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Aerosol black carbon over Svalbard regions of Arctic

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ABSTRACT

In view of the climate impact of aerosol Black Carbon (BC) over snow covered regions (through enhanced absorption of radiation as well as snow-albedo forcing), and in view of the increasing anthropogenic presence and influence in the northern polar regions, continuous long term measurements of airborne BC have been undertaken from the Svalbard region of Norwegian Arctic (Ny-Ålesund, 79°N, 12°E, 8 m a.s.l.). This study, employing data over a period of 4-years (2010–2013) have shown a consistent spring-time enhancement in BC concentrations, having a (climatological) seasonal mean value of ~50.3 ± 19.5 ng m^{-3}, nearly 3-times higher than the lowest BC concentrations in summer (~19.5 ± 6.5 ng m^{-3}). Spectral variation of absorbance indicates that long-range transported biomass burning aerosols contribute as high as 25% to the high BC concentrations in the Arctic atmosphere in spring. Concurrent estimates of BC concentrations in the Arctic snow (for an ensemble of snow samples collected over a period of time during spring) showed values ranging from 0.6 ppb to 4.1 ppb. These values have been used to estimate the BC scavenging ratio (SR). Our studies revealed a mean value of SR ~98 ± 46, which varied over wide range from 40 to 184 for individual samples. In a broader perspective, the seasonal variations of atmospheric BC concentrations at the Arctic are similar to those seen at the high altitude Himalayas; even though the concentrations are much lower at Arctic. It is found that synoptic conditions mainly influence the high altitude Himalayas, while the influences of local anthropogenic influences are not negligible at the Arctic in modulating the seasonal variations of absorbing aerosols.

1. Introduction

Aerosol Black Carbon (BC) emitted from both natural (biomass burning including forest fires) and human activities (industry, transport and household) are extremely efficient absorbers of solar radiation. While in the atmosphere, BC contributes to global warming and alters cloud formation processes (McConnel et al., 2007), its deposition on snow and ice have large potential to change the surface albedo and feedback mechanisms (e.g., Nair et al., 2013). The nature and magnitude of the impact of BC on the atmosphere and cryosphere vary largely across the globe. The seasonally varying source strengths and long-range transport processes make the spatial and temporal distribution of BC highly heterogeneous. The transport of BC from lower latitude regions to the Arctic atmosphere and subsequent deposition on Arctic snow, glaciers and ice sheets has been a major scientific concern in the last decade, as the Arctic is a net sink for the black carbon (deposition > emission). Unlike the case with populated continental regions, air pollution in the remote Arctic is primarily a result of long-range transport from source regions outside the Arctic. It has been reported that contributions from the European emissions dominate near the surface at the Arctic, while those from East Asian emissions dominate in the upper troposphere (Shindell et al., 2008). It is thus interesting to note that meridional particulate transport shares a major fraction of the Arctic aerosol burden. The long-term surface (Sharma et al., 2004; Eleftheriadis et al., 2009) as well as aircraft based measurements (ARCPAC: Warneke et al., 2009; ARCTAS: Jacob et al., 2010) have revealed rapid build up of BC concentrations at Arctic as a part of the Arctic haze phenomena

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(Shaw and Stamnes, 1980; Iversen and Joranger, 1985; Shaw, 1995), which is associated with clear, typically anti-cyclonic conditions (Koch and Hansen, 2005). The haze is densest during winter and spring due to a combination of more efficient pole ward transport during these seasons and diminishes thereafter associated with the increased removal by low-level drizzling clouds in the summer (Shaw, 1995).

Despite the fact that only 10–20% of the global BC emissions end up in the Arctic, the direct effect of BC is potentially large in the Arctic due to feedback processes, as the absorbing aerosols are located over highly reflective snow/ice surfaces (Pueschel and Kinne, 1995; Hansen and Nazarenko, 2004; Koch et al., 2007; Flanner et al., 2007). The large extent of ice and snow cover, feedback positively to the atmospheric forcing due to absorbing BC and it is furthered by forcing from snow darkening arising out of the accumulation of BC on ice surface. Due to the BC deposition in Arctic snow during 2007–2009, winter season recorded 0.4% decrease in snow albedo, while 0.6% change was reported in spring (Wang et al., 2011). Clarke and Noone (1985) have found that the Arctic snow albedos were reduced by 1–3% in fresh snow and by another factor of 3 as the snow aged and the BC became more concentrated. All these result in higher forcing efficiency for the Arctic BC compared to lower latitude regions, despite the lower BC abundance (for e.g., Sand et al., 2013). It is reported that BC on snow would produce warming about three times more than an equal forcing of CO_2 (Hansen and Nazarenko, 2004). Simulations by Flanner et al. (2007) have estimated a global averaged warming of 0.15 °C (during 1998) and 0.10 °C (during 2001) due to the deposition of BC in snow and reported that the Arctic had the greatest impact of snow darkening. Simulations by Shindell and Faluvegi (2009) estimated 0.5 °C–1.4 °C Arctic warming (including atmospheric and snow forcing) due to transported BC to the Arctic. Wang et al. (2011) have reported the mean surface radiative forcing of 1.2 W m^{-2} in spring associated with open fires, whereas anthropogenic sources led to the forcing value of 0.6 W m^{-2}. This is consistent with the anthropogenic value of 0.53 W m^{-2} previously reported by Flanner et al. (2007). Hansen and Nazarenko (2004) have reported hemispheric radiative forcing of +0.3 W m^{-2} due to decrease in albedo in the Arctic snow and sea ice. However, quantitative estimates of forcing and temperature change are still uncertain due to the lack of simultaneous measurements of BC in the atmosphere and in snow.

The results of our long-term measurements of airborne BC (for a period of 4 years from 2010 to 2013) over the Svalbard region of Arctic (Ny-Ålesund) are examined in the above context. Concurrent analysis of snow samples during the Arctic spring (Mar to May – 2012) has been carried out to estimate the concentration of BC in snow. These are then used to estimate the scavenging ratio of BC from the atmosphere to snow. The study is further extended to another snow covered region by considering the long term BC measurements (2009–2013) from the high altitude Himalayan location Hanle, to understand a broader picture of absorbing aerosols and their behaviour in pristine atmospheric and snow covered surfaces. The present study thus provide valuable information to global aerosol database on the amount of BC in the atmosphere and snow, for understanding the long term change in the cryosphere properties over the high latitude Arctic and the high altitude Himalayas. However, more observations are required to study the effects and impacts of climate change in the Himalayas, since only a handful of stations are conducting in-situ observations in the mountain regions. Little is known about the chemical composition, origin and transport pathways of aerosols arriving in the Himalayas, air-to-snow transfer processes, and the fate of aerosols once they are deposited. Sure Arctic region is much more monitored than Himalayan, but in general the Arctic is under measured as well.

The geographic position of Ny-Ålesund in the Arctic and Hanle in the western trans-Himalayas are shown in Fig. 1, along with the snow sampling locations (right panel) in the Arctic. Ny-Ålesund (79°N, 12°E, 8 m a.s.l.) is located at the northernmost point of the warm Atlantic Ocean inflow at the coast of Kongsfjorden and close to the Zeppelin Mountain on the island of Spitsbergen in the Svalbard archipelago. This high latitude location is very unique owing to its accessibility, as no other place at a location of 78° N is as easily accessible as Ny-Ålesund. It has a highly developed logistical infrastructure with regular flights, a harbour, accommodation, meeting and lab facilities, and high speed Internet, offering excellent conditions for scientific research. The geographical position also provides the possibility to measure both the pristine, clean Arctic atmosphere with minimal background values and increased pollution episodes due to long range atmospheric transport processes, enabling observations of climate relevant parameters in the ocean, on land, and in the atmosphere. For that reason, observations in Ny-Ålesund allow monitoring of background values of trace substances, as well as investigation of physico-chemical transformation processes of air mass characteristics. In the present study, the atmospheric BC measurements were carried out from the Gruvebadet observatory at Ny-Ålesund.

The Himalayan sampling site at Hanle (32.78°N, 78.96°E) in the western Indian Himalayas is located at an altitude of 4520 m a.s.l. and approximately ~300 m above the base camp in the Hanle valley. The site is mostly rocky, sandy and desert like having very little vegetation (like shrubs). It experiences snow falls during winter (December to February) and summer (June to August), while the snow cover persists over many mountain peaks surrounding the experimental site throughout the year. The Hanle valley has scattered settlements of a population of ~1700 over an area of 20 km^{-2}. The Hanle River, fed by melting of glaciers during spring and summer, flows through the far end of the valley and becomes dry (frozen) in winter. The experimental location is completely isolated from populated and industrialized cities. The nearest township is located almost 270 km Northwest. As the site is far remote from anthropogenic sources and elevated from local activity, it is reasonable to consider it as representative of background free tropospheric regions (Babu et al., 2011; Moorthy et al., 2011).

2. Measurement/sampling details

2.1. Measurements of BC in the Arctic atmosphere

Continuous measurements of airborne particulate BC mass concentrations (M_{BC}) have been carried out at the Svalbard location of Arctic 'Ny-Ålesund (NYA)'. A 7-channel aethalometer (Model AE-30, Magee Scientific, USA) was used to suck ambient air at a flow rate of 5 LPM from a height of 3 m above ground during each 30 min time settings of measurement intervals. At the high altitude Himalayan site Hanle (4520 m a.s.l.), the BC mass concentrations were monitored in each 5-min interval using a 2-channel (model AE-20; 370 nm and 880 nm) aethalometer supported by an external pump catering the need arising out of the low ambient pressure. During winter, a heated inlet was used to ensure continuous and smooth operation of the aethalometer.

Aethalometer is a field rugged instrument. It has been extensively used over a variety of environments for continuous measurements of ambient BC mass concentration, with a typical uncertainty of <5% (Babu et al., 2011).

The major uncertainties in BC measurements made with the aethalometer are:

1. Inconsistent change in attenuation during collection of light-absorbing particles in the filter media. In general, BC mass