

## ***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 #3 for its useful and thorough reviews. Our replies to its comments follow below. Note that a revised version for our manuscript can be found in the supplementary material associated to our answer to Referee #1.

1. General comments: Referee #3 points out that it would like to have more information about emission scenarios and coupled models. As the introduction and the section dedicated to the model description is yet quite long, we do not want to add to much information about the coupling methods. Such description has yet been done in previous studies. Nevertheless, we suggest to add one sentence referring to these studies in the revised version of our paper (Section 2.1): “The coupling between LMDz and ORCHIDEE is described by Hourdin et al. (2006), and those between LMDz and INCA  
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is detailed by Hauglustaine et al. (2004) for chemistry and tracers and by Balkanski et al. (2007, 2010) and Déandreis et al. (2012) for the computation of the aerosols radiative forcings.” Otherwise, as pointed out in our paper, the reader can find all the descriptions of the emissions scenarios in Moss et al. (2008). This paper can provide all the information about the emissions scenarios for a person who is not expert in this topic.

2. As pointed out by the other referees, we modified our title, because boreal was not fully appropriate. Here is the new title: “Boreal and temperate snow cover variations induced by black carbon emissions in the middle of the 21st century”. However, we did not add the term snow season length: We do not discuss only the duration of the snow cover, as we analyse also changes of snowfall and snow water equivalent. Moreover, it would make the title very long.

3. 4734-Line 4 (and on several other lines): We used capitalization to detail which letters are used in acronym.

4. 4734-Line 13: reformulation: “In particular, considering the RCP8.5 in our simulation leads to a decrease in the spring BC deposition down to 110 Gg month<sup>-1</sup> in the 2050s.”

5. 4737-Line 22: reformulation: “The earlier occurrence of forest fires has recently been observed in high latitudes, in particular during warmer and dryer spring periods, in response to climate warming (e.g. Warneke et al. 2009).”

6. 4737-Line 27: reformulation: “The goal of this study is to estimate the snow-cover variations in the boreal and temperate regions for the middle of the 21st century using simulations with a global coupled atmospheric general circulation and chemistry model prescribed with different aerosol local emission scenarios.”

7. 4738-Line 4: reformulation: “We evaluate the snow-cover changes in the 2050 decade for the intensive RCP8.5 scenario (Representative Concentration Pathway 8.5, Moss et al., 2008, 2010, Riahi, 2007), and analyse thereafter the role of possible en-

hanced aerosols local emissions in the Arctic region.”

8. 4738-Line14: Aqueous-phase is the correct term.

9. 4739-Line 4: See point 6 of the response to Referee #1. 10. 4739-Line 13: We need to detail all the experimental set-up before analyzing the results. In particular, we think it is important to speak about the processes neglected in our model. For that reason, we need to say in the experimental set-up that the snow albedo variations induced by OC deposition are currently not simulated by our model. 11. 4739-Line 24: It is quite difficult to choose a spatial and temporal constant value for snow density. The historical choice of 330 kg.m<sup>-3</sup> applied in our model LMDz-ORCHIDEE is based on an average between maximum and minimum observed values. It is quite common to use ~80 kg.m<sup>-3</sup> and ~350 kg.m<sup>-3</sup> for these extrema (e.g. Brun et al., 2012). However, Chalita (1992) reports a larger spectrum, with minimum values reaching 10 kg.m<sup>-3</sup> and maximum values of 840 kg.m<sup>-3</sup> (névé). Gouttevin et al. (2012) reported a value of 200 kg.m<sup>-3</sup> for taiga ecosystems and a value of 330 kg.m<sup>-3</sup> for tundra ecosystems. The value used in our simulation is therefore more representative of regions without vegetation than forested areas. This value is certainly higher than the global average snow density. However, we assume this choice has not affected so much the results of our sensitivities experiments. Anyway, we would like to improve our model in the future. We suggest adding the following statement in the revised manuscript: “Note that we considered a constant snow density of 330 kg m<sup>-3</sup>. In further studies, we hope to include a more realistic representation of snow density in our model.”

References:

Brun, E., V. Vionnet, A. Boone, B. Decharme, Y. Peings, R. Valette, F. Karbou et S. Morin, Simulation of northern Eurasian local snow depth, mass and density using a detailed snowpack model and meteorological reanalysis, *J. Hydrometeorol.*, doi:10.1175/JHM-D-12-012.1, 2012.

Chalita, S., Sensibilité du modèle de circulation atmosphérique du LMD à l'albédo

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de surfaces enneigées : Résultats préliminaires de rétroactions liées à la couverture neigeuse, thèse de doctorat, 189 pp., 1992.

Gouttevin, I., Ménégoz, M., Dominé, F., Krinner, G., Koven, C., Ciais, P., Tarnocai, C., Boike, J.: How the insulating properties of snow affect soil carbon distribution in the continental pan-Arctic area, *Journal of Geophysical Research*, 117 : G02020. DOI:10.1029/2011JG001916, 2012.

12. 4740-Lines 4-5: We added the following paragraph in the conclusion: “Besides, the snow albedo variations induced by absorbing aerosol deposition is quite dependent on the chemical composition of these aerosols (Wang et al., 2012), their evolution within the snow cover (Aamas et al., 2011, Conway et al., 1996), and their mixing state with snow grains (Flanner et al., 2012). Further experiments dealing with these processes could provide a realistic spread about the existing knowledge concerning BC and its interactions with snow albedo.”

13. 4741-Line 1: “Realized” has been changed with “performed”.

14. 4741-Line 7: We suggest to add the following statement: “The nudging is applied only for horizontal winds as described in Coindreau et al. (2006). Such protocol is very useful to reproduce the observed atmospheric state (Douville, 2010), letting however the model partially free to react to external forcings. We only applied the nudging to winds to avoid possible inconsistencies between winds and other meteorological variables (pressure, temperature, and moisture).”

15. 4742-Lines 5 and 8: New statement: “These larger ship emissions are based on the “high-growth” scenario of Corbett et al. (2010), considering a high increase in ship traffic over the current Arctic routes. This scenario takes also into account the diversion routes opened during the summer following the seasonal retreat of sea-ice expected in the next decades.”

16. 4742-Line 12-> “pair of 11-yr simulations” – Performing several similar simulations

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with different initial conditions or different models is a very common procedure. When it is possible to have a sufficient number of experiments, one can call these experiments “ensemble simulations”. This protocol is often used to construct a spread of results, to give an idea of the uncertainty of climate models, or to give an idea of the natural variability. Here, we applied such protocol with two parallel realizations of 11 years, as we estimated that 20 years of simulation were sufficient to characterize the signal of BC deposition on snow. We did not want to perform 20 consecutive years of simulation with a nudging toward the observations, as we would certainly have detected a tendency associated to external forcings like anthropogenic greenhouse gases for example.

17. 4742-Line 28-> There is many papers which have been published concerning the emissions scenarios. We invite Referee #3 to read the works of Lamarque et al. (2010) and Moss et al. (2008, 2010) to have more details about this topic. These papers are quoted in our paper. Anyway, the introduction of new technologies is expected to lead to a decrease in aerosol emissions on average over the Northern Hemisphere.

18. 4743-Line19: We leave the sentence to be as clear as possible.

19. 4744-Line 7 -> Correction: “Note that we did not consider the number of days with snow at the ground over glaciers, icecaps or sea ice in our study.”

20. 4744-Line 15 -> the sentence is quite long, but quite clear. . .

21. 4745-Line 15 -> The sentence was corrected (see First major point of Referee #2).

22. We decided to leave all the aspects characterizing the results in Section 3. However, to detail the results, we need to introduce some discussions about the protocol that we followed (e.g. nudging). Section 4 is a discussion more dedicated to the physical explanations of the snow cover variations described in Section 3. Moreover, we do not make Section 4 too long, as we completed it with different points suggested by Referee #2.

23. 4746-Line 6-> and Line 26 -> rephrasing: “Both the scenario with enhanced

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biomass burning emissions and those with increased Arctic ship traffic emissions produce very low emissions in winter.”

24. 4747-Line 9 “concomitant”: replaced by simultaneous.

25. Line 20 “nowadays” – replaced with current.

26. Line 20: rephrasing: “In simulation S2, a drastic decrease in BC deposition is obtained over the whole Northern hemisphere for 2050 (Figure 5b), with the exception of central Asia and Alaska. In these regions, the anthropogenic emissions are increasing in the RCP8.5 scenario compared to current level (see Figure 1b).”

27. Sections 4.2 and 4.3 describe results. However, they appear in the discussion section as they are supposed to contribute to the explanation of the results exposed in Section 3.

28. 4750-Lines 2 and 5 : Diminution has been replaced by decrease and reduction.

29. Conclusion: Even if it includes some repetitions, we choose to repeat the main results of our study in the conclusion. However, we fleshed out the conclusion with (1) the limits of our study (2) more perspectives about which aspects could be improved in a further study. In this new version, the conclusion is therefore more differentiated from the discussion part. A particular focus is done following the major point suggested by Referee #2.

30. 4752-Line 1: “a temperature rise that substitutes snow to rain”: means that the snow is transformed into rain because of a warming of the atmosphere.

31. 4753-Line 19-> the conclusion was slightly rephrased, as explained in point 29. Reading the conclusion, Referee #2 can understand that: \* Recent papers (Jacobson, 2004, Flanner et al., 2007, 2009, 2012) showed that the “snow darkening effect” affects the snow cover as much as the GHGs forcing. This one is expected to strongly increase during the next decades. Therefore, the strong decrease in aerosol emissions expected for the next decades will not be sufficient to avoid a strong reduction of the

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snow cover in Northern hemisphere. To limit the reduction of the snow cover, both the emissions of aerosols and GHGs need to be decreased. \* The possible increase of local emissions in temperate and boreal regions associated to enhanced fires and increase ship traffic will not affect strongly the snow cover directly via snow darkening effects. However, the snow cover could be affected by these aerosol emissions through atmospheric feedbacks.

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

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