Anonymous Referee #2

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We are very grateful for the referee's critical comments and suggestions. The followings are our point-by-point responses to the comments. Our responses start with "R:".

Summary This study uses remote observations (and models) to quantify the radiative forcing (RF) of light absorbing particles deposited in snow in Northeastern China. The authors use a combination of observations and models, including MODIS, SNICAR, SBDART, as well as ERA-Interim reanalysis and MIROC5 BC deposition simulations. Spatial variations in the RF are primarily attributed to light absorbing particles, and multiple linear regression shows BC deposition and snowfall explains the bulk of the spatial variation in light absorbing particles (based on an impurity index). Finally, the inferred RF is compared with in situ estimates. Overall, the authors combine a lot of data from various sources to construct the RF of light absorbing particles in snow. There are a lot of uncertainties! But the authors appear to do a good job at acknowledging these uncertainties, and quantify them when possible.

R: Thanks very much for your comments and suggestions, we have addressed all of the comments carefully as detailed below.

Comments

Why use ERA-Interim for snowfall data? Is it any good?

R: Actually, we collected four types of snowfall data, including the surface observational data from China Meteorological Administration (126 observation stations), the ERA-Interim reanalysis (http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/), the Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2), and the National Centers for Environmental Prediction (NCEP) Climate Prediction Center (CPC) (https://www.esrl.noaa.gov/psd/data/gridded/data.cpc.globalprecip.html). Figure S1 shows the spatial distribution of the observational stations over Northeastern China.

We note that the observation stations are limited in our study areas, especially in WNEC and ENEC. Compared with the observed snowfall data, we also assessed the snowfall data from ERA-Interim reanalysis, MERRA-2 reanalysis, and CPC in NEC. We found that the ERA-Interim reanalysis data is more consistent with surface observations (Figure S2). Besides we examine the spatial distribution of the retrieved radiative forcing by using ERA-Interim snowfall data in this study, the results based on other types of snowfall data are also estimated. The R^2 of retrieved I_{LAPs} and fitted I_{LAPs_fit} based on the snowfall data from ERA-Interim reanalysis, MERRA-2 reanalysis, and CPC are 0.84, 0.82-0.83, and 0.81-0.82, which are really similar (Table S1). Therefore, we prefer to use ERA-Interim snowfall data in our study. We also added more details that why used ERA-Interim snowfall data in Section 2.4 in Page 13 Lines 20-22 and Page 14 Lines 1-13.

Why use MIROC5 for BC deposition data? What about the other CMIP5 models?

R: We have replaced MIROC5 BC deposition data with MERRA-2 BC deposition data in this study and added the description of MERRA-2 data in Section 2.3. In addition, we have added the discussions about using different BC deposition data in Section 4.3 in Page 12 Lines 14-22 and Page 13 Lines 1-9, and the results of comparisons between MODIS retrieved I_{LAPs} and fitted I_{LAPs_fit} using different BC deposition data are listed in Table S1 in the supplements.

To our knowledge, there is no surface measurement data for the spatial distribution of BC deposition in NEC. Therefore, we just collected reanalysis data of BC deposition from the Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2) from 2003 to 2017 and the modelling data of BC deposition from the Coupled Model Intercomparison Project Phase 6 (CMIP6, the latest CMIP phase) including CESM2, CESM2-WACCM, and CNRM-ESM2-1 historical experiments from 2003 to 2014 (Eyring et al., 2016). So far, only the above three models in CMIP6 provide BC deposition data. In this study, we prefer to use MERRA-2 data, because MERRA-2 data is the latest atmospheric reanalysis of the modern satellite era produced by NASA's Global Modeling and Assimilation Office (GMAO) and assimilates aerosol observations and other observation types to provide a viable ongoing climate analysis. Both observable parameters and aerosol diagnostics have widely potential applications ranging from air quality forecasting to aerosol–climate interactions (Bocquet et al., 2015; Randles et al., 2016, 2017).

Where does BC emission density come from?

R: BC emission density data is obtained from the research group at Peking University (http://inventory.pku.edu.cn/home.html, Wang et al., 2014). Please check more description of BC emission density in Section 2.3 in Page 13 Lines 10-15.

Why only year 2014, when the study spans 2003-2017?

R: BC emission density data used in this study is from 2003 to 2014, we have corrected the mistakes in the manuscript. Among all available BC emission density data, we prefer to use the data from Wang et al. (2014) after taking spatial and temporal resolution, data period, data quality and other factors into account. Although the BC emission density is only updated to 2014, which does not completely cover the study period of 2003-2017, the spatial patterns of BC emission density from 2003 to 2017 are similar. As a result, the BC emission density data used in this study from 2003 to 2014 is reasonable.

Are there not interannual variations in BC emissions? Or is this not important?

R: The major novelty of this study is to reveal the spatial distribution of MODIS retrieved radiative forcing in NEC, which is compared well with our surface measurements during the snow field campaigns. We note that the interannual variations of radiative forcing are also important, however, due to no more long-term datasets of surface measurements, the interannual variations could lead a large uncertainty due to several key factors, such as the large variations of snowfall each year, dry and wet deposition of LAPs in snow. As a result, we considered that the interannual variations of retrieved radiative forcing by using the remote sensing will be investigated in the future study based on more surface measurements to constrain the uncertainties. Therefore, we also didn't highlight the interannual variations of BC emission.

Several awkward/incomplete sentences exist. For example, L 15 P 26.

R: We have carefully corrected the awkward/incomplete sentences throughout the manuscript. The sentence in Page 26 Line 15 has been revised as "Previous studies have attempted to retrieve the radiative forcing by LAPs in snow by using remote sensing (e.g. Painter et al., 2012, 2013), however, attributing the spatial variations of radiative forcing by LAPs in snow is really sparse, and need to be further investigated.".

This paper uses a large number of data sets. It would be helpful to list these in figure captions, as a reminder of where the variable comes from.

R: We have updated the related information in figure captions as suggested.

The quoted RF represents a snap shot under clear sky conditions (and other caveats). I think this should be included in the abstract, since it puts the very large RF (~45 W/mˆ2) into context.

R: We have revised the "…to retrieve the radiative forcing by LAPs in snow (RF_{MODIS}^{LAPs})…" as "…to retrieve the instantaneous spectrally-integrated radiative forcing at the surface by LAPs in snow (RF_{MODIS}^{LAPs}) under clear-sky conditions at the time of MODIS Aqua overpass …".

Figure 2. "density" repeated.

R: We have removed the repeated "density".

Figure 4. Dotted areas hard to see.

R: We have revised Figures 4, 6 and 10, and make the dots more clearly.

Table S1. R^2 between MODIS retrieved I_{LAPs} versus fitted I_{LAPs_fit} using different datasets.

BC Wet Deposition Data	BC Dry Deposition Data	Snowfall Data	R^2 (MODIS Retrieved I_{LAPs} Versus Fitted I_{LAPs_fit})
MERRA-2	MERRA-2	ERA-Interim	0.84[b]
MERRA-2	MERRA-2	MERRA-2	0.82[b]
MERRA-2	MERRA-2	CPC	0.82[b]
CMIP6[a]	CMIP6	ERA-Interim	0.84[c]
CMIP6	CMIP6	MERRA-2	0.83[c]
CMIP6	CMIP6	CPC	0.81[c]

a: CMIP6 data in this study is CIMP6 multi-model ensemble mean data including CESM2, CESM2-WACCM, and CNRM-ESM2-1 historical experiments from 2003 to 2014. So far, only the above three models in CMIP6 provide BC deposition data.

b: data used to fit I_{LAPs_fit} is from 2003 to 2017.

c: data used to fit I_{LAPs_fit} is from 2003 to 2014, which is due to that the data of CMIP6 historical experiments is only updated to 2014.

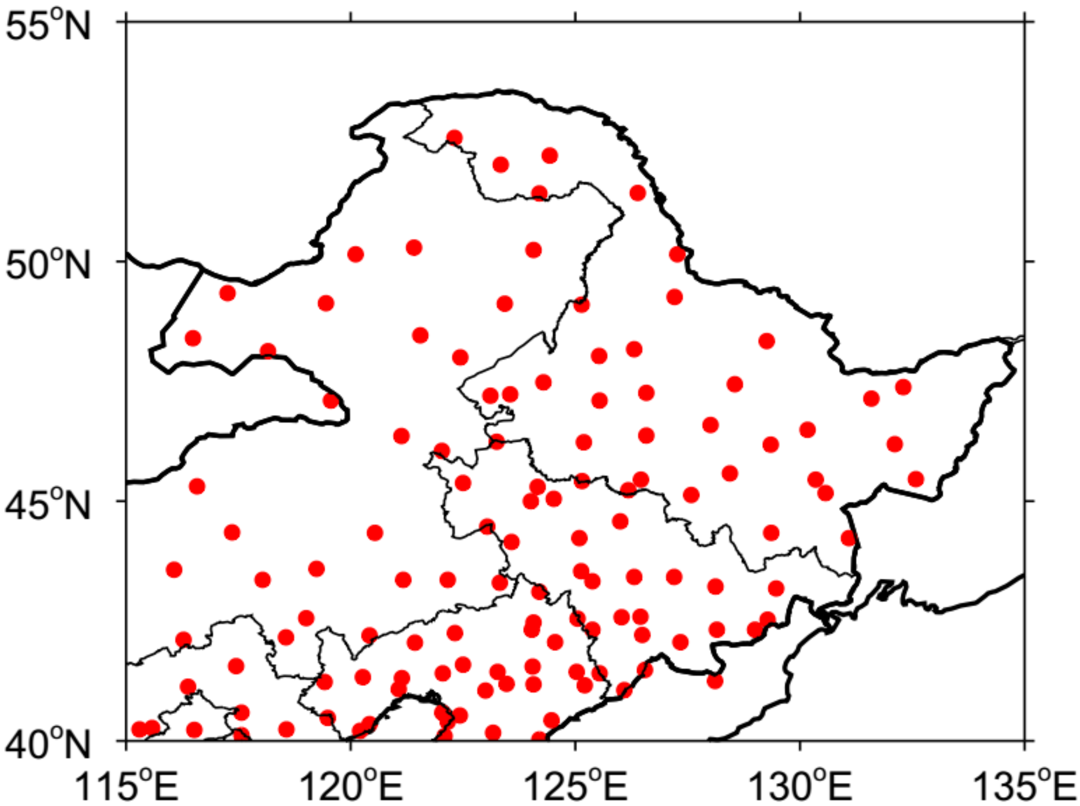

Figure S1. Spatial distribution of 126 meteorological observation stations in NEC.

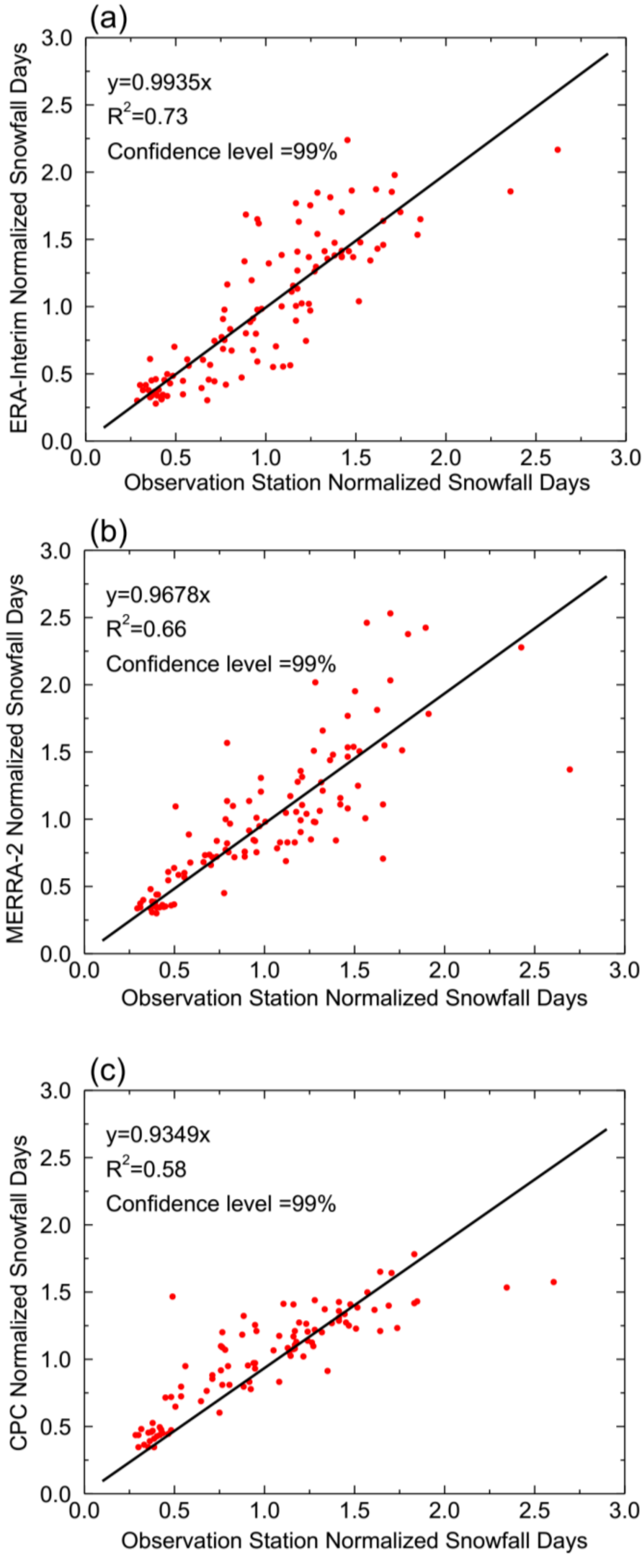

Figure S2. A comparison of 126-station normalized snowfall days versus (a) ERA-Interim, (b) MERRA-2, and (c) CPC normalized snowfall days.

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