RADIATIVE EFFECT FROM RADIATION-ABSORBING AEROSOLS IN SNOW

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INTRODUCTION

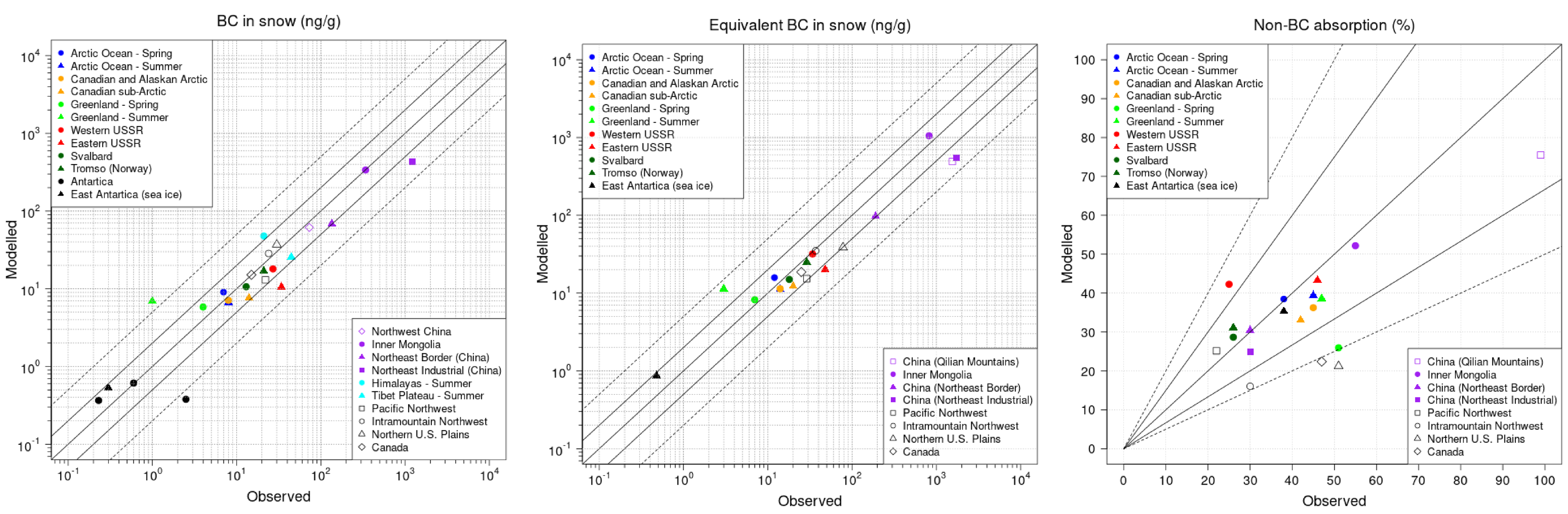
Black carbon (BC), brown carbon (BrC) and soil dust are the most radiation absorbing aerosols (RAA). When RAA are deposited on the snowpack, they lower the snow albedo, increasing the absorption of the solar radiation. The climatic impact associated to snow darkening induced by RAA is highly uncertain. RAAs deposition on snowy surfaces results in an enhancement of the absorbed solar radiation in snow, due to the albedo reduction of snow pack. This process increases melting and reduces the snow duration, consequently. As a result, this amplifies the alteration of runoff timing and magnitude due to the climate warming, with consequences on water resources. Forcing efficacy by RAA in snow is about three time larger than the one resulting from carbon dioxide. However, the climatic effect associated to RAA in snow is still highly uncertain. In this work, a 5-years numerical simulation is performed, in order to calculate the present-day radiative forcing (RF) of RAA in snow. RF was estimated taking simultaneously into account the presence of BC, BrC, and mineral soil dust in snow.

METHODS

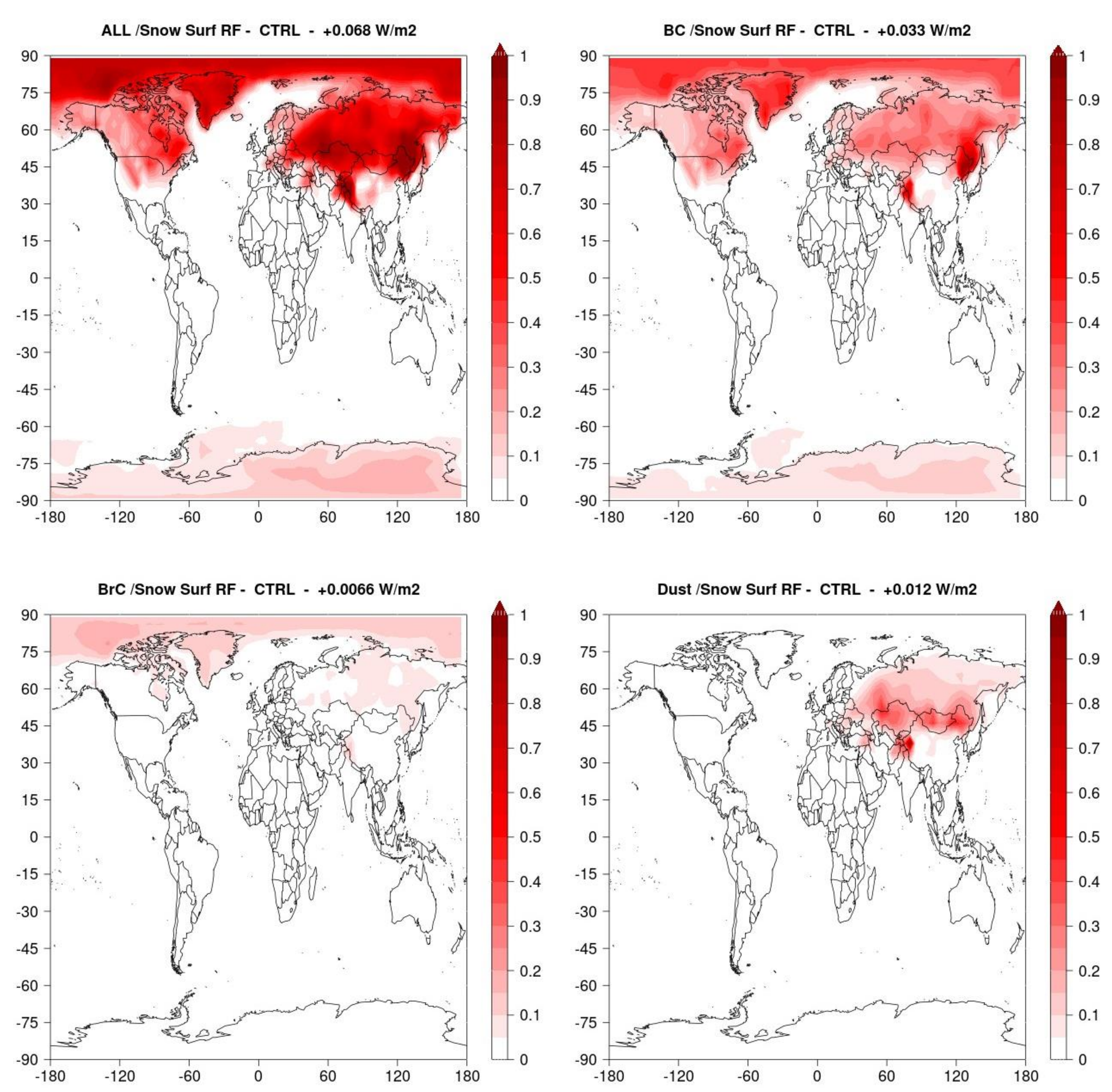
- GEOS-Chem global chemical and transport model is used to simulate the aerosol mass and deposition (dry and wet).
- Hydrophobic and hydrophilic BC are tracked for fossil fuel (FF), biofuel (BF) and biomass burning (BB) sources.
- BC from BF and BB sources is assumed to be emitted as 70% hydrophilic and 30% as hydrophobic with an aging e-folding time from hydrophobic to hydrophilic of 4 hours. 80% of BC from FF sources is emitted as hydrophobic and converted to hydrophilic with an aging rate related to sulphate dioxide and hydroxyl radical levels in the atmosphere.
- We have added four tracers to the GEOS-Chem for hydrophobic and hydrophilic BrC from BF and BB sources. We assume that 50% and 25% of primary (POA) is emitted by BF and BB sources is primary BrC.
- Dust emission is simulated with the DEAD scheme. Emitted dust is distributed in four dimensional bin by using the brittle fragmentation theory..
- The geometrical median radius is set to 30 and 70 nm for FF and BF/BB BC, while the standard deviations are 1.4 and 1.6, respectively. The refractive index is 1.95-0.79i.
- Geometrical median radius and standard deviation adopted for BrC are 90 nm and 1.6, respectively. The refractive index is taken from Wang et al. (2018). The blanching effect of BrC-BB absorption is included in our simulations.
- Snow albedo perturbation due to RAA deposition is calculated with a parameterization of Mie theory.

RESULTS

- BC and BC equivalent (BCE) in snow were diagnosed starting from deposition fields simulated by GEOS-Chem and precipitations.
- BC, BCE, and the light fraction absorption due to non-BC compounds (f_{non}-BC) were compared with worldwide observations reported in scientific literature.
- The regional variability of BC and BCE in snow, spanning over 5 order of magnitudes, is reproduced by the model.
- Biases were mainly linked to the model emissions, while error in BCE and f_{non}-BC simulations is likely related to the assumptions about the RAA optical properties. A source of uncertainty in model evaluation could be represented by measurement errors.



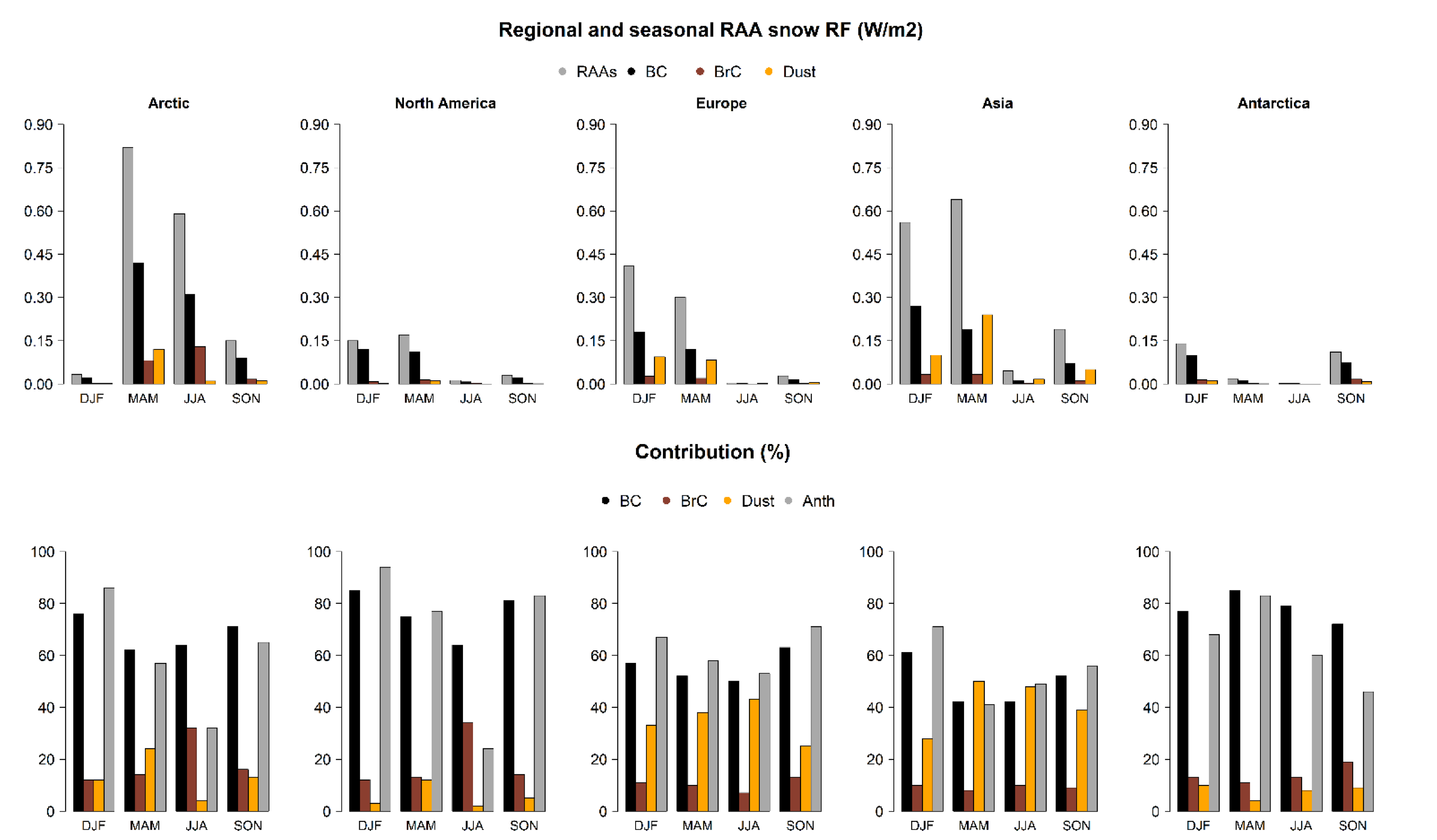
Scatter plots of the observed and modelled BC, BCE mixing ratio in the snow, and f_{non}-BC.



All-sky annual mean (2010–2014) radiation-absorbing aerosols (RAA), black carbon (BC), brown carbon (BrC), and soil dust in snow radiative forcing (RF) calculated from CTRL experiment.

- Global average RF associated to all RAA was +0.068 W/m^2. The largest values were founded in Northeastern China and Tibet Plateau. As expected, global RAA snow RF was dominated by BC RF, resulting in +0.033 W/m^2.
- Soil dust is the second light absorber in snow, having an average RF of +0.012 W/m^2 which was about 3 times lower than the one due to BC. RF of dust in snow was relevant in the Asian regions, especially downwind the deserts and Tibet Plateau, where values up to +1.7 W/m^2 are simulated. In some regions of Kazakhstan, Mongolia, Manchuria, Tibet Plateau, Pakistan, and Afghanistan, dust snow RF is on average 2-3 times larger than the one exerted by BC. In Mongolia, dust RF is up to 4 times larger than BC.
- Estimation of snow RF for BrC was +0.0066 W/m^2, about 5 times lower than the one calculated for BC.
- Non-BC compounds account for about 40% of the absorption in snow. In addition, we found that carbonaceous aerosols (BC+BrC) control about 75% (+0.046 W/m^2) of snow RF exerted by RAAs.
- The contribution of anthropogenic emissions to RAA absorption in snow is around 56% (+0.031 W/m^2), meaning that slightly less than half of RAA snow forcing is due to natural sources.

- At regional scale, the largest total RAA snow RF was found in Arctic during spring (+0.83 W/m^2) and summer (+0.59 W/m^2) and 40% of this forcing was due to non-BC compounds. In particular, non-BC spring RF is mainly due to the dust (+0.12 W/m^2), while non-BC was driven by BB BrC (+0.13 W/m^2) in summer.
- In the middle latitudes, the most relevant RAA snow forcing was obtained in Asia with +0.56 and +0.64 W/m^2 in winter and spring, respectively. BrC contribution was constant during winter and spring (10%, about +0.033 W/m^2), while soil dust exerted a key role in forcing over Asia: its radiative effect (+0.24 W/m^2) was larger than the one of BC and represented 50% of the total RAA RF in spring. RAA forcing on High Mountain region was up to 3 W/m^2 in summertime and 60% of it is attributable to non-BC aerosols.
- North America exhibited the lowest RAA snow RF (0.15 and 0.17 W/m^2 in winter and spring, respectively) and the lowest non-BC contribution (about 20%) in the middle latitudes.
- As for Europe, total RAA RF was +0.41 and +0.30 W/m^2 in winter and spring, respectively. BC contributed slightly more than half of the total forcing. The most relevant non-BC was given by dust (30%-40% of the total).
- In Antarctica, the highest values of RF have been found in winter and fall (+0.14 and +0.11 W/m^2, respectively) and the contribution of non-BC compounds was estimated to be in the range of 20-30%.



Top panel: all-sky regional and seasonal averages (2010–2014) (top panel) of total RAAs, black carbon (BC), brown carbon (BrC), and soil dust snow radiative forcing (RF), calculated from CTRL experiment in Arctic, North America, Europa, Asia, and Antarctica. Lower panel: contribution of each single species and anthropogenic RAA to total forcing. The anthropogenic contribution is given by BC and BrC from fossil fuel (FF) and biofuel (BF) sources and aromatic SOA.