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Chemistry of snow cover and acidic snowfall during a season with a high level of air pollution on the Hans Glacier, Spitsbergen

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ABSTRACT

The central Arctic is within the range of air pollution transported from industrial areas of Eurasia and North America. A poor network of weather stations means that there is limited information available about air quality and contaminant deposition in the Arctic environment. For this reason seasonal snow cover is an important source of information. Chemical properties of precipitation, snow cover and fresh snow were monitored at the Hornsund Polish Polar Station (Spitsbergen) and in the altitude profile of the Hans Glacier. Meteorological data from the coast and the glacier helped to examine in detail the impact of atmospheric processes on snow cover contamination. The episode with extremely acidic precipitation was recognized in snow cover analysed in spring 2006. The source area of pollution and type of synoptic situation which enhanced transfer of pollution to the European Arctic were identified. Changes in snow chemistry in the altitude profile demonstrated the impact of the atmospheric boundary layer on chemical properties of precipitation and snow cover. Non-sea salt SO_2 emissions and the role of nitrate in acidification should be considered a serious threat to the Arctic environment.

1. Introduction

The central Arctic is within the range of air pollution transported from industrial areas of Eurasia and North America because of the patterns of atmospheric circulation over the North Atlantic (Eckhardt et al., 2003). However, both the extreme climatic conditions and the poor network of weather stations mean that there is limited information available about air quality and contaminant deposition in the Arctic environment. Only three of the Arctic Monitoring and Assessment Programme (AMAP) stations which monitor air and precipitation chemistry are situated in the central part of the Arctic (Hole et al., 2006). Two stations are located on Spitsbergen (Ny-Ålesund and Hornsund) and one collects information in the Canadian Arctic (Alert). For the above reasons snow cover is an important source of data about air pollution transport and contaminant deposition affected by atmospheric circulation patterns (Głowacki and Pulina, 2000; Burzyk et al., 2001; Sharp et al., 2002; Toom-Sauntry and Barrie, 2002; De Caritat et al., 2005).

The Arctic is a very sensitive region, especially in spring (Solomon et al., 2007). The melting season increases the snow-albedo feedback and aerosols can directly influence the Arctic radiation budget by scattering and absorbing sunlight or by settling on the ground and thus decreasing the albedo (Stock et al., 2014).

The most important phenomenon regarding polar aerosols is Arctic Haze – accumulation mode particles consisting mainly of sulphates and soot transported into the Arctic throughout the winter and early spring (Quinn et al., 2007; Stock et al., 2014). Recent observations of air pollution show that one of the most important events in early spring is biomass burning (Westerling et al., 2006; Turetsky et al., 2011).

According to the report of the European Monitoring and Evaluation Programme (EMEP), sulphur emissions have decreased markedly since the 1990s (Vestreng, 2003). Quinn et al. (2007) suggest that concentrations of non-sea salt (nss) SO_4 in the

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Canadian, Norwegian and Finnish Arctic were found to have decreased by 30–70% from the early 1990s to the present. From 2000 to 2006, sulphur oxide (SO_x) emissions in the EU and Eastern Europe were reduced by around 20–24% (Tarrason et al., 2008). Both in situ measurements and trend analyses for the Arctic indicated declines in sulphur concentrations ranging from 30 to 70% from the early 1990s to the present (Quinn et al., 2007). During this time the quantity of nitrogen oxides (NO_x), NH_3 and PM10 emitted decreased slightly (<5%), except for the Russian territory, where an increase in NO_x (+14%) and PM10 (+10%) was observed. Hole et al. (2006) note that an increase in pH was not necessarily connected with a decrease in total and non-marine SO_4 concentrations. It could be linked to the contribution of marine sulphur as well as to NO_3 and NH_4 emissions. The authors state that the role of nitrate in the Arctic air pollution and precipitation needs to be better understood. The pattern of NO_3 and NH_4 concentrations in the air and wet deposition is unclear and there have been no significant trends for nitrate and ammonium concentrations observed in the last two decades (Hole et al., 2009; Kühnel et al., 2011).

In general, Arctic air quality is improving but weather events like that of spring 2006, when a high level of air pollution and anthropogenic haze were recorded, do still take place. High air pollution was observed in the Arctic in early May 2006 (Law and Stohl, 2007; Stohl et al., 2007; Treffeisen et al., 2007). It was a typical rapid transport of biomass burning aerosols (smoke) from agricultural fires in Eastern Europe to the Arctic. The episode of polluted air which reached Spitsbergen in spring 2006 was called "Arctic smoke" due to the agricultural fires in Baltic countries, Belarus, western Russia and Ukraine.

In Ny-Ålesund (northern Spitsbergen), in springtime, over a period between 2001 and 2011, mean values of Aerosol Optical Depth (AOD) at 550 nm reach 0.0843 ± 0.005 (SD 0.0348) with Ångström Exponent (AE) 1.431 ± 0.005 for 870 nm–440 nm; April AOD − 0.0872 ± 0.005 (SD 0.0352), AE − 1.455 (Stone et al., 2014). These values suggest relatively clean air and typical atmospheric turbidity conditions at the site (Tomasi et al., 2007). High concentration of aerosols was observed on 27 April 2006 with peak concentrations of AOD (at 500 nm) measured in Ny-Ålesund from 2 to 3 May (Stohl et al., 2007; Treffeisen et al., 2007).

Even though sources of pollutants deposited over the Svalbard archipelago in spring 2006 were described in numerous publications (e.g. Stohl et al., 2007; Law and Stohl, 2007), none of the publications included information on chemical composition of these deposits. The main aim of this study is to provide insight into chemical composition of deposited precipitation and long-range transport of pollutants from lower latitudes.

This episode confirms the opinion voiced by Macdonald et al. (2005), according to whom the assessment of contemporary trends is made more difficult by the inherent variability of atmospheric processes over different timescales. There is a recognized direct effect of aerosols on the radiation balance and microphysical properties of clouds, but it is not known what proportion of pollutants transported to the Arctic is deposited on land and what on sea surfaces. The mining and metallurgical industry on the Kola Peninsula and in the area of Norilsk (in eastern Siberia) is the largest source of SO_2 emissions in the European Arctic, which acidify terrestrial and freshwater ecosystems (Skjelkvåle et al., 2006; Głowacki, 2007; Derome et al., 2008). Atmospheric circulation which is controlled by conditions over the Norwegian Sea, Fennoscandia and Siberia, transports these pollutants towards the central parts of the Arctic Sea.

2. Study area, materials and methods

The research reported here was carried out on Wedel-Jarlsberg Land (SW Spitsbergen Island) and targeted the Hornsund Fjord area where the Hornsund Polish Polar Station (PPS) is located. The coastline of the area is very irregular with several embayments constituting lower reaches of valleys occupied by retreating glaciers (Błaszczyk et al., 2013). Mountain massifs with elevations of approximately 500–600 m a.s.l. aligned longitudinally and coastal plains dominate the landscape (Giżejewski et al., 2013). The plains are mainly marine terraces covered with very rich tundra vegetation (Birkenmajer, 1960; Karczewski et al., 1981; Owczarek et al., 2014). Niedźwiedź (1993, 2013) and Matuszko and Soroka (2013) stated that Spitsbergen lies close to the Arctic Front and is characterized by a high level of cyclonic activity (on 56.5% of days in the year on average). Anticyclonic situations occur on average on 40.6% of days in the year. The northern arm of the Gulf Stream running along the western coast of Svalbard tempers the climate of this area (Walczowski and Piechura, 2011). Frequent changes in temperature, humidity, air pressure and wind speed are characteristic of Spitsbergen and seasonal conditions fluctuate in Hornsund from year to year. The mean annual air temperature (1978–2012) is −4.1 °C (SD 1.4), ranging from −10.5 °C (SD 4.3) in January to +4.4 °C (SD 0.5) in July. The mean yearly precipitation total is 443.9 mm (SD 95.1), with 20.1 mm (SD 12.1) in May and 68.3 mm (SD 48.9) in September (Marsz and Styszyńska, 2013).

Chemical properties of precipitation and snow cover have been monitored at the Hornsund Polish Polar Station since 1988 (Głowacki, 2007). Apart from the standard measurements and chemical analyses of daily totals of precipitation, the chemistry of fresh snow episodes and properties of snow cover are monitored in the altitude profile of the Hans Glacier (Fig. 1). The data contribute to both the AMAP monitoring network and to glaciological studies of the Hans Glacier. Studies carried out by Głowacki (2007) in the Hornsund area indicate that in the period between the years 1990 and 2005, the weighted mean of pH for summer and winter precipitation was 4.89 and 4.96 respectively. Nearly half of all the episodes demonstrated pH < 5, which occurred in cyclonic situations with the advection of air masses from S–SW.

To examine in detail the impact of atmospheric processes on physicochemical properties of the seasonal snow cover accumulated on glaciers, since 2003 continuous meteorological measurements have been conducted on the Hans Glacier and in its surroundings. For this purpose a network of Automatic Weather Stations (AWS) and HOBO Temperature External Data Loggers (Onset, USA) have been used.

The long-term meteorological data were taken from the PPS meteorological synoptic station which is part of the Norwegian meteorological network and is registered in the World Meteorological Organisation (WMO) under 01003 number.

Field research conducted in the 2005/2006 winter and spring season provided the key to the detailed analysis and identification of pollution sources. After snowfall episodes, fresh snow was collected along the altitude profile of the Hans Glacier, close to the ablation stakes and about 20–30 m from snow scooter tracks. To limit contamination, pre-rinsed 1000 ml polythene bottles and fresh silicon gloves were used.

During the snow pit campaign, after digging, snow layers were recognized and their physical parameters were described. Later, shaded snow walls were cleaned and snow samples were collected to new, clean and pre-rinsed LDPE bags. Samples were transported to the PPS chemical laboratory, where the snow was melted under cover at room temperature and immediately filtered through pre-rinsed Millipore 0.45 μm White Gridded cellulose membrane filters.

Specific electric conductivity (Elmetron CC-401) and pH (Elmetron CP-401) were measured using meters calibrated prior to measurements. Accuracy for pH and specific electric conductivity