Review of « Combining atmospheric and snow layer radiative transfer models to assess the solar radiative effects of black carbon in the Arctic », by Tobias Donth et al.

General comments

This study aims at estimating the radiative impact of black carbon (BC) particles suspended in the atmosphere and contained in the snowpack in the Arctic. It simultaneously and consistently computes the radiative forcing of BC in both the snowpack and the atmosphere. To this end it couples an atmospheric and a snow radiative transfer model. The BC atmospheric concentrations are taken from three aircraft campaigns that explored various atmospheric conditions, from early spring to summer. A variety of radiative transfer simulations are performed, where snow properties and BC mass concentrations are varied to cover the range of Arctic conditions reported in the literature. The main conclusion is that the radiative impact of BC is marginal in typical Arctic conditions, amounting to about a few percent of the total heating rates and to less than 1 W m^{-2} in terms of surface forcing. The authors also point a competition between shading of the surface by atmospheric BC that counteracts the warming effect of BC in snow. The impact of clouds is investigated, also showing complex interactions, where depending on their altitude and optical thickness, clouds can either enhance the effect of BC through multiple scattering, or reduce it by shading. In any case, the authors highlight that other drivers of the Arctic energy budget are more significant than BC, such as absorption by water vapour, snow metamorphism and clouds.

The topic of the study is relevant to *ACP* because it combines numerical simulations and field observations to provide a geophysical analysis. The paper is well written and easy to follow. There is much relevant physical insight and the conclusions are drawn rigorously from the computations. The findings are not a breakthrough but they have the merit to provide a self-standing investigation of the total BC impact in Arctic conditions, where previous studies have either focused on the atmosphere or in the snow. This is probably the greatest added value compared to previous work. We may regret the lack of field data for the snow. Likewise, the fact that only offline radiative computations are performed precludes a rigorous quantification of the impacts on atmospheric dynamics and snow evolution. As a consequence, the numerous conclusions on the impact of BC with a dynamic perspective appear quite weak and should be better motivated with appropriate references. Practically, data from aircraft campaigns are only used to derive average profiles of temperature, humidity (in a manner that should be more detailed) and BC, but snow properties are chosen based on other studies and more as varying parameters. This is not an inappropriate approach but this makes the importance of novel data quite limited in this work. Based on the comments above, I recommend this paper be published after the corrections suggested below are tackled.

Specific comments

1) It is clear that the study focuses on BC and the conclusion is that BC is not so critical with the amounts currently observed in the remote Arctic. However, recently there have been plenty of studies clearly showing altered surface albedos because of light absorbing impurities. The latter could then be dust, micro-organisms or anything else. It might be worth insisting that you only deal with BC, which is one amongst many others light absorbing species, so that the conclusion should not be over-interpreted as « there is no impact of impurities in the Arctic ». Likewise, the geopgraphical area to which the work is relevant should be better identified.

2) The paper focuses on energy budgets (of the atmsophere and snow). Although the impact of BC on these budgets is very limited, BC strongly impacts the light penetration depth in snow, or equivalently snow transmittance. For instance, if a 20 cm snow layer in the Arctic has a transmittance of 1 %, adding BC may decrease this value down to 0.5 %. This is nothing for the

snow budget, buth this makes a huge difference for the amount of energy transmitted. This will for instance be critical for photosynthesis within or under the snowpack. Maybe this should be mentioned somewhere so that again readers don't think « BC does not matter ». The paper by Tuzet et al., (2019) may be a useful reference for that.

3) The iterative coupling between libRadtran and TARTES is a first valuable step towards consistent radiative transfer simulations. I can only encourage the authors to fully incorporate the scattering snowpack in libRadtran for their future work. This can be done simply by providing the single scattering properties computed by TARTES to create new « atmospheric » layers in libRadtran which would be extremely thin. Such strategy would avoid the iterative coupling and be overall more elegant. See for instance Blanchet and List (1987) for a very similar study.

4) The evaluation of BC contribution to heating rates or total absorption is sometimes misleading. The authors often conclude that BC contribution being a few percents its impact is negligible. However think in terms of CO_2 forcing, where a few W m^{-2} (in addition to hundreds of W m^{-2}) can fully change the face of the Earth. I simply mean that it is hard to conclude that a few percents perturbation of the energy budget due to BC is insignificant. Be more cautious in the conclusions, unless you have strong and better argumented reasons to think that it is indeed negligible.

5) The paper somehow lacks a bit of discussion, where the limits of the study and recommendations for future work would be provided. In particular, the importance of BC in locations where it is much more concentrated could be discussed. The representativity of the BC atmospheric profiles used as well. The use of daily averages to asses a radiative impact may not be relevant (maximum values matter as well). The link with snow metamorphism is only qualitative why models allow to explicitly simulate the impact of these heating profiles of metamorphism, etc. All these points should be brought to the reader and further investigated in future work, if not already further discussed in the present paper.

Technical corrections

title : would **forcing** be more appropriate than « effects » ? Consider also removing « layer »

p.1

l.1 : the absrtact could be written using the present. More generally there is no conssitent use of present or past in the manuscript. Some homogenization would be recommended.

l.2 : BC particles are not really « suspended » in the snowpack. They're rather embedded or contained. Consider changing this throughout the paper.

l.2 : « by » → using

l.4 : « interactions » is unclear. Maybe use multiple scattering or coupling

l.4 : « a snow layer » should be replaced by « a snow » because multi-layer snowpacks are explored. Maybe write « An atmospheric and a snow radiative... »

l.6 : this radiative effect is very dependent on the SZA chosen. Please clarify

l.9 : counteracting «effect »

l.10 : technically snow density also impacts snow optical properties l.10 : « however » does not really oppose to anything

l.12 : I think « ice » could be used instead of « ice water »

l.19 : absorb~~s~~, scatter~~s~~

L.24 : predominantly

p.2

l.1 in higher → to higher

l.4-5 : using « nevertheless » and « still » in two consecutive sentences makes it diffcult to follow

l.7 : « of suspended » is awkward

l.9 : can be expected → are observed

l.14 : double « the »

l.20 : associated with → , thus increasing the amount…

l.29 : there is no « novel » feedback described here. BC is just shown to trigger the snow metamorphism feedback. There is actually a feedback because BC impact will be stronger for lower SSA, but this should be described here if this is what you actually mean.

l.34 : warm~~ing~~

l.34 : « the atmospheric layer containing BC »

p.3

l.4-10 : this paragraph is not very clear and could probably be removed

l.15 : why only « local » ? Not clear whether this refers to local pollution or not

l.16 : With

l.15 : « interactions » is not very appropriate

p.4

l.5 : « relevance » is not well chosen → contribution

l.7 : « setup » suggests there is some evolution from an initiation which is not the case. « Configuration » would be better.

l.8 : change title to «BC profiles from aircraft campaigns »

l.9 : not clear what this « atmospheric » model is l.23 : are these « snow properties » used later on ?

p.5

l.5 : **is** available

l.10 : consider adding some information about the thermodynamical profiles measured during the flights, if actually used further

l.13 : url for libRadtran download should be provided here or in the Data availability section

l.15 : is reference to « Evans 1998 » relevant here ?

l.15 : precise that this assumes a plane-parallel atmosphere

l.19 : mention explicitly humidity (or water vapor)

p.6

l.1 : « adjusted » is unclear. Do you mean that profiles from the mid-campaign were used ?

l.7 : where do the cloud optical properties come from ?

l.9 : can you provide optical thickness values ?

p.7

l.2 : provide url for TARTES

l.6 : The reference provided is not about delta-Eddington approximation. Prefer Joseph et al. (1976)

l.8 : SSA should not be italic (throughout the text)

l.9 : there are two shape parameters (B and g). Please provide the values used.

l.12 : ot → to

l.13 : another important point is that impurities are assumed to be Rayleigh scatterers

l.23 : please provide some references for the SSA values assumed

l.33 : SSA for fresh snow could be larger

p.8

l.5 : no, spectral albedo does not depend on the spectral distribution of irradiance. Broadband albedo does

l.7 : « shifts » suggests a conversion of some wavelengths to some others. Maybe say « filters/absorbs longer wavelengths so that the downward irradiance spectrum is shifted towards shorter wavelengths » l.9-10 : for which snowpack ?

p.9

Figure 2 : « adjusted » parameters is not clear. Do you mean that they can vary ? Maybe specify that the procedure is done at high spectral resolution so that the figure holds for a single wavelength. Consider adding a title with TARTES/libRadtran (or SNOW/ATMOSPHERE) on top of the colored boxes.

l.4 : surface radiative effect is not clear (radiative forcing ?)

l.7 : specify what the default cases are when snowpack is considered (what BC in atmosphere ?) or atmosphere is considered (what BC in snow ?)

l.11 : can ? Should be « does » ?

p.10

l.5-7 : the details about the vertical resolution of both radiative transfer codes should be given earlier in the presentation of the models configurations.

l.13 : daily means may hide much larger instantaneous values which are very relevant both for snow metamorphism and atmospheric dynamics. Adding the max values on the subsequent plots would be very useful

p.11

l.2 : should be HR_BC ?

l.6 : what kind of dependence ?

l.6 : « respectively » is awkward

l.15 : I don't see any zoom of the Figure 4, but definitely this would be useful

l.31 : please specify that this is the impact of BC **on the broadband albedo**. Other optical quantities might be much more altered

p.12

Table4 : particle

l.3 : the distinction between titles 3.1.1 and 3.1.2 is not obvious. Say radiative **forcing** ?

l.5 : twice « effect »

l.5 : **first** calculated… (because standard is with daily cycle). Note also that sometimes the past is used, sometimes the present. It'd be worth homogenizing this.

p.13

l.8 : are **then** analyzed

p.14

l.1 : how much in %? Using relative contributions rather than absolute forcing may be instructive to compare campaigns. This holds also when evaluating the contribution of clouds. Of course they shade the surface, but how does the relative forcing of BC vary ?

p.16

l.5 : of ~~by~~

l.15-16 : already said in the introduction

l.19 : remove « were applied »

l.32 : « is less pronounced … significantly »

p.17

l.2 : one order of

l.15 : slight

l.27 : « to access » is awkward

l.32 : « transmittance » is unclear. Do you mean irradiance with respect to surface irradiance ? Then relative illumination or relative irradiance is better.

l.33 : what is « quickly » for a heating rate decrease?

p.19

l.2 : I'm surprised not to see the shading of the lower layers by BC in the topmost layers. Did you observe that below ?

l.12 : = 0 or ≈ 0 ?»

l.17 : I think the conversion from a contribution to a snow heating rate into a metamorphism rate is not that straightforward, especailly with daily means. Providing snow physics references would be helpful to strengthen your conclusions

l.33 : were used **in** the

p.20

l.3 : « other parameters » is awkward. Please clarify. Maybe mention reference/unpolluted conditions

l.5 : again, « local » is unclear

l.6 : why « therefore » ?

l.6 : show**s**

l.7 : « driver » means that its variability controls the variability of the heating rates. Is that the case (then it should be detailed) ? You could have varying BC for constant water vapour, then the variations of the heating rates would be driven by BC.

l.15 : lapse-rate feedback refers to the response of the atmsophere to a surface temperature change. In terms of vertical gradient of temperature. I'm not sure you really mean this here (as a feedback).

l.16-17 : again, what is « small » ? can you provide elements to support the fact that 0.1 K day^{-1} cannot change atmospheric stability ?

l.17-18 : this could be moved to the introduction, that the study focuses on remote Arctic locations, not on locally polluted areas.

l.33 : these **two** cloud

p.21

l.4 : « Atlantic Arctic » should be emphasized in the introduction

l.5 : cooling is at the surface, please clarify

l.10 : some elements should be provided about other types of impurities which may eventually be more critical than BC in the Arctic

References

BLANCHET, J. P., & List, R. (1987). On radiative effects of anthropogenic aerosol components in Arctic haze and snow. *Tellus B*, *39*(3), 293-317.

Joseph, J. H., Wiscombe, W. J., & Weinman, J. A. (1976). The delta-Eddington approximation for radiative flux transfer. *Journal of the Atmospheric Sciences*, *33*(12), 2452-2459.

Tuzet, F., Dumont, M., Arnaud, L., Voisin, D., Lamare, M., Larue, F., ... & Picard, G. (2019). Influence of light-absorbing particles on snow spectral irradiance profiles. *Cryosphere*, *13*(8).