

Interactive comment on “Boreal snow cover variations induced by aerosol emissions in the middle of the 21st century” by M. Ménégoz et al.

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We would like to thank Referee #1 for its useful and thorough reviews. Our replies to its comments follow below. He will find in the supplement material a revised version for our manuscript.

1. As recommended by Referee #1, we replaced “aerosol emissions” by “black carbon emissions” in the title of our paper since our paper focuses on this aerosol specie.
2. P4733/L1: As pointed out by Referee #1, “boreal” does not define correctly the domain of our study. We replaced in the title of the revised manuscript “Boreal” by “Boreal and temperate”. Moreover, we specified in the abstract that our analysis focus on the regions located “North of 30°N”, and added in the introduction the following

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sentence: “As our quite coarse model is not able to describe realistically the seasonal snow cover over regions with complex topography, we excluded from our analysis most of the mountain ranges of the Northern Hemisphere. In particular, we excluded a large part of Himalaya, choosing a domain of study extended from 30°N to the North Pole”.

3. P4736/L25-27: We added in our paper the more recent reference proposed by Referee #1.
4. P4737/L17-22: Concerning the petroleum activities in the Arctic, we added in our introduction the following sentence: “the possible increase of petroleum activities, extraction and refining, could induce an enhancement of ship traffic in some parts of the Arctic. However, the atmospheric pollution associated to such emissions in the Arctic should be limited by the decrease in emission factor as technology progresses (Peters et al., 2011)”.
5. P4737/L28: In the revised version, we replaced “pan-Arctic area” by “boreal and temperate” region as it is more correct. In the rest of the paper, we used sometime the statement “pan-Arctic area”, defining it in its first apparition on the text by “North of 60°N”.
6. P4739/L6-9: We are fully aware that our snow model is very simple, and cannot be used to simulate accurately snow depth. However, a detailed representation of the snow albedo has been included in our model. This work has been presented in detail in Krinner et al. (2006) who analysed the impact of dust deposition on snow. We completed the parameterisation used by Krinner et al. (2006) to deal with BC aerosols. This parameterisation is based on Wiscombe and Warren (1980), a theory which has been used to develop a large part of the existing snow models: both Flanner et al. (2007) and Rypdal et al (2009) used a similar parameterisation, which is based on look-up tables (Stamnes et al., 1988, itself inspired from Wiscombe and Warren, 1980). Even with a limited number of snow layers, Krinner et al. (2006) explained that, in terms of snow albedo, they yields results equivalents as those reported by

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Wiscombe and Warren (1980). Therefore, the use of only two layers to compute the snow albedo appears sufficient to make sensitivities experiments of the snow cover to aerosol deposition at large spatial scales. A limited number of layers either does not allow to simulate accurately the vertical profile of the BC content in the snow. However processes governing the vertical profile of BC in snow are currently very badly known so adding more layers may not be a guarantee of a better parametrisation. We remind to Referee #1 the part of our paper dealing with this topic (P4739/L24 to P4740/L1): "Conway et al. (1996) observed that BC could be flushed effectively through the snow in melting conditions, with velocities strongly dependent on the particle size. However, the Conway et al. (1996) study was based upon experiments with particularly high rates of snow melting since they were performed during summer at altitudes around 2000 meters over the Northern United States. More recent observations by Aamaas et al. (2011) in Spitsbergen showed that BC aerosols tend to stay at the surface of the snowpack even during melting conditions." Facing this uncertainty, different modellers follow very different ways to include this process in their models: Jacobson (2004) and Flanner et al. (2007) included a characteristic time of residence of BC in the snow, driving the flushing of this aerosol through snow layers. In contrast Rypdal et al (2009) decided to neglect this extremely uncertain process. Building on the experimental evidence of Aamaas et al. (2011), and not willing to add one more uncertain parameter in our climate model, we decided to make the same choice as Rypdal et al (2009). This choice makes also possible to use only two layers in our snow scheme, as the BC deposited is either accumulated on the surface (top layer) during dry periods or diluted deep down during periods of snowfall (low layer). As stated in our paper, we have to keep in mind that neglecting the flushing of BC through the snow layers may lead to an overestimation of the magnitude of BC aerosol effects on the snow cover and climate.

7. P4739/L21-P4740/L5: As recommended by the first referee, we added in the new version of our paper a statement to explain in more details how melting is taken into account in our model: "During melt or sublimation, snow mass is supposed to be lost from the surface layer. This one is therefore extended downwards to attain 8 mm SWE

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(if enough snow remains in the bottom layer). The aerosol mass corresponding to the lost snow height is added to those of the new surface layer. The transfer of liquid water through the two snow layers is neglected in our model. More details about this snow scheme can be found in Krinner et al. (2006)."

8. P4742/L8-12: To clarify our explanation of the 2050 fire scenario that we followed, we propose to add the following sentence in our paper: "Following Flannigan (2009a; 2009b), we consider an increase of 50% of BC and other aerosols emitted by fire during all the year. In addition, we consider also a 1-month extension of the fire season in the Northern hemisphere (starting 15 days prior and extending 15 days after the fire season of the present-day). From January to June (resp. from August to December), monthly emissions are computed as the average between the emission of the current month and those of the following (resp. previous) month."

9. P4742/L23-25 : We specified that the 2878 Gg year⁻¹ of BC emitted north of 30°N are those pointed out in the CMIP5 emission inventory that we used for our S1 simulation.

10. P4743/L4: We changed "Sovde et al." with "Søvde et al."

11. P4743/L20-27: We corrected a mistake in the caption of Figure 2: the RMSE was computed using the present simulation taking into account the effect of BC aerosol on snow albedo. Note that the RMSE is hardly modified when taking into account the BC deposition effect on snow albedo.

12. P4744/L27: Mote et al. (2005) added to the reference list.

13. P4745/L14: We write a clearer sentence in the new manuscript: "Considering an increase in aerosol emissions from Arctic ships or from biomass burning in our 2050–2060 nudged experiment induce MNDWS variations almost equal to zero (see Fig. 3c and d, showing respectively MNDWS differences S3_N-S2_N and S4_N-S2_N). It clearly means that the snow albedo changes associated with this possible increase in

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aerosol emission is negligible in comparison with the snow albedo changes induced today by the current aerosol emissions in the Northern Hemisphere.”

14. P4750/L26: The reference Fig. 7e has been moved after “North-east Asia”.

15. P4764: As said previously, we corrected the mistake in the figure caption.

16. P4767/Fig 5: North of 30°N, aerosol emissions are slightly increased in a scenario of enhanced ships traffic in the Arctic (+3.9 Gg/yr). Note that this value is low as the increase of ships traffic in the Arctic is partly compensated by a reduction of the ships traffic over the routes currently used. The corresponding variation of continental deposition is -0.8 Gg/yr. This value is low and even negative because the part of aerosols deposited over the ocean is increased in this scenario with deviated route over the Arctic.

17. P4769/Fig 7: We corrected the caption in the new version of our manuscript.

Please also note the supplement to this comment:

<http://www.the-cryosphere-discuss.net/6/C2955/2013/tcd-6-C2955-2013-supplement.pdf>

Interactive comment on The Cryosphere Discuss., 6, 4733, 2012.