Atmospheric Environment 88 (2014) 275–284

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Long-term particle measurements in Finnish Arctic: Part I – Chemical composition and trace metal solubility

James R. Laing [a], Philip K. Hopke [a,*], Eleanor F. Hopke [a], Liaquat Husain [b,c], Vincent A. Dutkiewicz [b,c], Jussi Paatero [d], Yrjö Viisanen [d]

[a] Center for Air Resources Engineering and Science, Clarkson University, Potsdam, NY 13699, USA
[b] New York State Department of Health, Wadsworth Center, Empire State Plaza, Albany, NY 12201-0509, USA
[c] Atmospheric Sciences Research Center, and Department of Environmental Health Sciences, School of Public Health, SUNY, Albany, NY 12201-0509, USA
[d] Finnish Meteorological Institute, Helsinki, Finland

HIGHLIGHTS

- Forty-seven years of week-long Finnish Arctic PM chemical compositions are given.
- Seasonality of the chemical species is presented.
- Trace metals were analyzed providing near-total and soluble metal concentrations.
- Trace metal solubilities in Arctic aerosol are presented.

ARTICLE INFO

Article history:
Received 10 October 2013
Received in revised form
25 February 2014
Accepted 1 March 2014
Available online 4 March 2014

Keywords:
Arctic aerosol
Composition
Arctic haze
Trace metal solubility

ABSTRACT

Week-long total suspended particle filter samples collected between 1964 and 2010 from Kevo, Finland were analyzed for trace metals, soluble trace metals and major ions. Ion chromatography was used to measure major ions. Inductively coupled plasma mass spectrometry was used to measure the trace metal and soluble trace metal concentrations. Species of anthropogenic origin (V, Co, Cu, Ni, As, Cd, Pb, SO_4^{2-}) have significantly higher concentrations compared with other Arctic locations. A clear seasonal trend with winter/spring maxima and summer minima is observed for most species, although it is less pronounced than those found in the high Arctic due to the relative proximity to Eurasian pollution sources. High concentrations of Cu (14.1 ng/m^3), Ni (0.97 ng/m^3), and Co (0.04 ng/m^3) indicate the influence of non-ferrous metal smelters on the Kola Peninsula, although Cu unexpectedly did not correlate with Ni or Co. Ni and Co were highly correlated. Cu, Re, Tl, As, W, and V had high solubilities (61%–87%), Co and Ni had solubility's of ~33%, and Pb had a solubility of 22.9%. The solubility of metals can help determine if the source is natural or anthropogenic. It also dictates the bioavailability of metals once introduced to the environment.

1. Introduction

Arctic haze has been actively studied for over 40 years. High concentrations of ground level particulate matter (PM) as well as layers aloft are observed in the late winter and early spring, while low concentrations are typically observed during the rest of the year. Extensive reviews characterizing PM and the related transport phenomenon have been published (Barrie, 1986; Shaw, 1995; Law and Stohl, 2007; Quinn et al., 2007). Long-range transport of mid-latitude anthropogenic and wild fire emissions drive the seasonality observed in the Arctic. The ground-level winter–spring maxima in the Arctic are mainly due to enhanced long-range transport from Eurasia. Eurasian sources are higher in latitude than North American or Asian sources and therefore are more readily encompassed by the polar front in winter. Atmospheric blocking and the development of anticyclones over Eastern Europe and Siberia also enhance rapid transport into the Arctic from Eurasia (Iversen and Joranger, 1985; Raatz and Shaw, 1984; Raatz, 1989). During winter, stable, dry, and cold conditions enhance pollutant's atmospheric lifetime by restricting vertical mixing and dilution, minimizing wet scavenging, and slowing the oxidation of

DOI of original article: http://dx.doi.org/10.1016/j.atmosenv.2014.01.015.
* Corresponding author.
E-mail address: phopke@clarkson.edu (P.K. Hopke).

http://dx.doi.org/10.1016/j.atmosenv.2014.03.002
1352-2310/

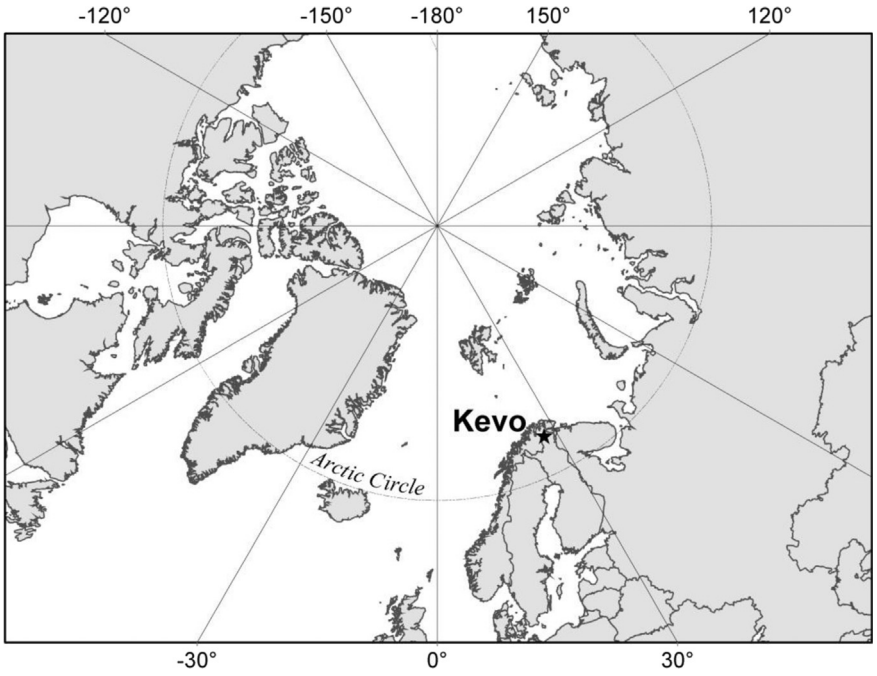

Fig. 1. Map of the sampling location, Kevo, Finland.

SO_2 (Barrie and Barrie, 1990; Raatz and Shaw, 1984). Transport from North America or Asia to the Arctic are along cyclonic paths where wet scavenging is very effective at ground level (Raatz, 1991). Transport from these regions tends to be at higher elevations along sloping isentropes into the free troposphere, entering the Arctic from above by radiative cooling (Stohl, 2006).

There are only a few long-term studies of Arctic aerosol composition. Measurements of PM compositions have been made at Alert, Canada by the Meteorological Service of Canada starting in 1980 (Barrie and Hoff, 1985; Gong and Barrie, 2005; Sirois and Barrie, 1999; Xie et al., 1999a,b); Barrow, Alaska by the National Oceanic and Atmospheric Administration (NOAA) and seven National Park Service locations in Alaska starting in 1986 (Polissar et al., 1998a, 1998b, 1999, 2001; Quinn et al., 2009); and the Zeppelin Observatory at Ny-Ålesund by the Norwegian Institute for Air Research (NILU) starting in 1994 (Berg et al., 2004; Hirdman et al., 2010a,b). Decreasing concentrations of anthropogenic components have been found with a sharp decrease in the early 1990's coinciding with the economic collapse of the Soviet Union and Eastern Europe.

The solubility of trace metals is important because of its environmental implications, and also because it can provide information about its emission source. Solubility depends on the source of emissions, pH of the particle, and particle size (Colin et al., 1990; Desboeufs et al., 2001, 2005). Trace metals on particles of anthropogenic or marine origins are more soluble than crustal particles (Desboeufs et al., 2005; Giusti et al., 1993). Oxides are usually formed during combustion, which are highly soluble. Crustal derived elements are bound to insoluble alumino-silicates. The solubility of trace metals determines their bioavailability and toxicity. A particle consisting of a highly soluble metal will be much more bioactive and more readily taken up by plants and animals (Qureshi et al., 2006).

For this study, the chemical composition of weekly PM samples from 1964 to 2010 collected in the Finnish Arctic were measured, providing a 47-year dataset of trace metals, water-soluble trace metals, and ionic species. This dataset will provide valuable information about trace metal solubility in the European Arctic, long-term changes in the chemical composition of the European Arctic aerosol, and their potential source areas. A previous paper has analyzed non sea-salt SO_4^{2-} and methane sulfonic acid (MSA) (Laing et al., 2013), and black carbon (BC) (Dutkiewicz et al., submitted for publication). Detailed trend analysis and source identification of the trace metals and ionic species reported in this paper will be presented in a companion paper (Laing et al., 2014).

2. Methods

2.1. Sampling site

The Kevo Subarctic Research Institute (latitude 69°45′N, longitude 27°02′E, height 98 m above sea level) is located 350 km north of the Arctic Circle (Fig. 1). The sampling location is described in more detail by Yli-Tuomi et al. (2003). The site is situated in the birch sub-zone of the boreal coniferous forest. The topography of the surrounding area is characterized by gently sloping fell highlands with river valleys. The elevation is mostly between 100 and 400 m above sea level. The area is sparsely populated (0.4 inhab/km^2).

The sun shines without setting from mid-May until the end of July, and remains below the horizon from late November to mid-January. The mean temperature of the coldest month (January) is −14.0 °C and the warmest month (July) +13.1 °C. The annual mean temperature is −1.3 °C. The ground is already covered with snow in October, and on average, the snow cover remains until mid-May. The mean annual precipitation is 433 mm of which 30–40% falls as snow (Pirinen et al., 2012).

When measurements started in 1964, there were four buildings. From 1968 to 1978, six additional buildings were built, and since 1990 two new buildings have been built. The meteorological station changed from wood burning to electricity in 1971. All of the new buildings are heated with electricity.