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Biomass burning in Russia during spring 2006 caused episodic high deposition of ammonia in northern Scandinavia

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Abstract (139 words)

High air concentrations of ammonium were detected at low and high altitude sites in Sweden and in Norway during the summer 2006, coinciding with polluted air from biomass burning in Russia passing over northern Scandinavia. Record high values for throughfall deposition of ammonium were detected at one low altitude site and several high altitude sites in north Sweden. The occurrence of the high ammonium in throughfall differed between the summer months 2006, most likely related to the timing of precipitation events. Dry deposition measurements with teflon strings under a roof confirmed episodic high occurrence of ammonium during 2003-2007 in northern Sweden. Unusual visible injuries on the shrub vegetation in northern Scandinavia occurred during 2006. High ammonia dry deposition might have contributed to this, together with high ozone concentrations which also occurred in the same area during the summer 2006.

Key words: ammonium, air concentrations, deposition, biomass burning, vegetation damage, Russia

Introduction

Expected increasing environmental strain in the Arctic and sub-Artic

The Arctic and sub-Artic is experiencing considerable change in climate, both during summer and winter (Bokhorst et al., 2009, more ref). At the same time, the air pollution climate is changing (ref). On important component of the large-scale, hemispheric air pollution is the large-scale biomass burning (Yurganov et al., 2004, Simmonds et al., 2005).

Reactive nitrogen

Reactive nitrogen is considered as a major, global environmental problem (Nitro-Europe ref). more text on reactive nitrogen

Occurrence of ammonia at higher latitudes

There has been a steady increase in NOx and NHy deposition at northern latitudes since 1860 (Hole et al. 2009) as a result of industrialization and intensified farming. After the 80s there has been a decline as a result of emission reduction measures such as the Gothenborg protocol. The general trend with an accelerating depositon during the 19th century and a decline in the last 20 years, corresponds well with ice core observations such as Weiler et al., 2005.

Trends in NHy deposition at Arctic stations were analysed by Hole et al. (2008, 2009). There were some stations with reductions in Fennoscandia, but also some with increasing trends in the same area. It has earlier been suspected that decreasing NHy-deposition in continental Europe due to lower surface NHy affinity will lead to higher NHy-concentrations in more remote areas (e.g. Sutton et al., 2003), but this was not confirmed (Hole et al. 2008, 2009). Hole and Engardt (2008) showed that changes in precipitation patterns due to climate change will have a significant influence on the deposition of sulphur and nitrogen compounds in northern regions in the next 50-100 years, with a strong increase of NHy deposition (40%) along the Norwegian coast. In other regions of Scandinavia changes will be moderate with some reduction due to lower precipitation in the interior and more scavenging along the coast.

Aas et al. (2008) made deposition maps for Norway based on data from approximately 700 precipitation stations and air and precipitation concentrations measured at a limited number of sites. The depositions of NOx and NHy in the interior of northern Norway (Finnmarksvidda) area were estimated 0.6 and 0.7 kg N/ ha, respectively. Aas et al. (2010) showed that the annual mean concentration of NHy in air in Karasjok was about 0.12 µg m-3, about 20% of other stations on the Norwegian mainland.

Ammonia/ammonium emissions, transport and deposition

The alkaline NH_3 reacts readily with acidic substances in the atmosphere to form ammonium salt particles, such as $(NH_4)_2SO_4$, NH_4NO_3 and NH_4Cl, that occur predominantly in the fine particle fraction (Finlayson-Pitts and Pitts, 1999, Hertel et al., 2011). $(NH_4)_2SO_4$ can under certain meteorological conditions be transported very long distances (Brosset et al., 1975, Irwin and Williams, 1988, Krupa, 2003). In the absence of sulphate, NH_3 will mainly react with HNO_3 and form NH_4NO_3. NH_4NO_3 has a higher deposition velocity as compared to $(NH_4)_2SO_4$, (ref). Hence the presence or absence of sulphate in the atmosphere has a large impact on the long-range transport of NH_3/NH_4 (Fowler et al., 2007, Fagerli and Aas, 2008, Hertel et al., 2011).

Biomass burning as a source for ammonia in the atmosphere

Biomass burning is the second most important source for ammonia in the atmosphere after agricultural activities (Krupa, 2003).

An overview of large scale biomass burning during the 2000 decade

Comparative fire statistics for total vegetated area and forest area burned in the Russian Fedration in the period 2000-2007, based on agency reports and remote sensing, is presented in Figure 1.

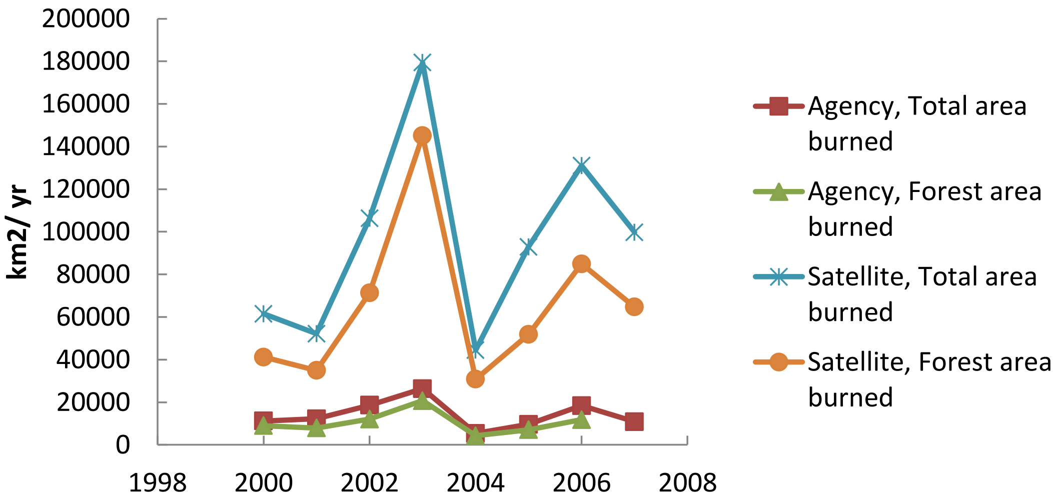


Figure 1. Comparative fire statistics for total vegetated area and forest area burned in the Russian Federation in the period 2000-2007 based on agency reports and remote sensing. Agency data provided by Avialesookhrana of Russia for the forest land under the jurisdiction of the Federal Forest Agency (Fedreal Forest Fund). Satellite based statistics provided by Sukachev Institute of Forest, Remote Sensing Laboratory, RAS, Krasnoyarsk, Russia. Source: Goldammer, J.G., Sukhinin, A. & Davidenko, E.P. 2007. Advance Publication of Wildland Fire Statistics for Russia 1992-2007 International Forest Fire News (IFFN) No. 37 (July – December 2007, in prep.) ISSN 1029-0864.

The distribution of forest fires in western Russian and Europe for May to June 2006 is presented in Figure 2. An estimated the 2 M ha burnt during April, May and June 2006.

http://firefly.geog.umd.edu/firemap/

A B C

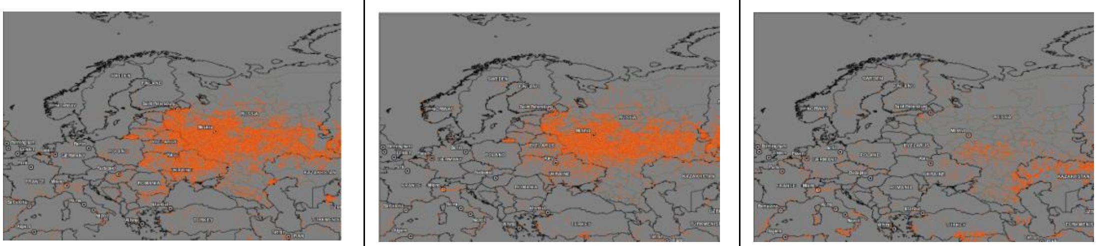


Figure 2. Distribution of forest fires in western Russian and Europe for April (A), May (B)and June (C) 2006. Source: http://maps.geog.umd.edu/firms/subsets.htm.

A description of the transport of polluted air from Russian biomass burning over northern Scandinavia in May 2006

If polluted air from biomass burning in Russia will affect the air quality over Scandinavia depends on the weather situation during the period of burning. A specific case where an anti-cyclonic weather situation over Russia caused polluted air to be transported to Scandinavia as well as to the entire northern Europe is described below. In the beginning of May 2006, there were large areas on Svalbard where the snow was colored black (Stohl et al, 2007). There were also record high ozone concentrations on Svalbard as well as on Iceland. This highly polluted air originated from biomass burning in Russia and neighbouring countries (Stohl et al, 2007).

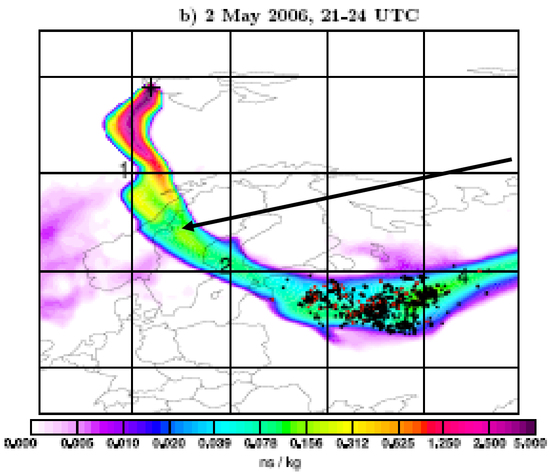


Figure 3. Trajectory analysis for air masses arriving at Zeppelin, Svalbard, on May 2nd 2006. Arrow indicate the county of Jämtland, Sweden. From Stohl et al., 2007. Atmos. Chem. Phys., 7, 511-534.

A high-pressure weather system over Russia transported this polluted air towards west and north ending up from Scotland to Finland (Anttila et al., 2008, Whitham & Manning, 2007). The trajectory analysis (Figure 3) shows that some of these polluted air masses were transported across the county of Jämtland in northern Sweden. Significant concentrations of several pollutant among them ammonia were detected in the polluted snow on Svalbard (Stohl et al, 2007, Figure 4a). High amounts of ammonia were also detected in the PM10 particles sampled in eastern Finland during May 2006 (Anttila et al., 2008).

Figure 4a. The chemical composition of clean and polluted snow samples at Svalbard as reported by Stohl et al, 2007.

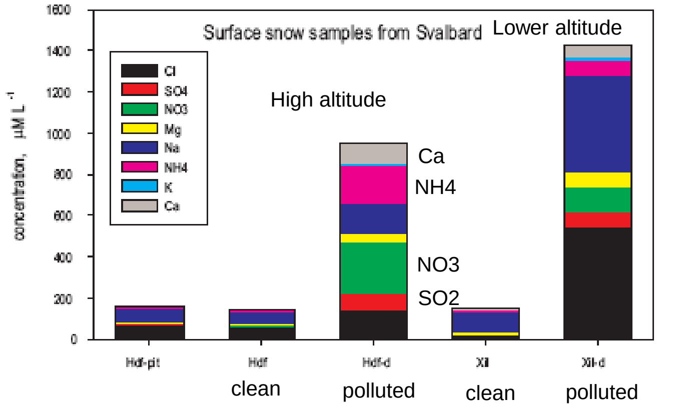
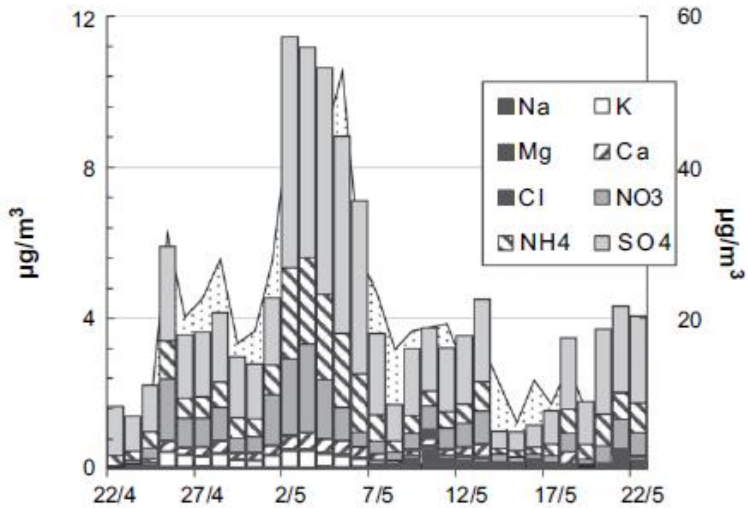


Fig. 25. Holtedahlfonna (Hdf) and Exile Pass (Xil) ion concentrations ("polluted" samples are marked with "–d") in μM L^{-1}. Maximum concentrations from the 2.8 m pit (covering a period of about 1.5 years) sampled at the summit are also shown for comparison (Hdf-pit).

Figure 4b. The chemical composition of PM10 sampled in Finland during spring 2006, as reported byAnttila et al, 2008.



Visible injuries on vegetation at European northern latitudes.

Visible injuries of air pollution like SO_2, heavy metals etc. have been recorded in Fennoscandia (Aamlid & Venn 1992, Tømmervik et al. 1995). Visible injuries of O_3 on herbaceous vegetation have been repeatedly observed in Fennoscandia over the last decades, at ambient O_3 exposure concentrations that are lower than those in Central and Southern Europe (e.g. Pihl-Karlsson et al., 1995; Pleijel et al., 1991; Harmens et al., 2005). This is likely to be due to the climatic conditions in Fennoscandia, which promote relatively high rates of O_3 uptake into the leaves (Matyssek et al. 2007).

Ammonia impacts on vegetation

Adverse effects of NH3 on higher plants include direct foliar injury, alterations in growth and productivity, drought and frost tolerance, responses to insect pests and pathogens (Krupa, 2003).

The study aims

The aims of this study were to analyse occurrence of ammonia in the air and in deposition at northern latitudes in Scandinavia, to examine links to large scale biomass burning events and to analyse the possible role for the occurrence of visible damage on the vegetation

Methods

Sites

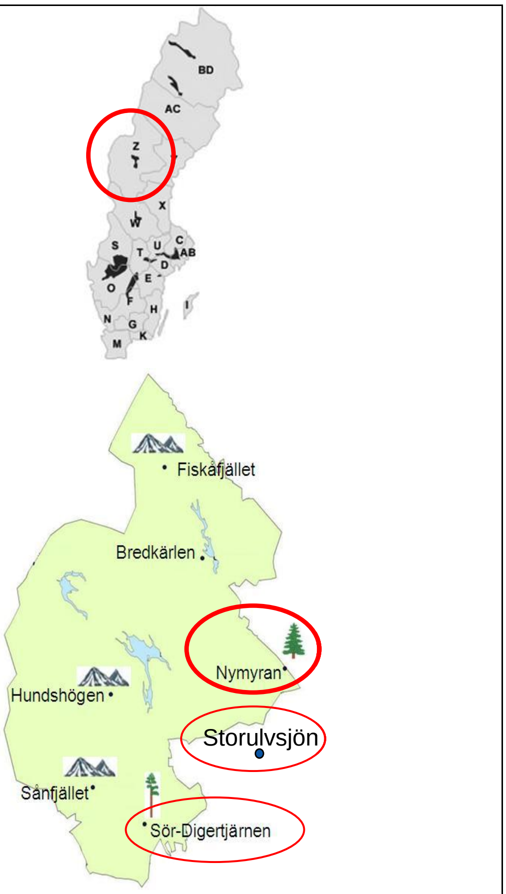


Figure 5. Map showing the locations of then different monitoring sites in the county of Jämtland, Sweden.

Air concentration measurements

Martin: Filterpack, Sweden.

Lars: Tustervatn?

Deposition measurements

Gunilla: KD + Martin, hög höjd, Sweden.

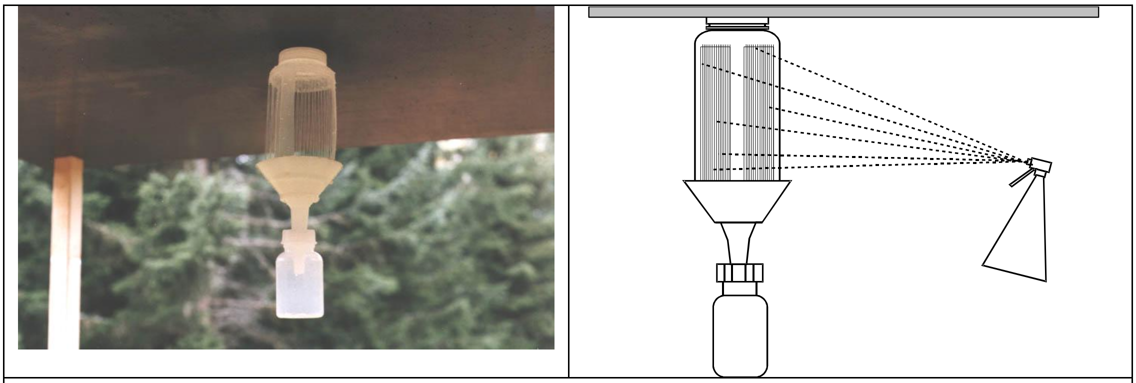
Table 1. Sampling period dates for throughfall measurements at the site Nymyran in the county of Jämtland, Sweden, during summer 2006.

Month	Period start	Period end	Sum period precipitation (mm)	Max period precipitation (mm/day)
April	2006-03-27	2006-04-23	61.7	10.9
May	2006-04-23	2006-05-22	44.2	12.8
June	2006-05-22	2006-06-19	54.4	13.5
July	2006-06-19	2006-07-24	68.8	22.7
Aug	2006-07-24	2006-08-27	49.8	7.2

Precipitation data for the location Nymyran originate from the weather service ("LuftWeb") provided by the SMHI. Estimates are based on interpolated weather data.

Dry deposition measurements with teflon strings

To be translated. Strängprovtagarna bestod av teflonsträngar under ett tak, som spolades av med avjoniserat vatten vid provtagningen en gång i månaden. Teflonsträngarna var ca 0,4 mm i diameter och 13 m långa för varje provtagare (Figur 3). I övrigt hänvisas till tidigare beskrivningar (Ferm & Hultberg, 1999, Ferm m. fl. 2000). Mängden destillerat vatten som används för att spola av strängarna varierar något mellan olika månader, men ligger på 150 ml +/- 30 %. Variationen har ingen direkt inverkan på beräkningarna eftersom det är kvoterna mellan koncentrationer av olika ämnen som används.



Figur 6. A photograph and illustration of the teflon string sampling equipment placed under a roof .

Meteorological information

PEK: Sweden, SMHI.

Vegetation survey

The episode of high concentrations of ozone and other pollutants reaching northern Fennoscandia during April and the first days of May 2006 motivated a series observations of the vegetation in Troms county later in the spring. Discolouration and injury to leaves of rowan (Sorbus aucuaparia) were observed in Tromsø. Sample leaves were sent to a forest pathologist in Norway and the conclusion was that the chlorosis on the leaves might have been caused by air pollution like ozone or other pollutants. These observations were followed by a campaign were leaf samples were collected near air pollution monitoring stations (EMEP, NILU etc.) in the northern Fennoscandia. Leaf samples of birch and rowan were collected at Øverbygd-Målselv (Veltvatn-Dividal) in Troms county (Norway), Karasjok in Finnmark county (Norway) and Esrange in northern Sweden. Further samples were collected during summer 2006 in Tromsø and Nordreisa (Troms county). These leaves were dried and stored for further investigations. Leaves were sent to Prof Bengt Nihlgård for further examination under the microscope ...

Results and discussion

Air concentrations of pollutants over Sweden and Norway

<u>Low altitudes</u>

Concentrations of black carbon are an indicator for polluted air originating from biomass burning (Hyvärinen et al., 2001). Daily mean air concentrations of black carbon, NH_4 and SO_4 during 2006 are shown in Figure 7for the EMEP monitoring site Bredkälen, positioned in the middle of the county of Jämtland,. The concentrations of black carbon started to rise above the baseline level around April 26 2006 and maximum daily mean concentration, 12 µg/m^3, was measured on May 2. The concentrations returned to baseline levels around May 9. The episodic increase in air concentrations of NH_4 (gaseous+particle) was not so pronounced but the highest concentration, 2 µg/m^3, was measured on May 3. There were also relatively high air concentrations of SO_4 during the same period.

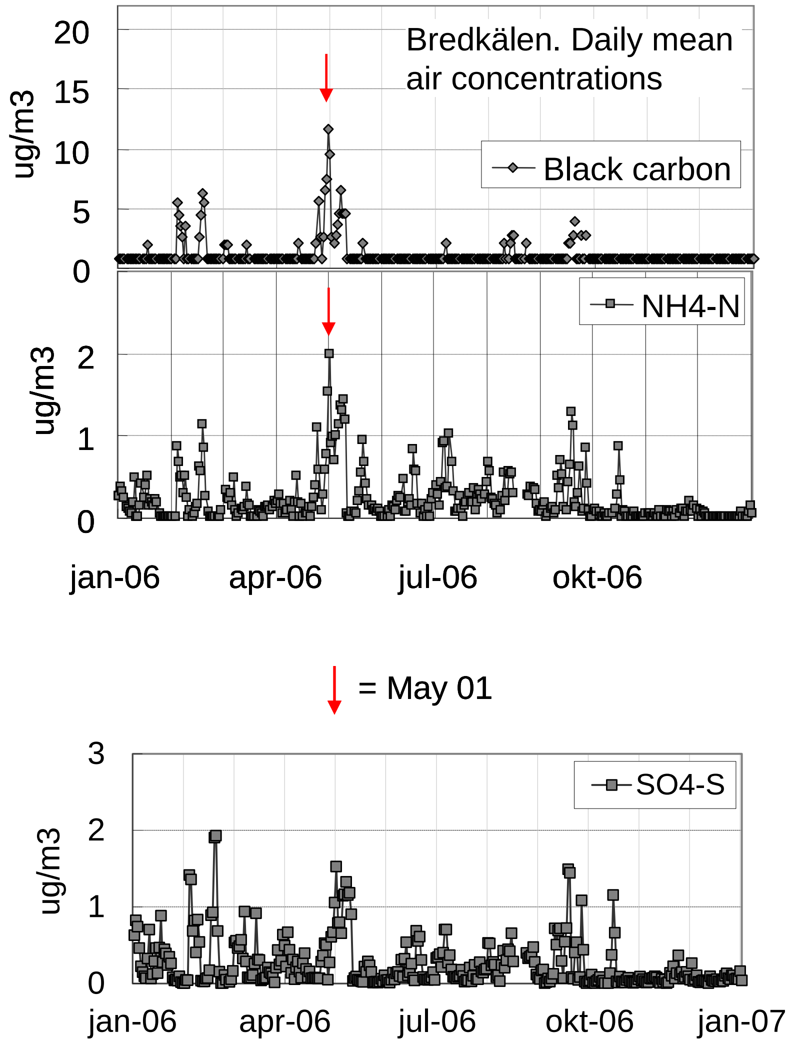


Figure 7. Air concentrations of black carbon, NH4 and SO4 (gaseous+particle) measured on a daily basis at Bredkälen, county of Jämtland, Sweden. Measurements were made with methods recommended by EMEP. Daily concentrations for the period Jan 1 to Dec 31, 2006. Diagrams to be combined

There were high air concentrations of reduced nitrogen measured also at the Norwegian EMEP site Tustervann, positioned x km north of Bredkälen, during the summer 2006 (Figure 8). There were however, high concentrations measured also during other years, e.g. 2004 (data not shown). There are possible influences from local sources of ammmonia around Tustervatn (ref??).

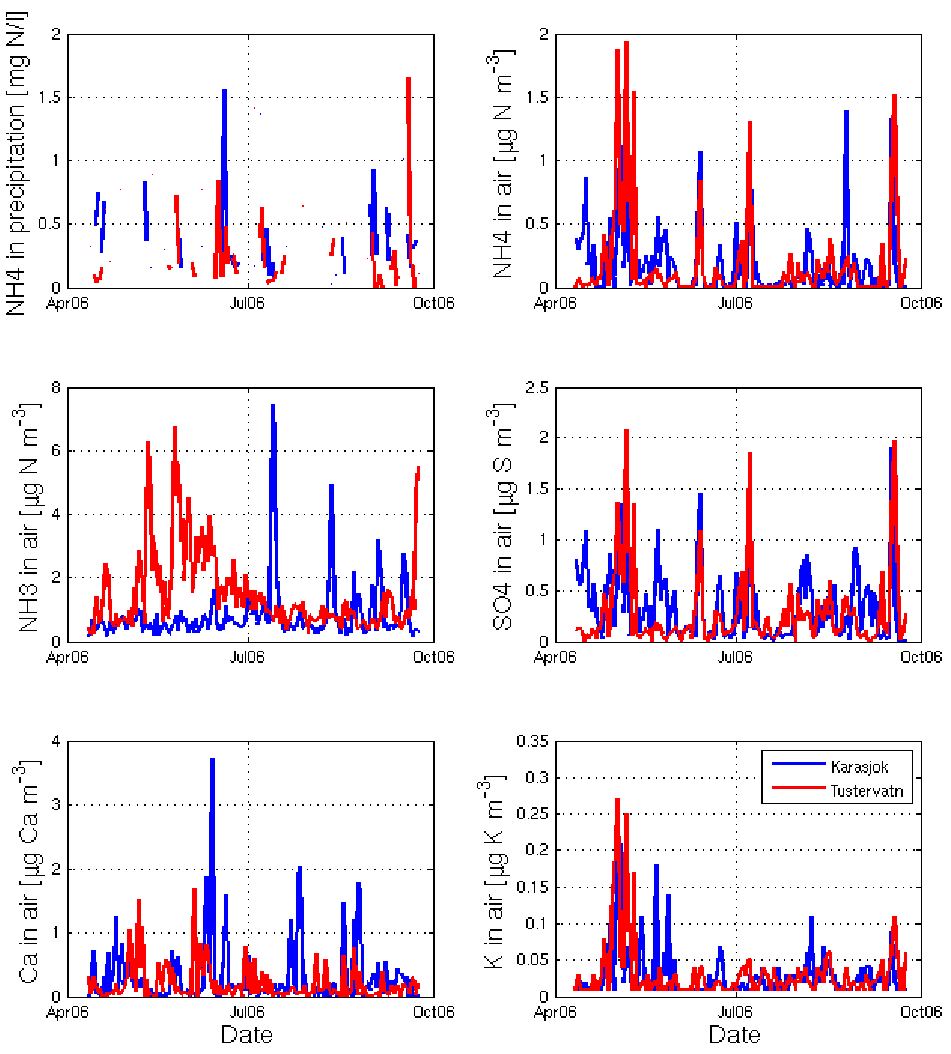
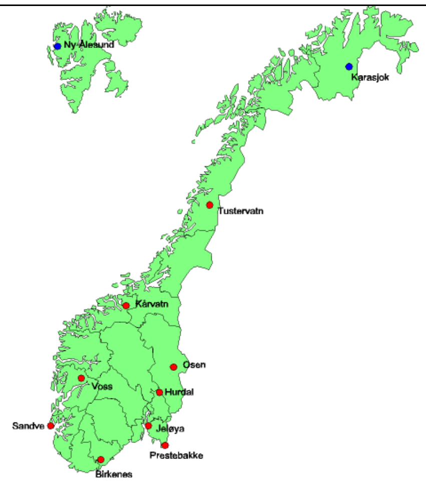


Figure 8. Air concentrations of different compounds measured at two northern latitude sites in Norway during the summer 2006. Monthly mean total air concentrations (gas+PM). Unit µgN/m3.



High altitudes

High concentrations of ammonia were detected at high elevation in northern Sweden during May 2006 (Figure 9). Also high sulphur and calcium concentrations were detected (data not shown). It is likely that the long-range transported ammonium detected at high altitudes in north Sweden was transported in the form of ammonium sulphate. (Martin, kan vi utveckla detta...?)

A B

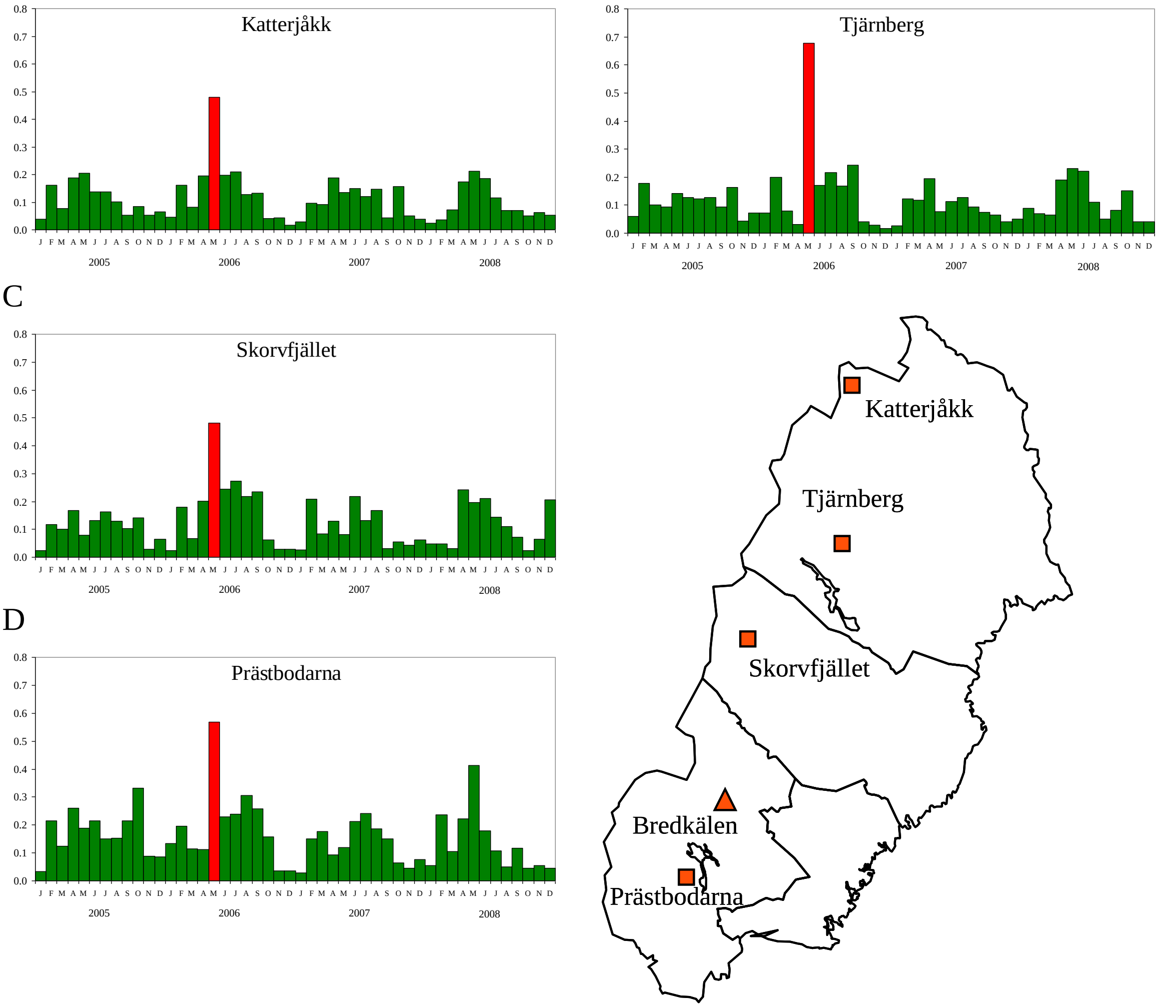


Figure 9. Ammonia air concentrations measured at high altitudes in northern Sweden, 2005-2008. Monthly mean total air concentrations (gas+PM) of NH_4^+. Unit µgN/m^3. The x-axis for all diagrams spans from Jan 2005 until Dec 2008. The red bar indicated the value for May 2006. A map indicating the position for the different measuring sites is provided. A, Katterjock, 515 m a.s.l.; B, Tjärnberg, 500 m a.s.l.; C, Skorvfjället, 808 m a.s.l.; Prästbodarna, 710 m a.s.l.

Deposition

<u>Throughfall, low altitudes</u>

A comparably very high monthly value for ammonia deposition in throughfall was detected at Nymyran in June 2006, a site with a 75-year-old Norway spruce forest at an altitude of 300 m a.s.l (Figure 10). Sample volume was average but NH_4 concentration in the sample was high. The sample was carefully checked for contamination, but there was no sign of bird droppings such as e.g. high pH or high phosphorous concentrations. Analysis of Kj-N showed that the sample content of organic N was relatively low. The low sample volume in April and May 2006, indicated that the precipitation in April and June was low at the site. The precipitation patterns are analysed further in the next section below.

Throughfall measurements at two sites nearby, Sör-Digertjärn under Scots pine and Storulvsjön under Norway spruce, did not show elevated NH_4 or Kj-N deposition during 2006 (data not shown).

It is well known that a large fractions of the nitrogen deposition to forests can be taken up directly to the canopies (e.g. Parker, 1983, Ferm, 1993, Adriaenssens m. fl., 2012), in particular in regions with comparably low deposition. This means that the NH4 deposition during the spring 2006 most likely would have been even larger than the throughfall deposition values that were actually measured.

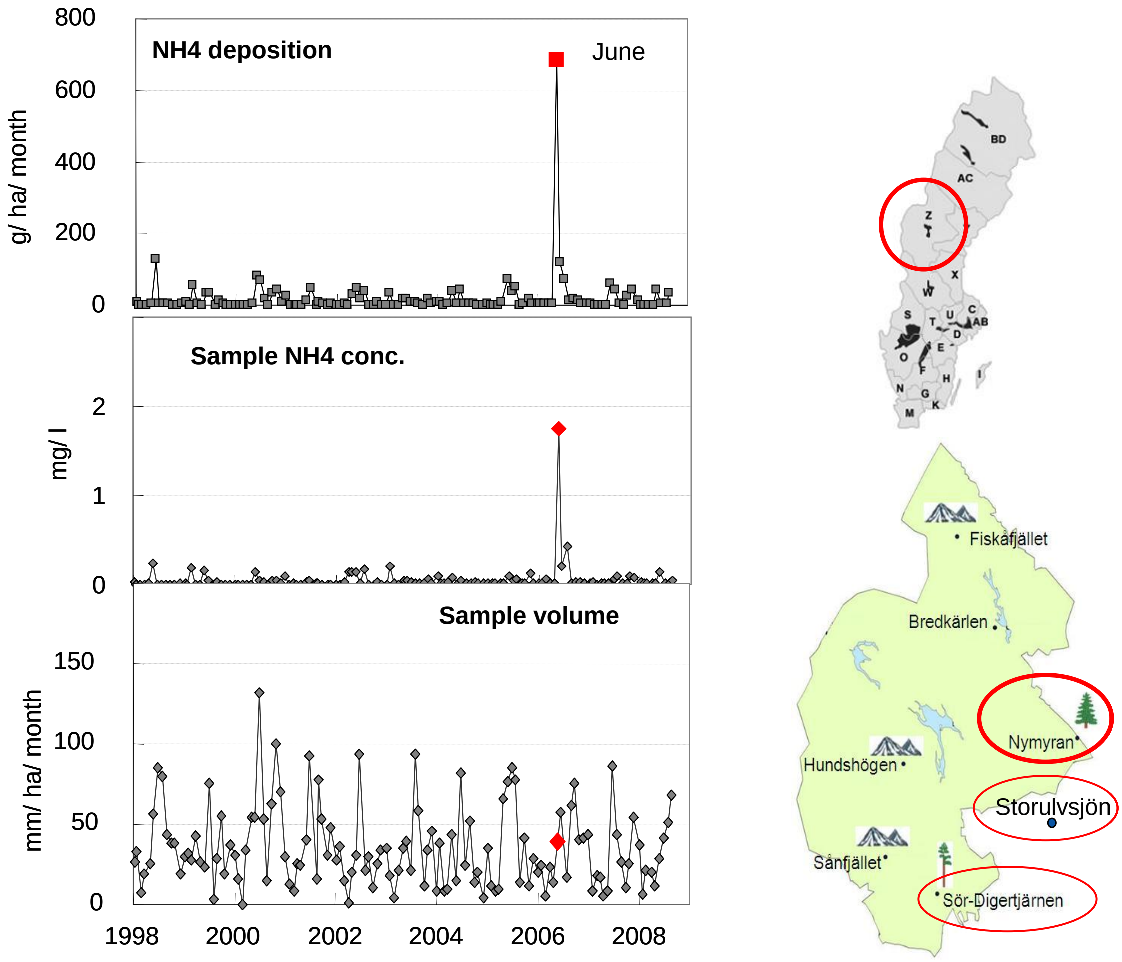


Figure 10. Monthly ammonia deposition in throughfall at the low altitude site Nymyran, 75-year-old Norway spruce forest at an altitude of 300 m a.s.l. Data is shown for the calculated deposition (upper), the sample ammonia concentration (middle) and the sample volume (lower). The datapoint for June 2006 is shown in red.

<u>Precipitation and temperature at the site Nymyran during the sampling periods 2006</u>

The collection of throughfall deposition is of course heavily dependent on precipitation. Therefore we did a careful analysis of the daily precipitation events at the site Nymyran (Figure 11). The analysis is based on data on daily precipitation for the exact position of the Nymyran site, provided by the Swedish Hydrological and Meteorological Institute (SMHI).

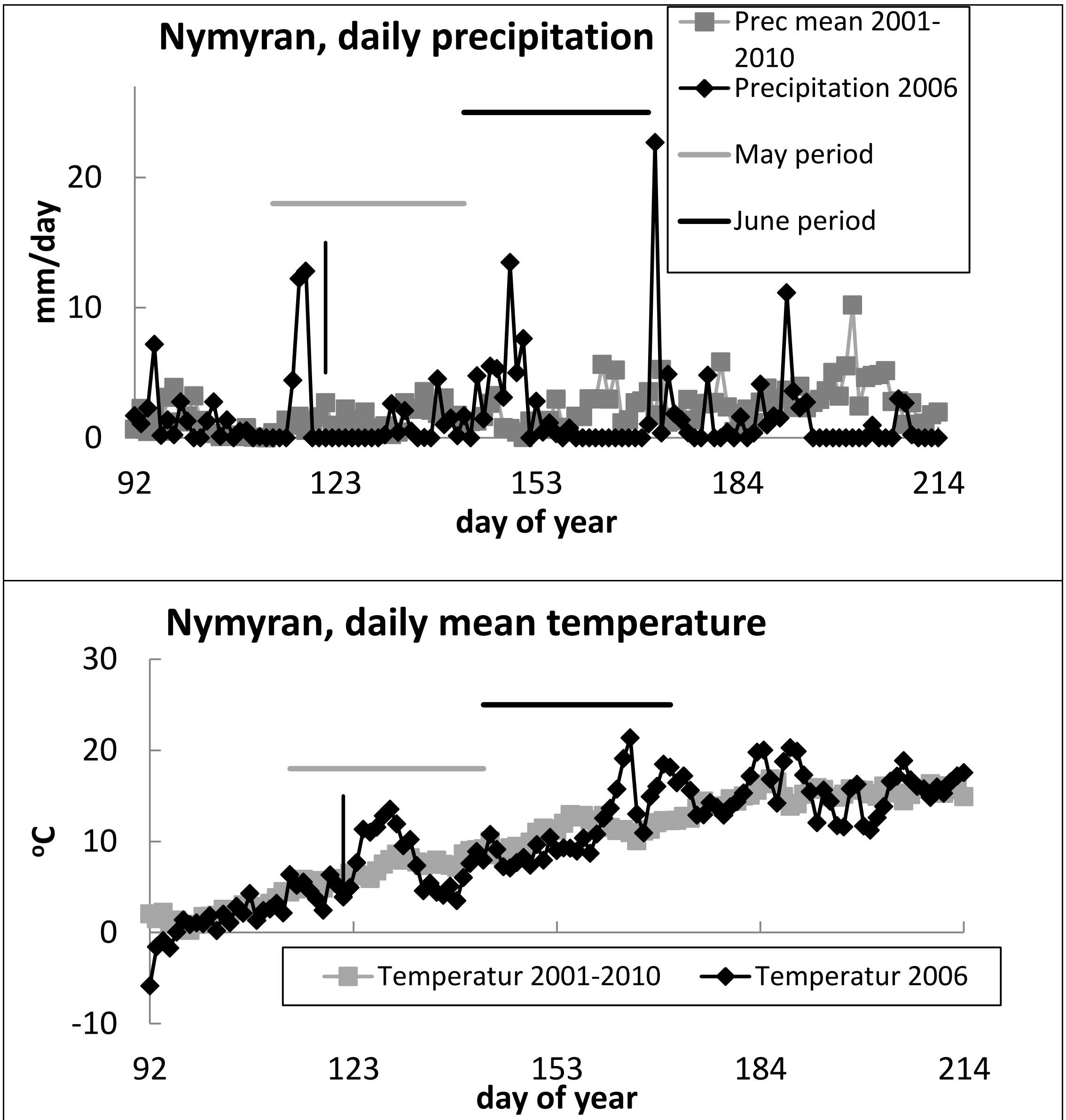


Figure 11. Daily precipitation and dily mean temperatures at the site Nymyran for the period 1 April – 31. Values are for the year 2006 as well as means per year-day for the period 2001-2010 except 2006. The horizontal grey line indicates the sampling period for throughfall at Nymyran for May 2006 and the thick black horizontal bar the corresponding period June 2006. The thinner, vertical, black line indicates the date 1 May 2006.

There was little precipitation during the period between the pollution event around 2 May 2006 and the end of the May sampling period for throughfall at Nymyran (Figure 11). Between May 1 and the shift of sampling period, May 22 2006, the accumulated precipitation was only 15 mm and the daily maximum precipitation 5 mm. In contrast, during the nine days between 22 May and 31 May 2006, the accumulated precipitation was 49 mm.

Hence, this analysis implies that the high amounts of NH_4 found in the June 2006 throughfall sample from Nymyran might well have originated from the highly polluted air masses that passed over Jämtland in the beginning of May 2006 if it was deposited a dry deposition, since there was little precipitation during the remaining part of the May sampling period but substantial precipitation to wash out the NH_4 to the throughfall samplers during the June sampling period.

The air temperatures were elevated for more than a week in the beginning of May 2006 indicating a sunny weather condition.

Throughfall, high altitudes

Monthly ammonia deposition in throughfall is shown in Figure 12 for three sites at high altitude (600-800 m a.s.l) in the county of Jämtland. These measurements were made under Norway spruce, but with a slightly different methodology, as compared to low altitude sites, due to the low stand density close to the timber line. All three sites show high monthly ammonia deposition during summer 2006, but at different months, also as compared to Nymyran. The relative ammonia deposition peak value for Hundshögen is not as high compared to the other sites. No Kjelldahl-nitrogen analyses are available for these sites.

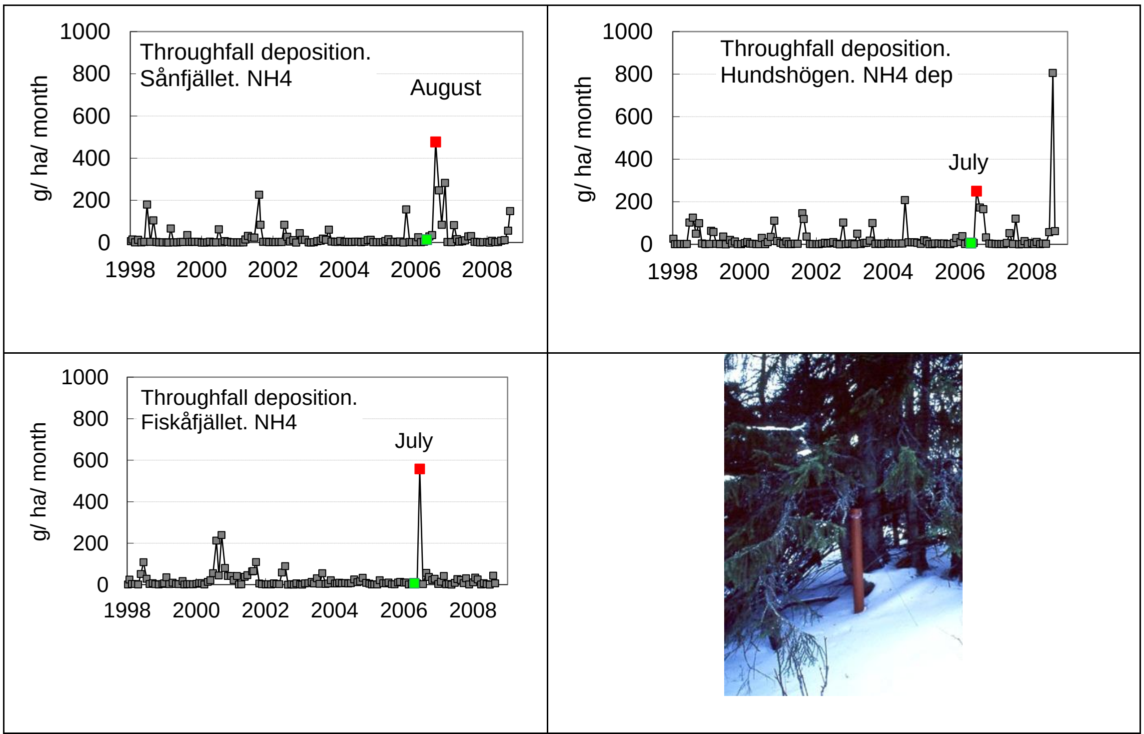


Figure 12. Monthly ammonia deposition in throughfall at the high altitude sites in the county of Jämtland (600-800 m a.s.l.) Fiskåfjället, Hundshögen, Sånfjället. Throughfall deposition measurements are made with a slightly different methodology, as compared with low altitude measurements, see photo. Peak values are shown in red together with an indication of month. Values for May 2006 are shown in green.

Elevated NH_4 deposition in throughfall at high altitudes was also evident at four other sites outside the county of Jämtland (Figure 13), one site south of Jämtland and three sites north of Jämtland. At these sites the NH_4 peak during 2006 occurred in June or July. However, the peaks at these sites were not as pronounced during 2006 as compared to peaks during other years

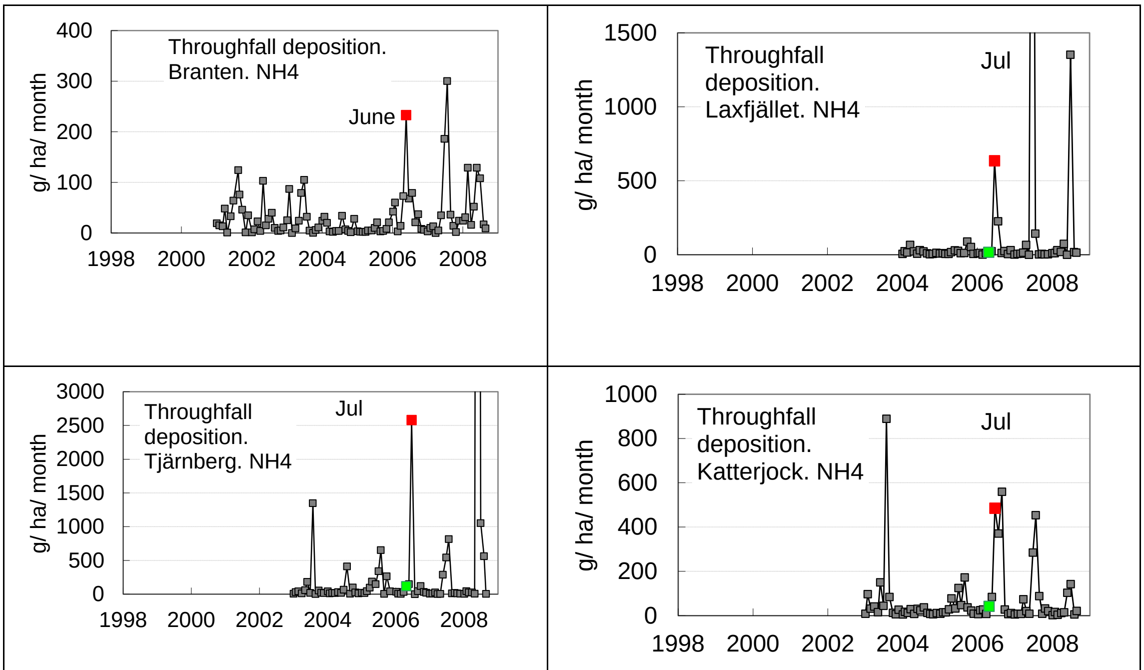
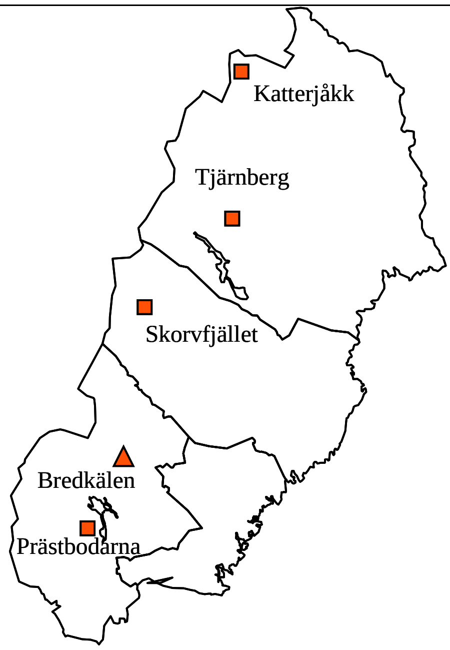


Figure 13. Monthly ammonia deposition in throughfall at the high altitude sites in other counties (600-800 m a.s.l.) Branten, Laxfjället/ Skorvfjället, Tjärnberg and Katterjock. The site Branten is positioned in the county of Dalarna, south of the county of Jämtland. Throughfall deposition measurements are made with a slightly different methodology, as compared with low altitude measurements, see photo. Peak values are shown in red together with an indication of month. Values for May 2006 are shown in green.



Relation between ammonia deposition at high altitudes and precipitation events

The throughfall sample volumes to some extent indicated the precipitation volumes, although interception and evaporation to weakens this relation. Monthly throughfall sample volumes during 2006 are shown in Figure 14 for the high altitude sites

Sånfjället, Fiskåfjället and Hundshögen. The value for May 2006 is indicated with a thick arrow, while the month with peak ammonia deposition is indicated for the respective site, except for Hundshögen. The relative peak value for this site Hundshögen was not as high as for the other sites.

There was a relation between the sample volume and the occurrence of the peak ammonia deposition value. A rough estimate is that the sample volume at the site has to approach or exceed 40 mm/ ha/ month for the peak ammonia deposition to appear.

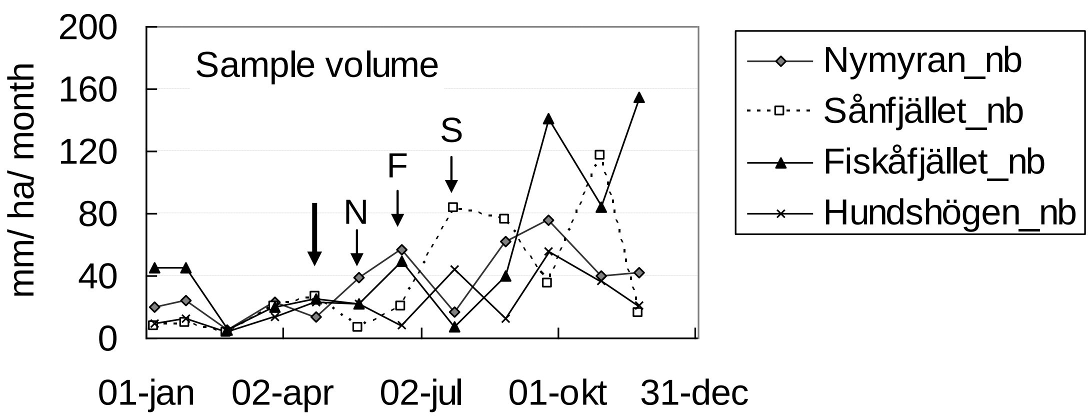
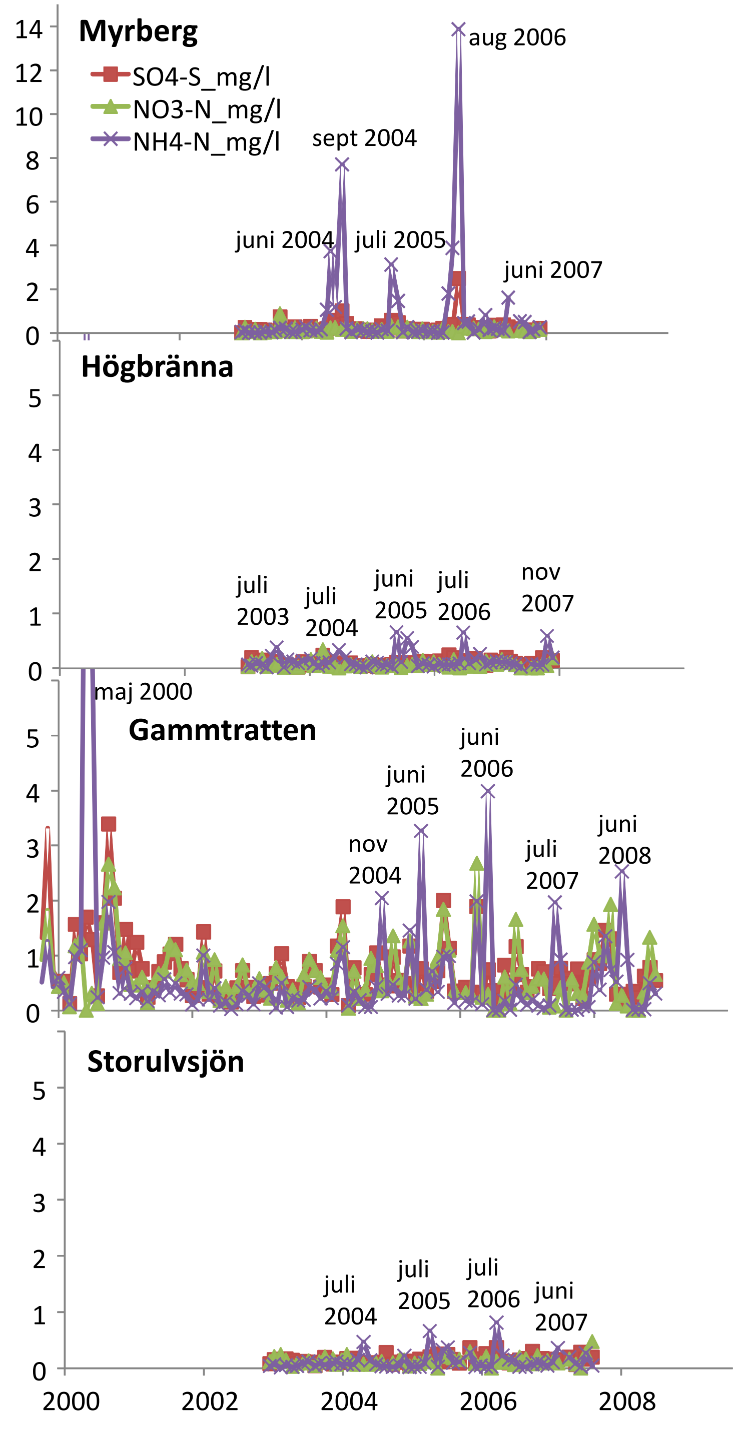


Figure 14. Monthly throughfall sample volumes during 2006 for the high altitude sites in Jämtland, Sånfjället, Fiskåfjället and Hundshögen. May 2006 is indicated with a thick, black arrow. The months with peak value ammonia deposition at the different sites are indicated with thin arrows, together with a letter indicating the site; F, Fiskåfjället; S, Sånfjället. Hundshögen is not indicated, since the relative peak value was not as high for this site. Data for Nymyran should be removed from this Figure!

Dry deposition to teflon string samplers

Dry deposition to teflon strings placed under a roof was monitored at four sites in northern Sweden during the period 2003-2007 (2000-2008 at Gammtratten). Since the volume of water used to rinse the teflon string could vary somewhat (+/- 30 %) between sampling occasions, the analysis was made comparing the ammonium concentrations with the concentrations of nitrate and sulphate.

There were several events with high ammonium concentrations, relative the concentrations of the other compounds, during the period (Figure 15). The by far highest concentrations were found for the two sites Myrberg and Gammtratten. Most events occured during the months June and July. The highest ammonium concentrations at Myrberg and Gammtratten were detected during 2006. There were events were ammonia concentrations were higher than the other ions during at least one summer month for all years 2004-2007, except Gammtratten were it was only during 2005-2007.



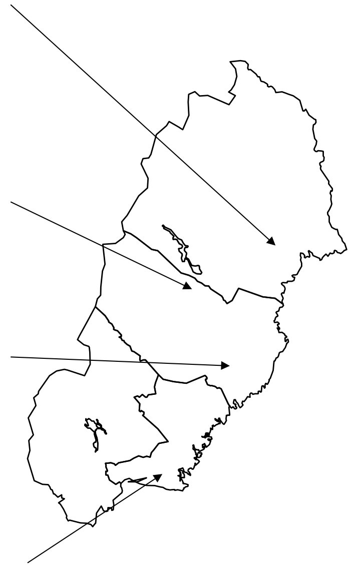


Figure 15. Ion concentrations in monthly samples from spraying teflon strings placed under a roof. Sample volume was each time 150 ml +/- 30 %. Arrows on the map indicate the position of the different monitoring sites. Months where the concentrations of ammonium clearly exceeded the concentrations ot the other ionsa are indicated with dates.

Bulk deposition measurements

There were no open-field, bulk deposition measurements made at Nymyran. However, there were bulk deposition measurements available from the nearby site Storulvsjön. There were no pronounced peaks in the monthly, bulk NH4 deposition during 2006 at Storulvsjön (data not shown).

Summary of NH4 deposition events during 2006 in north Sweden

To summarize, there were several montly pronounced NH4 throughfall deposition events during the summer of 2006, both at low and high altitudes, in particular in the county of Jämtland but also in other parts of north Sweden. These events occurred during different months, probably related to the timing of precipitation events. It is likely that the deposition to the forests occurred as dry deposition and then was washed to the throughfall sampling collectors when there was enough precipitation. The dry deposition at Nymyran most likely occurred during the pollution episode in the beginning of May 2006, originating from biomass burning in Russia and neighbouring countries, but for the other sites the deposition might be related to other pollution episodes during the summer 2006.

Leaf visible injury on vegetation during the summer 2006

During the summer 2006 some unusual leaf visible injuries (Figure 16) were observed in northern Fennoscandia. Manninen et al. (2009) presumed these injuries to be effects of unprecedented O_3 concentrations and other pollutants. measured in northern Fennoscandia in April and May 2006 due to a severe transport episode of highly polluted air masses partly linked to extensive agricultural fires in the Baltic region (Stohl et al. 2007). In order to assess these injuries samples of leaves were examined using microscopy. The results from these assessments are summarized in Table 1.

A B

Figure 16. A, Rowan (Sorbus aucuparia) leaves showing chlorotic and brown-reddish stippling and red-brown necrotic areas in the leaf margins. Photographed in Tromsø (69°38'N, 18°55'E), NW Norway, on 30 July 2006. B, Mountain birch, leaves, Karasjok, August 4^{th} 2006.

Table 1. Diagnostic characteristics of the injuries observed.

Site	Rowan	Date (2006)	Comment	Microscopy	Birch	Date (2006)	Microscopy	Phenological event (birch)
Tromsø (Norway)	Indication of chlorosis, bronzing and undeveloped leaves	20-05 and 10-06	Confirmed: Børja: 18-06-06 (The Norwegian Forest and Landscape Institute)		Slight yellowing leaves	05-06	Concentric rings caused by basic pollutants in combination with ammonia and O_3?	**Bud burst:** 06-05-06 **Yellowing of leaves:** 20-09-06
Øverbygd-Målselv (Veltvatn-Dividal) (Norway)	Indication of chlorosis, bronzing and undeveloped leaves	15-06		Small injuries and brown spots (Fig. 14). Fungi-attacks caused by air pollutants (ammonia and O_3).	Slight yellowing leaves	15-06	Change of colors, marbling, injuries in wax-layer (Fig. 15). . Small injuries and brown spots, caused by air pollutants (ammonia and O_3)	**Bud burst:** 06-05-06 **Yellowing of leaves:** 25-09-06
Nordreisa (Norway)	Indication of chlorosis, yellowing and undeveloped leaves	01-07		Small injuries; dead cells (browning). Changes in the wax-layer on underneath the leaves (Fig. 16).Most likely O_3 in combination with ammonia		01-07		**Bud burst:** 10-05-06 **Yellowing of leaves:**

								15-09-06
Esrange (Sweden)	Yellowing of leaves, undeve-loped leaves	03-08			Yellowing, mottling and bronzing of leaves. Indication of necrosis. Some oxidative stress due to prevailing ozone, ammonia, low temperatures, pathogens and nutrient imbalance	03-08-06		**Bud burst:** 10-05-06 **Yellowing of leaves:** 10-09-06
Karasjok (Norway)		04-08			Yellowing, mottling and bronzing of leaves. Some oxidative stress due to prevailing ozone, ammonia, low temperatures, pathogens and nutrient imbalance (lack of P)	04-08-06	Injuries in the wax-layer, brown spots, might be a combination of ammonia and O_3? Concentric rings caused by basic pollutants in combination with ammonia and O_3?	**Bud burst:** 20-05-066 **Yellowing of leaves:** 10-09-06

In Figures 17- 20, injuries on leaves of rowan and birch which are presented that may be caused by a combination of different air pollutants (mix of O3, ammonia and other compounds). Similar injuries to the species like we observed in 2006, have not been observed during other periods. Hence, there may be a connection between these leaf injuries and high ammonia episodes in combination with other pollutants like O3 or other compounds. Microscopy revealed injuries that may have a connection to elevated O3-levels in combination with ammonia or other pollutants, since injuries to the vax-layer were frequent. Marbling, mottling, stipling, brown spots, fungi-attacks as well as change in coloration were also frequent. Other drivers could also have reinforced the injuries observed, such as climate conditions (frost in spring and drier weather conditions). On the other hand, normal conditions due to precipitation were observed in northernmost Sweden and in northern Norway during spring and summer 2006 (www.met.no; www.smhi.se).

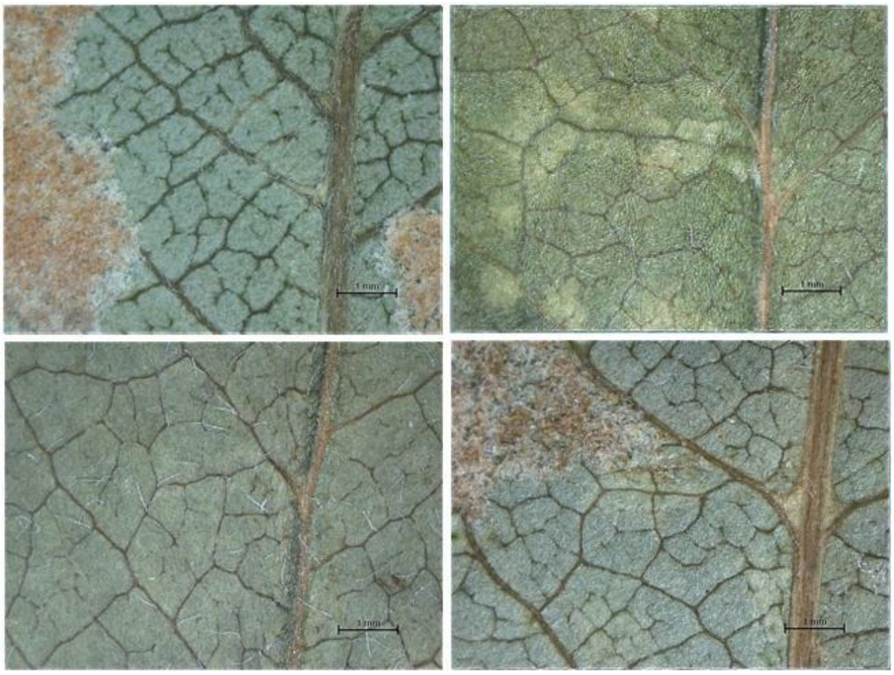


Figure 17. Rowan leaves (june 2006) from Veltvatn-Dividal (Øverbygd-Målselv), enhanced 10x.

Figure 18. Birch leaves from (june 2006) sampled in Veltvatn-Dividal (Øverbygd-Målselv), enhanced 10x (left) and 60x (right).

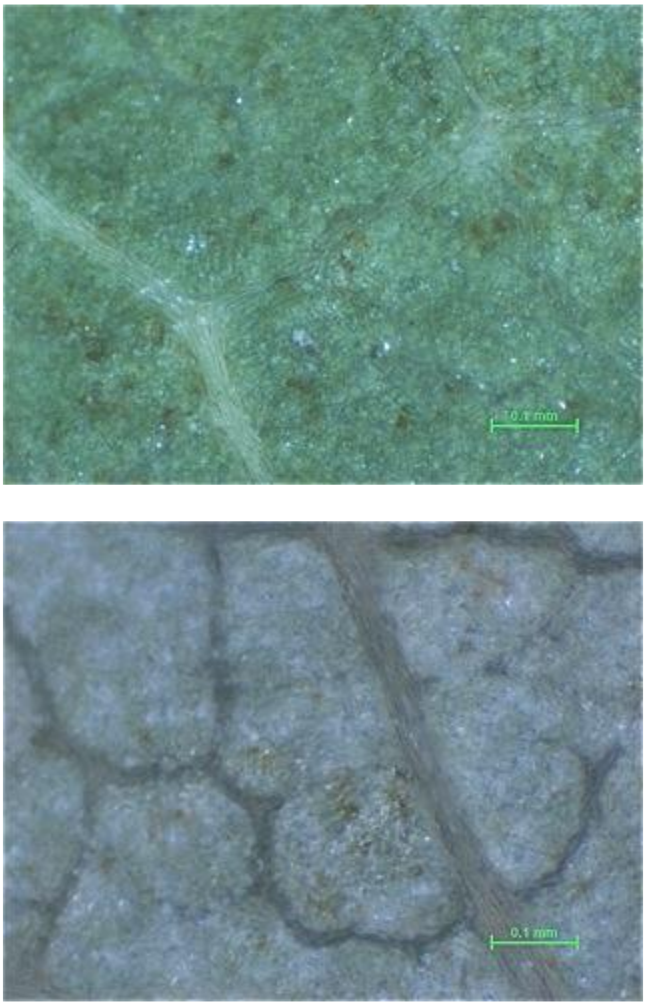


Figure 19. Rowan leaves from (July 1st. 2006) sampled in Nordreisa), enhanced 60x.

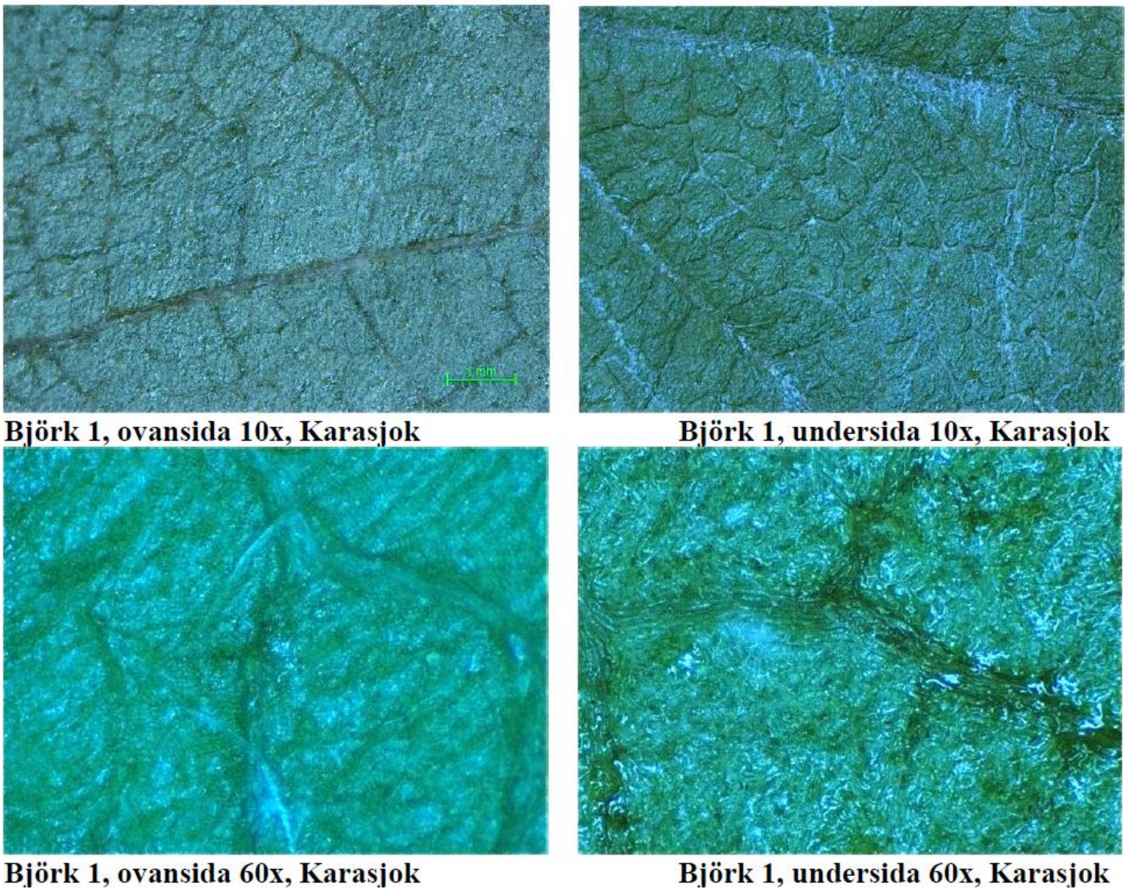


Figure 20. Birch leaves from Karasjok with concentric rings, injuries to the wax-layer and small brown spots.

The significance of long-range transport of ammonia and the impacts on vegetation

1. Is there an increasing frequency of large-scale biomass burning?

2. How often have similar ammonia episodes influenced Fennoscandia?

3. How important could these events be for total nitrogen deposition to northern ecosystems, for vegetation damage, for ?????

Conclusions

Several lines of evidences were found for frequent, episodic occurrence of ammonia/ammonium in air concentrations in northern Scandinavia. Dry deposition measurements with teflons strings under a roof confirmed episodic high occurrence of ammonia during 2004-2006, but also 2007, in northern Sweden. Particularly high air concentrations of particulate and gaseous ammonia at high altitudes were detected during May 2006, coinciding with a well described event with highly polluted air originating from large scale biomass burning in Russia, passing over the county of Jämtland. High air concentrations of ammonia was also detected at Tustervatn, a Norwegian site just north for Jämtland. Also at Bredkälen, a monitoring site within Jämtland, high concentrations of black carbon were detected in May 2006, together with relatively high concentrations of ammonia.

Exceptionally high values for throughfall deposition of ammonia were detected during the summer 2006 at one low altitude site and several high altitude sites in Jämtland. The occurrence of the high ammonia in throughfall in Jämtland varied between different summer months most likely related to precipitation events.

Unusual visible injuries on the shrub vegetation in northern Scandinavia occurred during 2006. High ammonia air concentrations and dry deposition might have contributed to this, together with high ozone concentrations which also occurred in the same area during the summer 2006.

Long-range transport of polluted air from large scale biomass burning might have an important role for nitrogen deposition in northern Scandinavia as well as for the occurrence of visible injuries on the vegetation in the region.

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Figure Captions.

Figure 1.

Table 1. xxxx

of ozone over a threshold of 40 ppb.