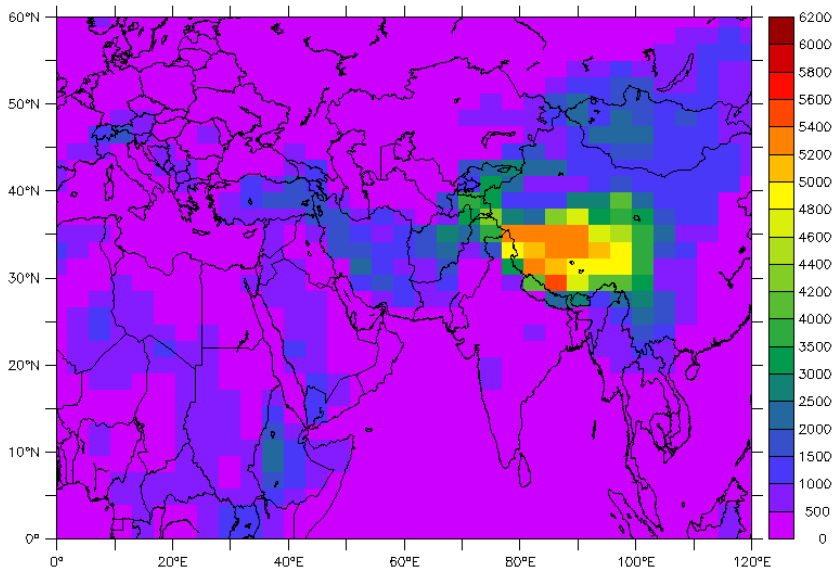

Fig. 1. Non-streched grid topography

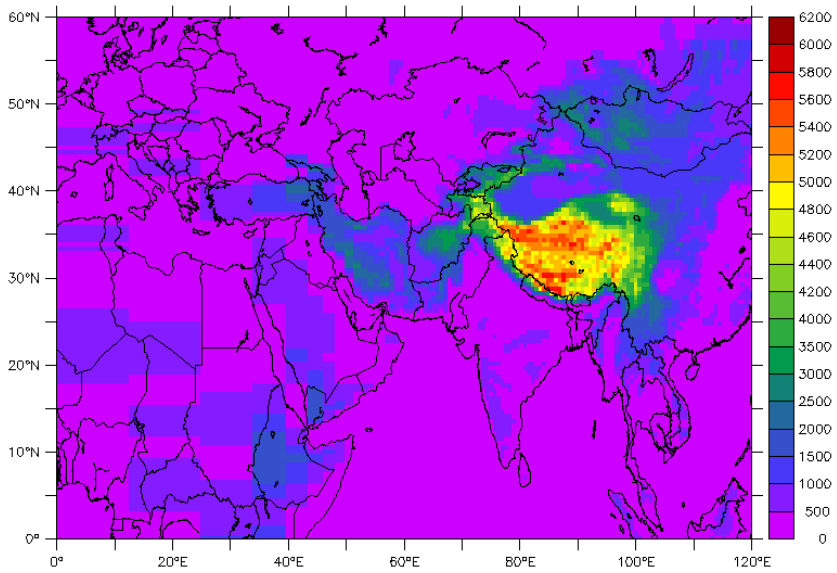

Fig. 2. Streched grid topography