Atmos. Chem. Phys. Discuss., 8, S11210–S11216, 2009
www.atmos-chem-phys-discuss.net/8/S11210/2009/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Springtime warming and reduced snow cover from carbonaceous particles" *by* M. G. Flanner et al.

M. G. Flanner et al.

Received and published: 13 February 2009

We thank this reviewer for helpful comments. The reviewer's first point, regarding the spatial distribution of BC deposition trends, prompted revisions that make this study more complete. Below are our responses ('A') to each reviewer comment ('R'), including descriptions of how we have modified the manuscript.

A current version of this manuscript, including revisions discussed below, is at: http://www.cgd.ucar.edu/˜mflanner/ppr/ppr_FlZ08.pdf

R - This study considers the impact of aerosols above and upon snow, with particular focus on the role of absorbing aerosols to enhance snowmelt in Eurasia during springtime. The combination of models and measurements leads toward the direction of constraining the aerosol-albedo effects. The study is innovative and informative and

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

overall a valuable contribution to the literature on aerosol-climate effects. Listed below are some major issues that should be addressed before the paper proceeds to ACP, followed by minor points. Overall the paper is quite well written.

Major points

R - 1) The authors note that the AR5 models failed to simulate the amount of snow-melt and increased temperature observed in Eurasia from 1979 to 2000, and that including the effects of BC/dust on snow albedo might have improved their results. However it is not clear to me that the BC trend in much of the region is even in the right direction. In the final section there is some mention of the BC trend increasing in southeast Asia but decreasing in Europe. The authors should a) do a more careful analysis of the sub-regional trends using Bond et al. 2007. I suspect that ONLY south-southeast Asia has increasing BC during 1980-2000, thus the analysis of the AR4 models should be limited to that area. Europe and northern Asia should actually have increased snow from (decreased) BC changes. Related to this, I suggest adding figures showing the change in snow cover and BC deposition for models T1 and T2 (like the bottom 2 panels of Figure 7). Do BC deposition and snow cover increase or decrease over northern Asia and Europe?

A - We agree that a more detailed analysis of the spatial distribution of trends is useful. We have added three geographic plots to Figure 7 (now Figure 8), showing the distributions of simulated 1979-2000 trends in spring snow cover with and without snow darkening, and of January-May BC deposition, simulated with historical emissions from Bond et al (2007).

We originally noted that aerosol emissions trends are of opposite sign over Europe and Asia, but there is also considerable variability within Asia, as hypothesized by the reviewer. The bottom panel added to Figure 8 shows increasing winter/spring BC deposition over eastern Asia and southern Asia, decreasing BC deposition over Europe and west Asia, and near-neutral trends over north Asia. Figure 8 also shows more

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

negative snow cover trends with inclusion of snow darkening (T2 versus T1) over large parts of Asia, _including_ portions of west and central Asia that experienced _decreasing_ BC deposition trends. This may seem somewhat counter-intuitive, but we disagree that decreasing BC deposition necessarily drives a slower rate of snow cover decline than when there is no darkening at all. It is important to remember that the control ensemble (T1) has no snow darkening from aerosol deposition, as opposed to constant snow darkening. Thus, in comparing these two sets of simulations (T1 and T2), we are seeing the convolved effects of absolute snow darkening and trends in snow darkening. The fact that snow cover decreases more rapidly in some areas subject to decreasing BC deposition may indicate that (in some cases) a baseline degree of snow darkening, combined with greenhouse warming, drives more rapid snow cover decline than when snow is pristine (has high albedo). Figure 7 (old Figure 8) does show a relatively large mean radiative forcing on snow over west/central Asia, caused by BC and dust darkening. An alternative explanation for this behavior is that dynamical feedback, caused by the 10% reduction in mean Eurasian snow cover, drives more rapid snow cover reductions in regions less directly affected by darkening. (If dynamical feedback is the cause, however, our experiments suggest that it only marginally involves the ocean, as we discussed in a response to the other reviewer regarding sea surface temperature changes.) Furthermore, the continental-scale Eurasian snow cover trend increased only marginally with darkening (Figure 6), and (as originally noted) the accelerated rate of land warming in experiment T2 may relate more to reduced mean snow cover than to trends in snow cover. A more thorough assessment of cause and effect would require additional simulations, applying various magnitudes of constant snow darkening and trends in darkening (and using a full ocean model, as noted below by the reviewer).

To convey these points, we have modified the manuscript as follows:

1) Added panels showing the geographic pattern of simulated snow cover and BC deposition trends to Figure 7 (now Figure 8).

2) added the following paragraph to section 3.3:

"Figure 8 also depicts geographic patterns of simulated trends in spring snow cover and January-May BC deposition. Snow cover declines slightly more rapidly over much of Asia when snow darkening is included. However, BC deposition trends are negative or near-neutral over large parts of western, central, and northern Asia (Figure 8). Although Asian fossil+biofuel BC emissions increased by 50% during the transient duration (Bond et al, 2007), positive deposition trends are constrained mostly to eastern and southern Asia. Because the control ensemble (T1) prescribed no snow darkening, rather than constant darkening, comparison of these experiments reveals influences of both absolute darkening and changes in darkening. These results may suggest that a certain degree of baseline darkening, and associated mean snow cover reduction, are as important for temperature change as the trends in darkening resulting from 1979-2000 deposition changes. Figure 7 does show rather large mean radiative forcing on snow in central Asia, caused by BC and mineral dust. Additional simulations, applying a full ocean model and varying degrees of darkening, are needed to address this issue more comprehensively. Over Europe and North America, fossil+biofuel BC emissions emissions decreased by 20% and 8%, respectively, during 1980-2000, while emissions of mineral dust and biomass burning BC exhibited no significant trend over either continent."

3) Modified the end of the abstract to read. "Inclusion of this forcing significantly improves simulated continental warming trends, but does not reconcile the low bias in rate of Eurasian spring snow cover decline exhibited by all models, likely because BC deposition trends are negative or near-neutral over much of Eurasia. Improved Eurasian warming may therefore relate more to darkening-induced reduction in mean snow cover."

R - 2) Some aspects of the experimental design should be clarified: a) Why do the PD experiments have biomass burning active in snow but not in air (according to Table 1)? Or maybe they do, but the table does not say so. b) It seems unnecessary to do an ensemble of simulations for prescribed SST experiments. How much variability is there among the ensembles? c) Bottom of 19830-top of 19831: A larger response is seen for the PI experiments than the similar PD experimental pairs. Indeed the snow response would be sensitive to the initial conditions. A warmer climate (higher CO2) reduces snow-cover so that there is less additional contribution from the BC-forcing. The point should be made that a realistic study requires a transient and fully coupled simulation. By the way, P19831 top line, instead of PI5-PI1 say what the experiments are.

A - Regarding (a): Both PD experiments do have biomass burning BC active in the atmosphere. We have added a column to Table 1 to clarify this.

Regarding (b): There is, in fact, considerable variability in simulated trends among the prescribed-SST ensemble members. This can be seen in the large extent of whiskers bracketing "T1" and "T2" points in Figures 5 and 6, and also in other CMIP3 SST-forced model trends. Multi-member ensembles are also necessary for deriving many of the statistics we report.

Regarding (c): We included the following sentence in paragraph 7 of section 3.3 to convey the need for fully-coupled experiments: "Additional simulations, applying an AOGCM with varying degrees of darkening, are needed to address this issue more comprehensively." Finally, we modified the text on P19831 to read: "...the influence of atmosphere+snow BC+OM on pre-industrial climate (PI5-PI1)...", clarifying what PI5-PI1 represents.

R - Detail points

R - 1) p 19823 line 2, How representative is 200um grain size and how sensitive is result to this assumption?

A - 200um is representative of fresh or moderately-aged snow. In the context of these results, this is a relatively conservative assumption, as the forcing of impurities in snow increases with increasing snow grain size, which can exceed 1000um in aged snow. We added the following to this line: "(representative of fresh or slightly-aged snow)".

R - 2) P 19827 line 15, Are results sensitive to assumption of 0.2 extinction optical depth?

A - Although the forcing magnitudes shown in Figure 1 are (obviously) sensitive to the prescribed extinction optical depth, our general conclusions about the nature of aerosol forcing over and within snow are robust under doubling and halving of the extinction optical depth. Specifically, atmospheric aerosol forcing transitions from negative to positive near co-SSA=1E-4 in all experiments, and snow darkening with alpha$>$0.01 reverses the sign of net (darkening+dimming) surface radiative forcing under all scenarios. One reason that robustness is expected, with respect to atmospheric extinction optical depth, is that the impurity amount in snow is expressed in terms of the atmospheric column burden. We added the following to the first paragraph of section 3.1: "Atmospheric extinction optical depth is fixed at 0.2, but the forcing behavior discussed below remains robust under a doubling or halving of this term."

R - 3) Figure 1 discussion. Since readers are used to "surface forcing" being from atmospheric aerosol suspensions only, please specify somewhere that surface forcing includes effects from aerosols in atmosphere and in snow.

A - We added the following sentence to the first paragraph of section 3.1: "Surface forcing, in this discussion, represents the combined effect of reduced absorption from atmospheric aerosols and increased absorption from snow darkening." We also added the following to the caption of Figure 1: "Forcings represent the combined influence of particles in the atmosphere and snow."

R - 4) Figure 1: Does the SSA change in both atmospheric and snow aerosols?

A - Yes. We added "... with identical optical properties applied to particles in the atmosphere and snow" to the first paragraph of section 3.1.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

R - 5) Figure 3: Instead of using labels "MAM snow fraction" on each panel, replace with the forcing (e.g. CO2; BC-snow; etc).

A - Thanks. We changed titles in this figure to describe the forcing mechanism.

R - 6) P 19831 line 22, clarify the meaning of "adjusted radiative forcing".

A - Here, we simply meant to apply the standard IPCC definition of radiative forcing (i.e., forcing at the tropopause after stratospheric adjustment). We derived this estimate of CO2 forcing from the empirical functions of Myhre et al (1998). This sentence was included only to provide context on the relative magnitudes of different forcing agents. To not distract the reader with the technical definition of adjusted forcing (which is not applied anywhere else in our study), we removed reference to "adjusted" and added the Myhre citation. This sentence now reads: "This compares with a global-mean forcing of about 1.5 W/m2 for a change in CO2 concentration of 289-380 ppm (Myhre et al, 1998)." (Note, originally we mistakenly stated 1.3 W/m2).

R - 7) I think that the GISS-ER model did include a parameterized BC-albedo effect, so in this model it did not apparently help

A - We added the following sentence to paragraph 4 of section 3.3: "The GISS-ER model did include a parameterized BC-albedo effect (Hansen et al, 2007), but trends from this model were similar to mean CMIP3 trends."

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 19819, 2008.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper