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The Cryosphere
Discussions

Interactive comment on "Black carbon and mineral dust in snow cover on the Third Pole" *by* Yulan Zhang et al.

Yulan Zhang et al.

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Dear editor,

The manuscript: Black carbon and mineral dust in snow cover on the Tibetan Plateau by Zhang Y.L. et al.

The manuscript number: tc-2017-111

We greatly appreciate the reviewers' constructive comments to improve the paper. We have revised our manuscript according to these comments (blue color in the main text), and hope the revised manuscript is suitable for publication in The Cryosphere.

The "point to point" response to comments are listed as below.

Sincerely yours, Yulan Zhang and Shichang Kang

Response to Referee #2 This manuscript presents results from snow sampling, laboratory analysis, and related modeling efforts for the presence and impact of light absorbing impurities in the Tibetan Plateau region. Although the manuscript is not wrong in stating more measurements are valuable in constraining our understanding of the spatial and temporal variability of light absorbing particulates, the techniques presented in this paper are unclear and as written does not contribute to the state of knowledge of light absorbing particulates in snow. Major changes are needed before this paper can be reviewed again for publication. I will not, at the point, do line by line corrections because they are numerous. The authors need to revisit the writing in each section for editing and to clarify there justification, methods, and results. Particularly, snow sampling and automatic weather stations need to be described in significantly more detail. Answer: Thank you very much for the comments and suggestions. We have tried to improve the methods and results in the main text (in blue color). Snow sampling and automatic weather stations are also described in detailed (Section2.2, Section3.3, in blue color).

Comment 1: My first and foremost concern is that samples were collected in November and December, and yet they are attempting to quantify the impacts of light absorbing particulates on melt. This does not make sense to me and if I misunderstood this it is because it is not made clear in the manuscript. Although the sample collection timing may be after the summer monsoon, these samples do not represent the impurities that are present during the ablation season- and therefore it is inappropriate to use these values to quantify reduction in snowpack duration. Particularly for dust, which tends to deposit in the spring when source regions dry out (peak radiative forcing by dust in snow is observed from MODIS imagery over the Himalayan region in April and May). Answer: Agree, these samples were collected during winter season when the snow cover were more stable and continuous, which might not represent the true impurities as these during the ablation season. However, during melting season, because of the poor accessibility on the snowpack in the TP, it was hardly to collect the snow cover samples. Besides, considerable heterogeneity in the topography and climate has led to complex spatial and temporal snow cover patterns (Xu et al., 2017). Discontinued snow cover during melting season may be a problem to represent the true impurities in snow. Thus in our study, we gave an estimation based on the different snow grain size and density, rather than the fixed data. We have to admit there existed uncertainties at present. In the future, we should do more related works to fill in gaps.

Comment 2: The backtrajectory footprint modeling was also very unclear to me, how the model runs were carried out needs to be described better, but it is unclear to me why the model runs were only completed for the winter. And were they run continuously? Typically particulates are deposited in episodic events so running it continuously does not inform the source region, it just informs of the regional synoptics. I suggest seeing Skiles et al., 2015 (Hydrological Processes) for how that study produced and described backtrajectory footprints. Answer: We agree. Since most of the snow cover will not exist during summer season in the TP, thus we only calculated the model runs in winter when the snow cover accumulated. The calculation is continuous in the winter season since we did not know the exact snow events during the periods. It is an estimation of all air mass which can be transported to the sampling sites. We have learned the recommended reference (Skiles et al., 2015), and tried to improve the descriptions in the main text as following (Page6, Line6-34). Calculation of air parcel trajectories is a widely used approach in different areas of atmospheric research. Conceptually, footprint analysis was considered as changes in concentration at the receptor site that can be attributed to different upwind source areas along the backward trajectories (Skiles et al., 2015). To determine the potential origins of the LAIs deposited on the snow cover of the TP, back trajectory analyses were performed using the European Centre for Medium-Range Weather Forecasts (ECMWF) analysis fields with the Lagrangian analysis tool LAGRANTO (Sprenger and Wernli, 2015), launched every six hours for six selected sampling sites as receptors (including three sites of MYL, NMC, and SETP

in region I, two sites of TGL and NETP in region II, and LHG in region III) during the winter season. The ECMWF fields (horizontal and vertical wind components) were retrieved on 137 model levels and then interpolated onto a $0.25^\circ\times0.25^\circ$ latitude-longitude grid. Trajectory starting positions can be defined easily and flexibly based on different geometrical and meteorological conditions; after the computation of the trajectories, a versatile selection is offered based on single or combined criteria (Sprenger and Wernli, 2015). First, starting positions are initialized with a suitable domain over the TP at 12:00 UTC on November 1, 2015 (or 2014). For this case, a domain from 0 to 75 and 60 °E to 120 °E was chosen. We choose starting positions in this domain that are horizontally equidistant with 80 km horizontal spacing and extend vertically from 1030 to 790 hPa with 30 hPa vertical spacing. Then, the trajectories are calculated from all starting positions 96 h backward in time. Finally, biomass burning emission data is traced along the calculated trajectories to estimate whether an air parcel at the receptor site is influenced by BC fire emissions or not. In this study, the Fire INventory from NCAR (FINN) v1.5 global fire emissions flux in 2012−2014, speciated with the GEOS-chem mechanism, was used to estimate contributions of BC fire emission at the six selected receptor sites. FINN emission estimates are based on the framework described by Wiedinmyer et al. (2011). FINN used the satellite observations of active fires and land cover, together with emission factors and estimated fuel loadings to provide daily, highly resolved (1 km) open biomass burning emissions estimates for use in regional and global chemical transport models. Then, the same calculation was performed for the Eclipse V5 inventory for the anthropogenic contributions of BC. The Eclipse V5 inventory was widely used in the simulations. The historical data for the period 1990−2010 were revised compared to preceding sets using the latest IAE (the International Energy Agency) and FAO (the Food and Agriculture Organization) statistics extending to 2010, as well as recent country reporting where available. Note that this analysis was not exactly quantitative and did not take into account wet and dry deposition. We also assumed that the anthropogenic emissions have not changed significantly from 2010 compared to the period from 2012−2014. Thus, the comparison of natural and anthropogenic BC contributions was reasonable. The relative differences between the BC contributions can provide information on regional differences in this study. References: Skiles, S. M., Painter, T. H., belnap, J., Holland, L., Reynolds, R. L., Goldstein, H. L., Lin, J.: Regional variability in dust-on-snow processes and impacts in the Upper Colorado River Basin, Hydrol. Process., doi:10.1002/hyp.10569, 2015.

Comment 3: The albedo measurements need to be better described. And how was snow effective grain radius retrieved? This should be an optically equivalent grain size, not an observable grain size. If an effective/optical grain size was used, the retrieval should be described. If observed grain sizes were used, the large error introduced by this (see Painter et al., 2007 in Journal of Glaciology) needs to be mentioned. Estimates of changes in snow cover duration should be removed or significant more detail and justification needs to be made for the timing of sample collection. Answer: In this study, we used an optically equivalent grain size, not an observable grain size.

In the field, the snow grains were sprayed on the MIG paper. Then we took a photo by using portable digital microscope (Anyty 3R-MSV500) (Fig. R1a). In the lab, we can measure the snow grain shape and obtain the lengths of a and b (Fig. R1b). Mugnai and Wiscombe (1987) demonstrated that a collection of unoriented non-spheroids produce the same scattering results as spheres, and Grenfell and Warren (1999) showed that the radius of a non-spherical particle was equal to that of a spherical particle that has the same volume-to-surface-area (V/A) ratio. Consequently, V/A ratio was used to transfer the measured snow grain size into the effective grain size. On this basis of field measurement, Hao (2009) proposed two assumptions: 1) The snow particle is an inequilateral spheroid; and 2) The major axis, minor axis, and height of the inequilateral spheroid is denoted by a, b, and c, respectively, in such a way that the relationship a = 2b exists. According to Kokhanovsky and Zege (2004), the effective snow grain radius (Ref) can be calculated equal to the radius of the volume-to-surface equivalent sphere by the following equation (1): R_ef=(3V ÌĚ)/(4A ÌĚ) (1) Where, V ÌĚ=4/3 πrˆ3 and A ÌĚ=πrˆ2, are the average volume and the average cross-section (geometric

shadow) area of the snow grains, respectively. And, r is the radius of geometric optics, r=(a+b)/4. Thus, R_ef≈0.35a Eq.1 was then employed to calculate the effective snow grain size.

We have added related information in the main text (Page 5, Line2-12): For the snow grain size observation, we sprayed the snow grains on MIG paper and took a photo using a portable digital microscope (Anyty 3R-MSV500) to calculate the major and minor axis (Fig. S2). Based on field measurements from previous studies (Mugnai and Wiscombe, 1980; Grenfell and Warren, 1999), two assumptions were proposed: 1) The snow grain particle is an inequilateral spheroid, and 2) The major axis (a), minor axis (b), and height (c) of the inequilateral spheroid are denoted by a, b, and c, respectively, in such a way that the relationship a=2b exists (Hao, 2009). According to Kokhanovsky and Zege (2004), the effective snow grain radius (Ref) can be calculated as equal to the radius of the volume-to-surface equivalent sphere by the following equation (1): R_ef=(3V ÌĚ)/(4A ÌĚ) (1) where V ÌĚ=4/3 πrˆ3 and A ÌĚ=πrˆ2, are the average volume and the average cross-section (geometric shadow) area of the snow grains, respectively. In addition, r is the radius of geometric optics, r=(a+b)/4. Thus R_ef≈0.35a (2)

Figure R1. Snow grain size observation in the field (a) and measurement in the lab (b).

For the estimates of changes in snow cover duration days, we have tried to improve the related details in the main text.

References: Grenfell, T. C., and Warren, S. G.: Representation of a nonspherical ice particle by a collection of independent sphere for scattering and obsorption of radiation, J. geophys. Res., 104(D24), 31697–31709, 1999. Hao, X.: Retrieval of alpine snow cover area and grain size basing on optical remote sensing. PhD thesis, Cold and Arid Regions Environment Engineering Research Institute, Lanzhou, China, pp. 103–104, 2009. Mugnai, A., and Wiscombe, W. J.: Scattering of radiation by moderately nonspherical particles. J. Atmos. Sci., 37, 1291–1307, 1987.

Comment 4: Section 3.3 and 3.4 are generally confusing- was shortwave radiation (uplooking and downlooking pyranometers) actually measured? This analysis seems far too simplified. Furthermore, the discussion of snow depth is misleading. This is a straightforward energy balance calculation, so less snow will melt faster than more snow for an equal amount of forcing- this is basic mass balance. So snow depth does not itself play an important role in the reduction of snow cover by particulates. This is a mixing up of forcing and state functions. The citations are also outdated or incorrect in many cases, and I suggest the authors revisit these. Answer: Shortwave radiation data used in this study was actually measurement by automatic weather station at different selected site near the snow sampling sites in region I, II, and III of the TP (Fig R2). Table R1 showed monthly short-wave radiation from automatic weather stations near the snow sampling sites during the snow melting season (March-May) when the temperature began to increase. On average, shortwave radiations in March, April, May, and June is about 238, 269, 292, and 271 W m–2, respectively. Short-wave radiation in March showed the minimum value in Tanggula (210 W m–2, lower than the average). Short-wave radiation in May showed the maximum value in Namco (314 W m–2, higher the average). Thus, in order to estimate the impact of input short-wave radiation on the snow cover duration, we gave a range of short-wave radiation from 220 to 310 W m–2.

We have added related information in the main text as following (Page11, Line14-23): In Eq. (4), monthly shortwave radiation (SW) input data were obtained from the Automatic Weather Station (AWS) near the snow sampling sites across the TP (Fig. S3). Table S3 shows monthly shortwave radiation data from AWS during the snow melting season (March-May) when the temperature began to increase. On average, shortwave radiation in March, April, May, and June is approximately 238, 269, 292, and 271 W m–2, respectively. Short-wave radiation in March showed the minimum value in Tanggula of the central TP (210 W m–2, lower than the average), whereas in May it showed the maximum value in Namco (314 W m–2, higher the average). Based on these data during the melt season, three scenarios (220, 270, and 310 W m–2)were defined as the minimum, median, and maximum scenarios of input shortwave radiation to estimate its

impact on changes of snow cover duration.

Figure R2. Automatic weather stations selected in the Tibetan Plateau.

Table R1. Monthly short-wave radiation from automatic weather stations near the snow sampling sites during the snow melting season. Sites Month of the year Monthly Shortwave radiation (W m–2) Month of the year Monthly Shortwave radiation (W m–2) Southeastern Tibetan Plateau March in 2014 248 March in 2015 237 April in 2014 288 April in 2015 259 May in 2014 305 May in 2015 280 June in 2014 265 June in 2015 250 Namco March in 2015 264 April in 2015 276 May in 2015 306 June in 2015 314 Tanggula March in 2014 210 April in2014 226 May in 2014 245 June in 2014 271 Laohugou March in 2014 229 March in 2015 238 April in2014 269 April in 2015 294 May in 2014 311 May in 2015 305 June in 2014 258 June in 2015 269

We agree that the equation for changes of snow cover duration is a straightforward energy balance calculation. Thus in this study, it means the duration days of less snow will be less than the more snow for an equal amount of forcing. So under the same level of LAIs in snow, the reduction of snow cover duration days can be affected by different snow depth. We have tried to revise in the main text (section 3.4).

Comment 5: I take issue with the use of the 'Third Pole' term, this is not universally recognized and is somewhat politicized, why not just use Tibetan Plateau or High Mountain Asia? Also light absorbing impurity is an outdated term, the community has moved toward the use of light absorbing particulates. Also mineral dust and the acronym MD are confusing you can simply say dust- which needs no acronym. Similarly, please be consistent in terminology, for example, albedo and reflectance are not the same thing. Answer: We have changed the term “Third Pole” to be “Tibetan Plateau”.

We have used the term “light-absorbing particulates” in the main text.

We have changed the “MD” as “dust” in the main text.

Albedo and reflectance are not the same thing. Albedo is defined as the ratio of irradiance reflected to the irradiance received by a surface. The proportion reflected is not only determined by properties of the surface itself, but also by the spectral and angular distribution of solar radiation reaching the Earth's surface. Unless given for a specific wavelength (spectral albedo), albedo refers to the broadband spectrum of solar radiation.

Reflectance of the surface of a material is its effectiveness in reflecting radiant energy. It is the fraction of incident electromagnetic power that is reflected at an interface. The reflectance spectrum or spectral reflectance curve is the plot of the reflectance as a function of wavelength. When we use ASD, we get the reflectance. In order to compare the albedo simulated by SNICAR model in this study, we have to calculate the reflectance based on the standard solar irradiance. We also carefully use the words consistent in the main text.

Comment 6: Uncertainties in modeling are not only due to lack of observations, and increasing our number of sampling points alone will not reduce our model uncertainty. To state this is misleading. Answer: Agree, and we have tried to revise this section in the section3.4 of the main text.

Please also note the supplement to this comment:
https://www.the-cryosphere-discuss.net/tc-2017-111/tc-2017-111-AC2-supplement.pdf

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Interactive comment on The Cryosphere Discuss., https://doi.org/10.5194/tc-2017-111, 2017.

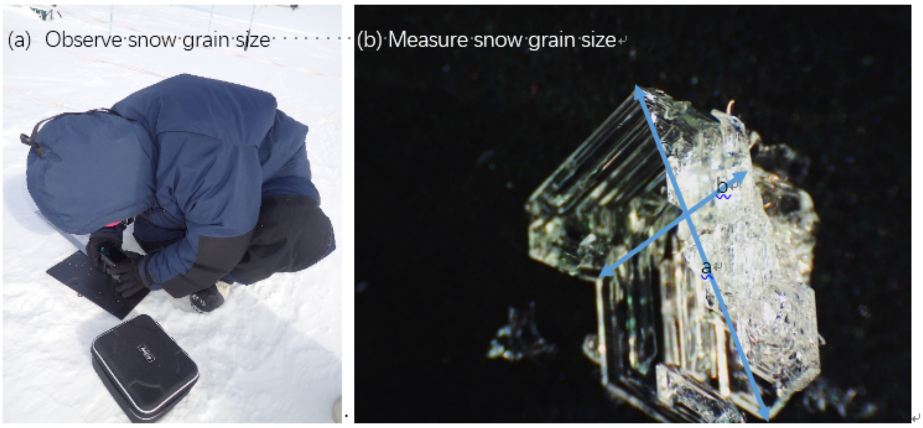


Figure R1. Snow grain size observation in the field (a) and measurement in the lab (b).

Fig. 1.

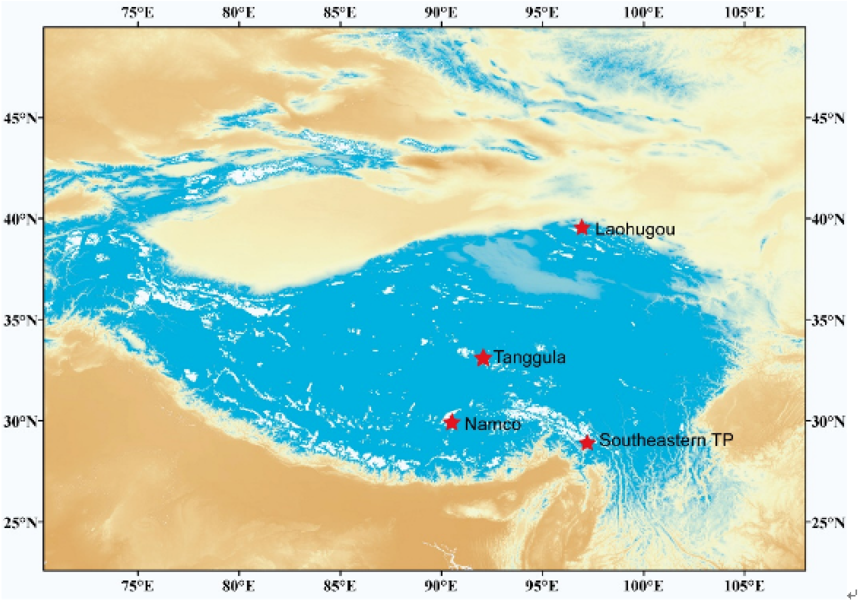
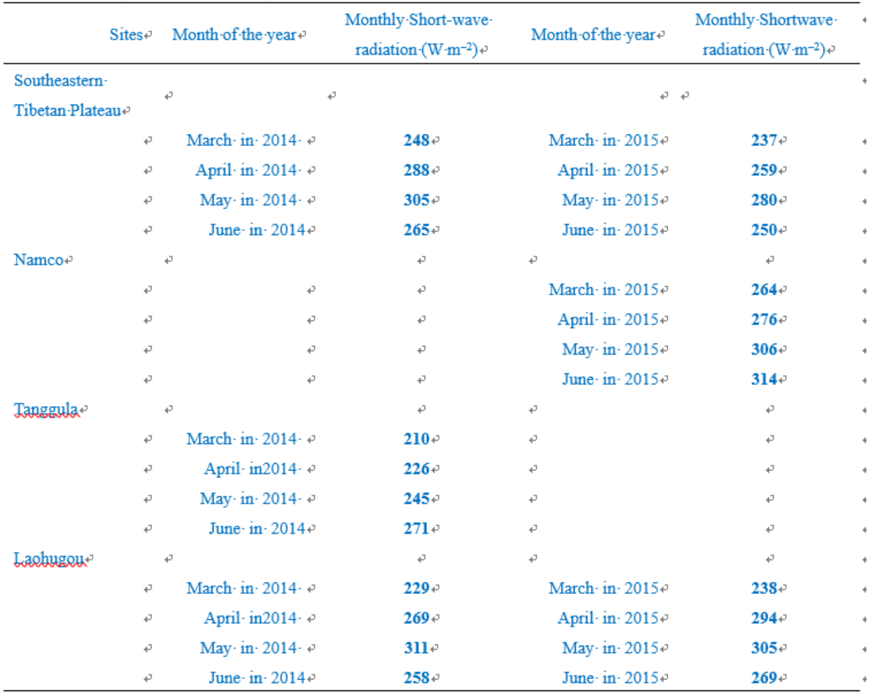


Figure R2. Automatic weather stations selected in the Tibetan Plateau.

Fig. 2.

Table R1. Monthly short-wave radiation from automatic weather stations near the snow sampling sites during the snow melting season.



Sites	Month of the year	Monthly Short-wave radiation ($W m^{-2}$)	Month of the year	Monthly Shortwave radiation ($W m^{-2}$)
Southeastern Tibetan Plateau				
	March in 2014	**248**	March in 2015	**237**
	April in 2014	**288**	April in 2015	**259**
	May in 2014	**305**	May in 2015	**280**
	June in 2014	**265**	June in 2015	**250**
Namco				
			March in 2015	**264**
			April in 2015	**276**
			May in 2015	**306**
			June in 2015	**314**
Tanggula				
	March in 2014	**210**		
	April in2014	**226**		
	May in 2014	**245**		
	June in 2014	**271**		
Laohugou				
	March in 2014	**229**	March in 2015	**238**
	April in2014	**269**	April in 2015	**294**
	May in 2014	**311**	May in 2015	**305**
	June in 2014	**258**	June in 2015	**269**

Fig. 3.