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Albedo Observations with Large Concentrations of Black Carbon in High Arctic Snow Packs from Svalbard

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ABSTRACT

Observations from the Arctic basin has proven Black Carbon to be present in sufficient concentrations to be detected. This black carbon can only originate from anthropogenic emissions further south. On land at Svalbard both local manmade emissions and weathering of the coal containing sediments can be a source.

Keywords: Albedo, black carbon, snowmelt

INTRODUCTION

Model results has shown that despite very small concentrations of black carbon (BC) in Arctic snow packs it can affect the snow albedo and the resulting radiation balance. An increasing interest in BC in Arctic snow has emerged due to model results showing that absorption of the entire Arctic has increased with 0.3 W/m^2 (Hansen and Nazarenko, 2004).

Under the most favourable conditions other model studies show that at a BC concentration as low as 10^{-8} the snow albedo can be reduced with 1% (Warren, pers. Comm. 2004). And, measurements of BC in snow from the Arctic basin in 1983-'84 show detectable BC in concentrations affecting the snow albedo with one to several percent (Clarke and Noone, 1985). As for the global radiation forcing balance the effect of BC in snow is mentioned as a component in the fourth assessment report from IPCC (IPCC, 2007). However, a problem with documenting the effect of low concentration of BC in snow is that the natural variability of snow albedo is too large to isolate the BC effect using surface albedo measurements only. Nor does retrieval of surface albedo from satellite images provide a clear proof of BC in snow. This leaves spectral radiation modelling in combination measurements of BC concentrations an important method for gaining information about the impact of BC in Arctic snow.

This study on Svalbard has been motivated by the fact that BC is detectable at very low concentrations on sea ice in the Arctic basin. However, on land higher BC concentrations are likely to occur since both local emissions and BC from weathering of sedimentary rocks will also contribute. The aim here is to analyse the impact of high concentrations of BC on snow albedo close to an emission source in an Arctic settlement on Svalbard, namely Longyearbyen.

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SOURCES OF BC ON SVALBARD

It has earlier been assumed that BC is only deposited locally or regionally with the largest particles closest to the source. However, BC has also been observed in Greenland as well as Antarctic ice cores, which can not be from a local source since both continents have no natural sources or a significant man made contribution. So, a fraction of the BC emission is transported inter-continentally, which also includes remote transport to Svalbard. In May of 2006 the highest concentration of anthropogenic pollution ever observed on Svalbard was recorded in Ny-Ålesund. Analysis of this particular event proved its source of origin to be central Europe. And, the pollution plume reached Svalbard with nearly initial concentration (Holmén, pers comm. 2006). Other studies have shown that high concentrations of particulate pollutants occasionally do reach the high Arctic on event basis (Heidam et al., 1999). (Fig. 1) So, remote sources can also be detected on land.

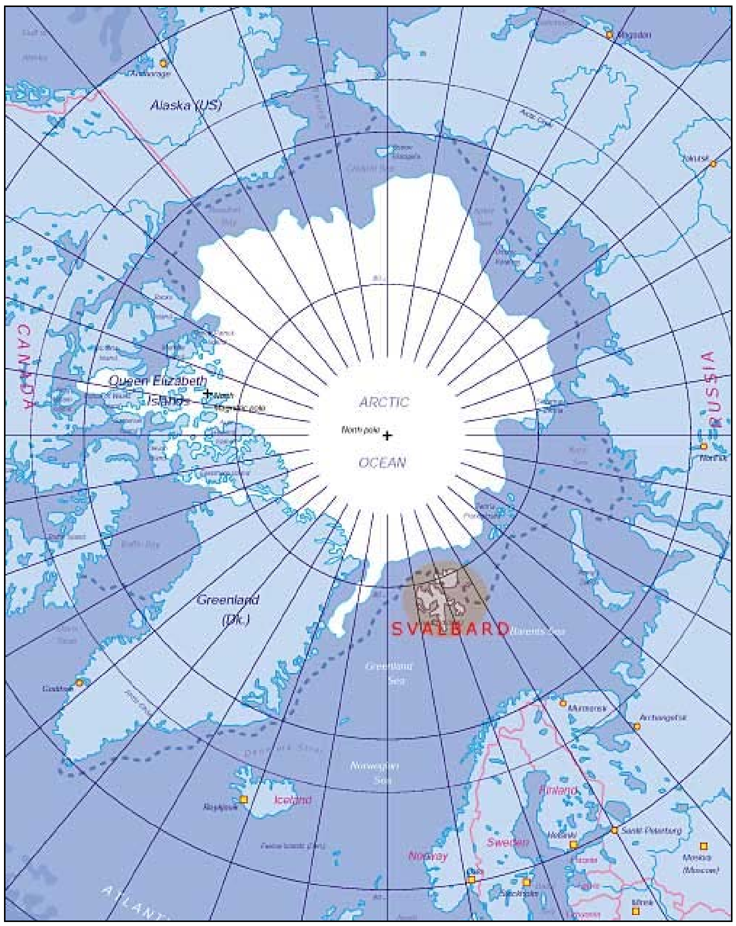

Figure 1. Geographical map of the north Atlantic including Svalbard, northern Europe and the Arctic Ocean.

A natural local source of BC is from weathering of carbon containing sandstone in the central Spitsbergen (see map 2). The geological setting has enabled coal mining on Svalbard for around 100 years. The major coal horizons exploited are predominantly under one meter thickness. But, the tertiary rocks include mudstone with high concentrations of BC. And, often the mudstone contain some 20% or more BC, which make them appear optically 'black' (Lotta Luthje, pers comm.). Whether this source is important still remains to be investigated. One assumption about the local BC from weathered rock on Svalbard is that most particles are large and deposited in the vicinity of their source (Holmen, pers comm.)

Man made emission of BC from settlements on Svalbard is assumed to be limited from the three municipals totalling 3000 inhabitants, namely Longyearbyen, Svea and Barentzburg. The other two settlements Ny-Ålesund and Hornsund have no or limited emissions due to their size and regulations.

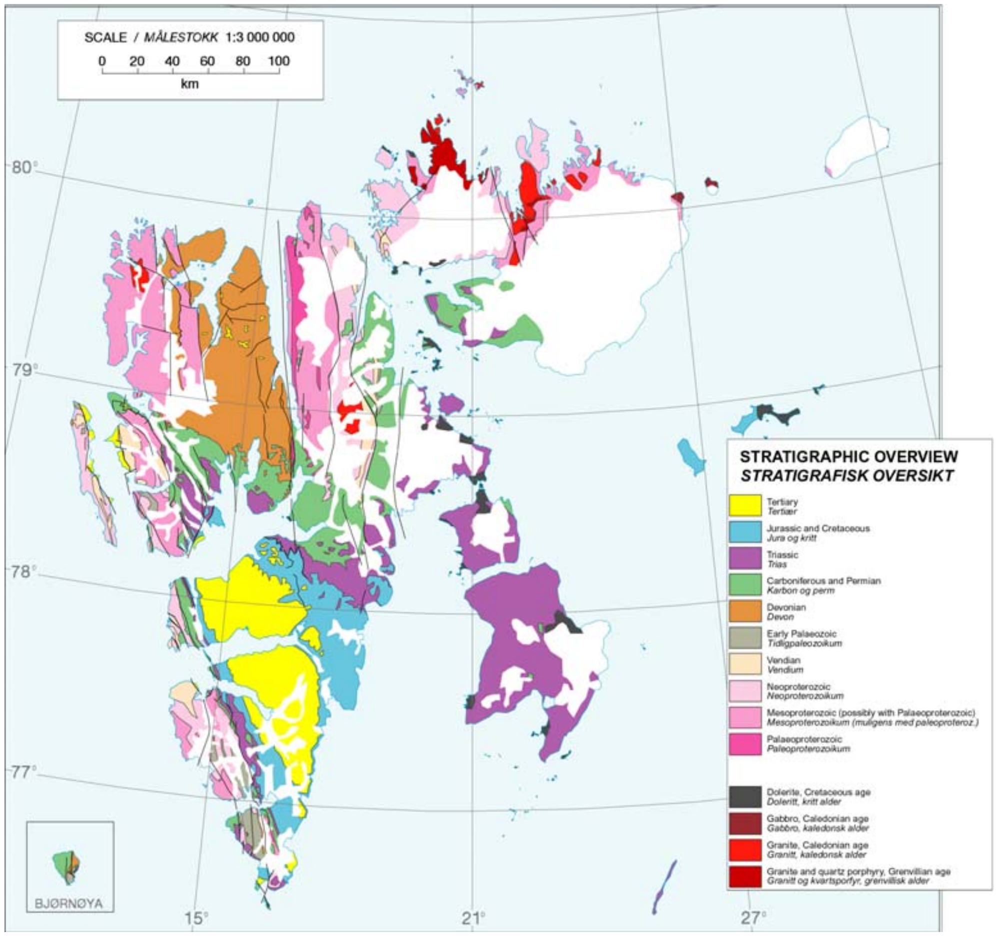

Figure 2. Geological map of Svalbard. Most coal deposits are found in the tertiary rock formations in the south-western Svalbard.

ALBEDO MEASUREMENTS NEAR A LOCAL COAL DUST SOURCE

Two major point sources in Longyearbyen are suited for high concentration BC analysis of albedo, namely a coal mine and a harbour coal processing site. Fig. 3 shows the only operating mine in Longyearbyen "Mine 7" from where the coal is transported to the harbour in open trucks all the year. In the centre of the picture, where the darkest snow appears, is the entrance to the mine. But, the airborne effect is clearly visible as the darkest snow is found nearest to the road all the way down the mountain side. Analysis of the snow-albedo relation has mainly been carried out along a line indicated as white in fig. 3.

Figure 3. Snow containing airborne BC at mine 7 in Longyearbyen, Svalbard. For scale the horizontal disk above the mine is 30 m in diameter. The3 white line refer to the transect where observation were carried out.

Albedo was determined using a FieldSpec3 spectroradiomenter and analysis of BC concentrations have been made from collecting surface snow samples, measuring the total mass and determining the dry mass of BC by melting and drying the sample. The results in fig. 4 show a clearly non-linear albedo-BC relation with a best match using a logarithmic curve. We interpret this non-linear relation as a result of two factors, 1) flocculation of particles at high concentrations (which we observed) and 2) the largest particles (large mass) is deposited closest to the road. At low concentrations the albedo is highly sensitive to BC concentrations whereas this sensitivity reduces with larger BC concentrations. Our results also show that the albedo reduces to around half i.e. from 0.71 with nearly clean snow to 0.296 with a BC concentration of only 0.91%. We had chosen our time of measurements to be in the early melt period (May 19) in order to carry out observations on homogenous snow surfaces.

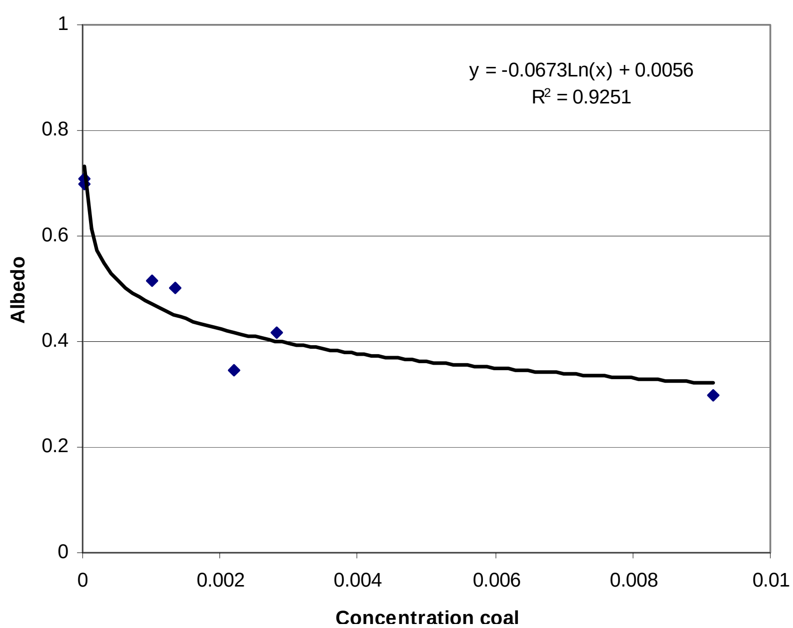

Figure 4. Observed BC concentrations plotted against surface albedo observations.
A logarithmic curve is the best fit to the points.

Other observations here have shown that at low temperatures, in this case -7°C, melting can occur in areas with high BC concentrations. The physics governing this melt is the formation of a transparent ice lens which allows solar radiation to penetrate. This radiation is then absorbed in the coal particles after passing an air space of some 3 cm thickness. Since the conduction and convection in the air void does not fully compensate the incoming radiation, temperatures at the very surface of each coal particle rises and melting takes place in the adjacent snow. Fig. 5 shows observed temperatures using an infrared temperature sensor at a snow surface, a transparent ice surface and on coal containing snow. We did not directly measure melting point temperatures on this coal containing snow using the IR sensor. But, the snow appeared wet and sticky, and we observed wet flocculation of the coal particles. A spot measurement covering several cm^2 will therefore provide an average observation of cold snow and particles whereas melting takes place in a thin film nearest to each coal particle.

The efficiency of this early melting under negative air temperatures is seen in fig 6 from May 16. 2007. The snow downwind from a production plant near the harbour did contain high concentrations of coal dust (BC) and has already melted away at the onset of continuous melting in Longyearbyen.

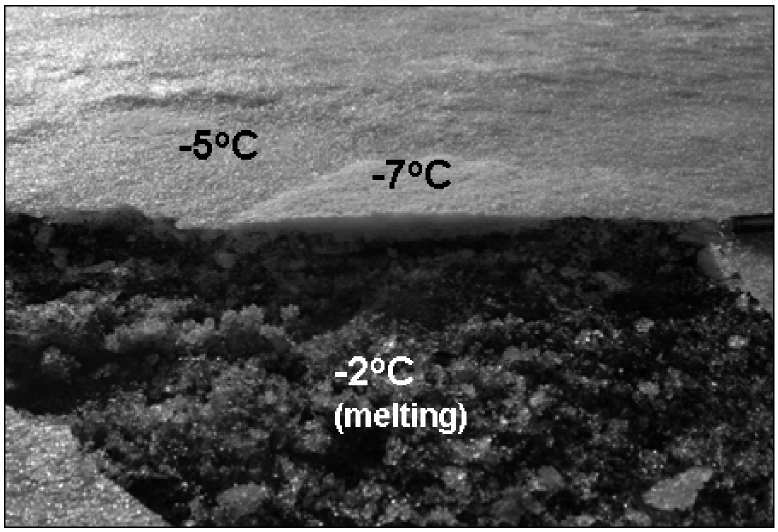

Figure 5. Observations of melting at negative air temperature conditions. Temperature were measured using an infrared temperature sensor, where the -7°C area is snow, the -5°C area is transparent ice and -2°C is the BC-snow mixture below the surface. The air filled void between ice and BC-snow is approximately 3 cm thick.

Figure 6. To the right the coal processing plant in Longyearbyen. Downwind from this (toward left) snow has melted on May 16. 2007 where melting had just initiated in Longyearbyen.

CONCLUDING REMARKS

The importance of the effect of BC in snow has been documented by Hansen and Nazarenko (2004), who state that as much as 0.3 Wm^{-3} is absorbed in the entire Arctic due to BC. Despite this importance the effect of BC can not be measured directly at low concentrations. Instead a combination of spectral radiative transfer modelling and retrieval of BC concentrations in snow has to be applied to determine the effect of BC.

When analyzing sources and the effect of BC in snow packs on land also local sources such as detritus from carbon containing sediments and emission from local anthropogenic sources has to be considered. How large these sources are is still unknown. But, around Longyearbyen relatively large concentrations of BC can be observed and measured in snow. Especially at a mine site and near a processing plant at the harbour.

Downwind from the processing plant at the harbour a “snow/ice based green house effect” (Bøggild et al. 1994) develop in dark BC containing snow. Even before melting starts a transparent ice lens is formed with an air void below and followed by dark coal containing snow beneath this. Despite a surface temperature as low as -7°C melting can take place in the snow surrounding each coal particle in this system. Development of this BC based greenhouse system inside the snowresult in onset of snowmelt much earlier than elsewhere.

Finally a number of surface albedo observations were made in combination with dry mass from snow at an area with wind blown coal dust particles. Our preliminary relation between BC concentration and albedo best matches a logarithmic regression fit. We interpret this non-linear fit to be a result of both flocculation of the BC particles and that the larges particles are found at highest concentrations of BC i.e. close to the source. The albedo reduces to les than half from 0.71 on nearly clean snow to 0.296 with a BC concentration as small as 0.91%.

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