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Past and future trends in concentrations of sulphur and nitrogen compounds in the Arctic

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ABSTRACT

Recent trends in nitrogen and sulphur compounds in air and precipitation from a range of Arctic monitoring stations are presented, with seasonal data from the late 70s to 2004 or 2005. Earlier findings of declining sulphur concentrations are confirmed for most stations, while the pattern is less clear for reduced and oxidized nitrogen. In fact there are positive trends for nitrogen compounds in air at several stations. Acidity is generally reduced at many stations while the precipitation amount is either increasing or stable. Variability of sulphate concentrations in air for the period 1991–2000 is reasonably well reproduced at most stations using an Eulerian, hemispherical model. Results for nitrogen compounds are weaker. Scenario studies show that even if large sulphur emission reductions take place in important source regions in South-East Asia in the coming decades, only small changes in Arctic deposition can be expected. This is because South-East Asian emissions have small influence north of the Arctic circle.

1. Introduction

Arctic acidification occurs in areas with both sensitive ecology and levels of acid deposition elevated to a point that exceeds the system's acid neutralizing capacity. Sulphur is the most important acidifying substance in the Arctic, with nitrogen of secondary importance (Kämäri and Joki-Heiskala, 1998). Significant anthropogenic sources of sulphur emissions, and to a lesser extent nitrogen emissions, exist within the arctic region. In addition, long-range transported air pollutants contribute to acidification and arctic haze. Emissions from natural sources within the Arctic (volcanoes, marine algae, and forest fires) are difficult to quantify and project (Kämäri and Joki-Heiskala, 1998), but comprise a relatively small contribution compared to the anthropogenic sources.

Based on firn core analysis from the Canadian high Arctic, Barrie et al. (1985) suggested that in the first-half of the 20th century the level of wintertime air pollution remained roughly constant, consistent with a pattern of little change in European sulphur dioxide (SO_2) emissions. However, between 1956 and 1977 there was 75% increase of Arctic air pollution which seems to be associated with a marked increase in SO_2 and total oxidized nitrogen (NO_x) emissions in the industrialized world. Weiler et al. (2005) analysed an ice core from a North Siberian ice cap and found that maximum sulphate and nitrate concentrations in the ice could be related to maximum SO_2 and nitrogen oxide (NO_x) anthropogenic emissions in the 1970s, probably caused by the nickel- and copper-producing industries in Norilsk and on the Kola peninsula or by industrial combustion processes occurring in the Siberian Arctic. In addition, they found that during recent decades, sulphate (SO_4^{2-}) and nitrate ($NO3^-$) concentrations declined by 80% and 60%, respectively, reflecting a decrease in anthropogenic pollution of the Arctic basin. However, this $NO3^-$ reduction is much stronger than the emission reductions reported by EMEP[1] for the Northern

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[1] Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air pollutants in Europe, www.emep.int.

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Table 1
Monitoring stations referred to in the text.

AMAP code	Station name	Parameters	Latitude	Longitude	Operation period	Heigh above sea level
CA0420G	Alert	Air	82 28	62 30 W	1980-	1
DK0010G	Nord, Greenland	Both	81 36	16 40 W	1990–2002 2006-	20
FI22	Oulanka	Both	66 19	29 24 E	1990-	310
IS02	Irafoss	Both	64 5	21 1 W	1980-	66
NO30	Jergul (with NO55)	Both	69 27	24 36 E	1977–1997	255
NO15	Tustervann	Both	65 50	13 55 E	1977	439
NO42	Zeppelinfjell	Air	78 54	11 53 E	1989-	474
NO47	Svanvik	Both	69 27	30 2 E	1986-	30
NO55	Karasjok (with NO30)	Both	69 28	25 13 E	1997-	333
NO57	Ny-Ålesund	Precip	78 55	11 55 E	1982-	8
RU01	Janiskoski	Both	68 56	28 51 E	1990-	118
RU13	Pinega	Both	64 42	43 24 E	1979-	28
SE05	Bredkäl	Both	63 51	15 20 E	1979-	404
SE93	Abisko	Precip.	68 21	18 49 E	1992-	0
	Snare Rapids	Precip.	63 31	116 00 W	1989-	
	Hornsund	Precip.	77 00	15 33 E	1988-	
Russian precipitation stations	Zarechensk	Precip.	66 7	31 4 E	1990-	
	Padun	Precip.	68 6	31 8 E	1991-	
	Krasnoshelie	Precip.	67 4	37 1 E	1990-	
	Nariyan-Mar	Precip.	67 7	53 0 E	1962-	
	Urengoy	Precip.	66 0	78 4 E	1989-	
	Turukhansk	Precip.	65 8	87 9 E	1962-	
	Deputatskiy	Precip.	69 3	139 7 E	1990-	
	Ust-Moma	Precip.	66 5	143 2 E	1990-	
	Palatka	Precip.	60 1	150 9 E	1962-	

Eurasian continent, which is about 20% (assessment report available at www.emep.int).

Kämäri and Joki-Heiskala (1998) concluded that there were no trends in atmospheric concentrations of acidifying compounds in Canada and Alaska during the 1980s, but that there were decreasing trends on Svalbard. Background data from Russia were not available. It was considered that about 75% of the deposition could be as dry deposition, but that there was a lack of observations and knowledge at this point. Model output for SO_2 and SO_4^{2-} compared well with time series observations series at one station (Nord, Greenland) and for long-term averages at a number of EMEP stations.

Although atmospheric lifetimes of SO_2, NO_x and their oxidation products are of the order of a some days at temperate latitudes (Schwarz, 1979; Levine and Schwarz, 1982; Logan, 1983), the atmospheric half-life of SO_4^{2-} has been reported to reach even two weeks or more in the high Arctic during winter (Barrie, 1986). The transport distances range from hundreds to thousands of kilometres (Seinfeld and Pandis, 1998). Thus, many factors, besides the primary emissions, affect the observed concentrations and trends of the compounds involved in the acid deposition process, including their relative concentrations in the atmosphere, the reversible nature of some of the reactions and the meteorological situation.

Trend analysis for several indicators of Arctic haze has been performed for the spring months by Quinn et al. (2007). The monthly average SO_4^{2-} concentration in air in March and April has decreased in the Canadian, Norwegian and Finnish Arctic by 30–70% from the early 1990s to early 2000. NO_3^- concentration in air has increased by 50% in Alert, Canada during the same period. For Zeppelin Norway (see Table 1), there is no trend, in accordance with Aas et al. (2008).

Here we present a comprehensive overview of trends in Arctic acidification from the late 70s to recent years, including Russian precipitation stations. Summer and winter mean values have been calculated separately in order to avoid the influence of the possible changes in the seasonal variation. New numerical modeling results using a Eulerian hemispheric model are compared to monitoring data for the period 1991–2004. In addition, we present total oxidized sulphur (SO_x) and NO_x concentrations in air and deposition from the late 1800s to 2020 for the whole Arctic, based on the same Eulerian model.

2. Description of monitoring stations

There is a lack of long-term time series of background concentrations of main atmospheric compounds in the high Arctic. Also there are few stations with co-located air and precipitation sampling. Table 1 lists the stations included here. The AMAP[2] atmospheric monitoring network consists of a number of stations spread across the Arctic. Most of these are EMEP stations that also report to the AMAP database. In addition, a few national stations report data. Some stations have been reporting data since the mid 1970s. As of 2002, 24 stations reported data to AMAP relevant for acidification and eutrophication (Fig. 1). Most stations are located in the European sector. The nitrogen compounds in air are at the EMEP stations measured as the sum of particulate nitrate and gas phase nitric acid and, respectively, the sum of particulate ammonium and gas phase ammonia. They are referred later in the text as total nitrate and total ammonium in air. Alert measures nitrate and ammonium in the particulate phase only.

The Russian national network for monitoring of precipitation chemical composition and acidity consists of 110 monitoring stations. Precipitation samples collected at these stations are analysed by regional laboratories for the main atmospheric compounds. The coordinating and analytical centre for the precipitation chemistry monitoring network is the Voieykov Main Geophysical Observatory, Roshydromet whose data are mainly used for this article. In addition to these stations, there are 105 monitoring sites where only pH value is analysed. Stations are unevenly distributed over the territory of Russia. Less than 40% of the stations are situated in the vast Siberian region. The period of observations reaches up to 40 years for some stations. For analysis of the acid precipitation and acidity we have used nine background monitoring stations situated

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[2] Arctic Monitoring and Assessment Programme, www.amap.no.