**CRAICC deliverable D7: Report on quantified records of variations of SLCFs over short (seasonal) and long (millennial) time-scales (M30)**

A master thesis has been finished evaluating the mass concentration of weekly samples of elemental (EC) and organic (OC) carbon over a period of four years at Station Nord, Northeast Greenland, showing distinct seasonal variations in the concentration values indicating the Arctic haze seasonal cycle. Additionally, the quantification of EC in selected snow samples from Station Nord has been evaluated within the thesis. The data is used for an improved analysis of source apportionment modeling at Station Nord to identify seasonal trends. A previous study on source apportionment at Station Nord, North East Greenland, has been published by Nguyen et al. (2013).

The source origin of major anions was investigated in late winter/early spring 2011 through analysis of mass size distributions of these anions at Station Nord. The idea was to improve the current understanding of the composition and the origin of aerosols observed in the high Arctic. A major finding was that just after polar sunrise the Arctic aerosol is a mixture of long-range transported and regional to locally originating aerosols. Results are published by Fenger et al. (2013).

The particle number size distribution is measured at Station Nord from July 2010 and ongoing. The number of accumulation mode particles is increased during the Arctic haze period showing a prominent mode during this time of the year. Clearly, the particle number size distribution is an indicator for the long-range transported air masses during late winter and early spring showing a distinct seasonal cycle in number concentration of accumulation mode particles. Only during summer and daylight periods particle nucleation events are observed with events lasting in some cases several days indicating precursor emissions from the ice or open leads in the Arctic region. Similar findings were reported by Tunved et al. (2013) for the Zeppelin measurement station in Svalbard.

Emissions of the primary marine aerosol (PMA) from the Arctic Ocean have been studied in situ by means of laboratory-field experiments at Ny Ålesund, Svalbard (Zabori et al., 2013). A comprehensive data set from the Arctic summer and winter showed a decrease in PMA concentrations with increasing sea water temperature between −1°C and 15°C.

Black carbon's seasonality in surface snow has been shown to have an increasing trend throughout the winter season (e.g. Doherty et al., 2013; Svensson et al., 2013). The amplification of BC has been observed to differ depending on the location of observation. For example Doherty et al. (2013) estimated an amplification of a factor of ~10-15 in Barrow, Alaska and ~2-3 in Tromsø, Norway.

BC is deposited to the surface and a certain fraction will end up in lake sediments. Analysis of cores from these sediments can provide information about decadal variations in deposition rates. In a recent paper (Ruppel et al., 2013) modelled and measured deposition fluxes to Nordic lakes since 1850 using the historical emission dataset from Lamarque et al. (2010) are compared.

Analysis of aerosol samples from Station Nord and Zeppelin Mountain during a full annual cycle showed the presence of biogenic organic acids and organosulfates. Highest concentrations were observed during Arctic haze in winter and spring when also anthropogenic SOA tracers peaked.
The seasonality of black carbon aerosol in air has been reported from different measurement stations in Finland (Hyvärinen et al., 2011), with the highest concentration during the spring and winter and lowest during the summer.

Ozone is very stable at Station Nord, Northeast Greenland, most of the year without a daily pattern. In January the level is about 40 ppbv and remains there until polar sunrise in the end of February. Then, a highly perturbed period appears where ozone is depleted to zero from about 40 ppbv. The concentrations remain at zero for periods that may last from hours up to several days before suddenly rising again. In July, the ozone concentration stabilizes just above 20 ppbv, and then it slowly increases to about 40 ppbv in September/October.

Models have a long standing problem to reproduce the seasonal cycle of observed black carbon aerosols (BC) in the boundary layer. A discrepancy of measured and modeled BC concentrations was found at Svalbard, Spitzbergen (Lee et al., 2013). It has been suggested (Stohl et al., 2013) that lacking emissions from flaring and domestic wood burning could be a major source of the discrepancy. Within CRAICC it has been looked at the role of different emission datasets (the RCP from Larmaque et al. (2010) and the new ECLIPSE dataset from IIASA), as well as different meteorological datasets and parameterizations of wet scavenging in the Oslo chemistry transport model. In fall and early winter there is a significant improvement in the model, however during spring the model still underestimates the concentrations significantly. The new ECLIPSE emissions were used in the paper by Sand et al. (2013) using the NorESM model to study the climate impact of Arctic versus mid-latitude BC emission sources.

The Lomonosovfonna ice core recovered from Svalbard in 2009 indicates seasonal BC mass concentration variations in the first analyzed 10 years of the 700 year record, determined in ca. monthly resolution with a Single Particle Soot Photometer (Wendl et al., in prep a). The highest concentrations are expected to occur in late winter to early spring due to the Arctic haze period.
Another 300-year ice core from Holtedahlfonna, Svalbard, shows significant decadal trends in elemental carbon (EC) deposition during the last century (Ruppel et al., in prep.). A large Arctic snow data-set suggests a factor of 2-3 higher EC concentrations in snow compared to model simulations obtained using the chemical transport model OsloCTM2 (Forsström et al., in revision; Pedersen et al, in revision). The spring melt period is found to lead to enhanced EC levels in surface snow.
The sulphate record in the Lomonosovfonna ice core shows increased concentrations since the industrial revolution. Before ~1850 AD sulphate mainly originates from marine or volcanic sources. Large volcanic eruptions detected are Laki 1783 AD, Kuwae 1459 AD and the unknown 1259 AD (Wendl et al., in prep b).

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