NILU OR: 20/97

NILU : OR 20/97
REFERENCE : E-96043
DATE : APRIL 1997
ISBN : 82-425-0867-4

NILU's Atmospheric Research at Ny-Ålesund

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Preface

Atmospheric research at Ny-Ålesund

NILU's atmospheric research in Ny-Ålesund serves three main purposes:

- ***Characterisation of the clean atmosphere and atmospheric changes***
- ***Investigations of atmospheric transport of pollutants into the Arctic***
- ***Studies of atmospheric processes and phenomena in the Arctic***

The Arctic is an interesting area for observations relevant to the cycling of carbon dioxide and other gases which are of concern in connection with climate change. It is also subject to influx of polluted air masses, particularly in the winter. This influx is caused by strong cyclonic activity in the North Atlantic and the Norwegian Sea in late winter and spring, and by limited photochemical activity and deposition as the air travels over snow-covered areas with almost no radiation. Marked changes in the photochemical activity and in the atmospheric conditions take place immediately after the Arctic sunrise in March-April.

The research facilities at Ny-Ålesund, and in particular the research station at the Zeppelin Mountain, are excellent for atmospheric research. This platform has been built at amountain ridge south of Ny-Ålesund, 475 m above sea level, in order to minimise any effects of emissions from the local settlement and infrastructure. At 79° north, Ny-Ålesund is easily accessible by commercial flights to Longyear-byen, and by small aircraft from Longyearbyen to Ny-Ålesund. The infrastructure at Ny-Ålesund is well developed with respect to accommodation and technical facilities.

The global atmosphere

The Arctic atmosphere is part of the global atmospheric circulation. However, unlike in the Antarctic, strong meridional circulation extends into and even across the polar cap. This has advantages as well as disadvantages for atmospheric research. However, it is possible to observe both the effect of anthropogenic releases as well as the slow changes of atmospheric composition which is caused by the total emissions of long-lived atmospheric species such as carbon dioxide, methane, nitrous oxide, chlorofluorocarbons (CFCs) and related chemical species. In the troposphere, ozone is also a greenhouse gas, and Ny-Ålesund is a particularly suitable location for investigations of ozone and the precursors of tropospheric ozone formation, *viz.* volatile organic compounds and nitrogen oxides

Cooling by atmospheric aerosol is another important topic in the climatic change issue. Arctic Haze is caused by influx of sulphate aerosols from the Eurasian continent in late winter and spring, and is generally confined to the lowest 800-1000 m of the Arctic atmosphere. Elevated haze layers may contain both

anthropogenic and natural aerosols from volcanoes as well as from deserts. These can be observed by optical methods, or by sampling from aircraft.

Atmospheric transport of pollutants into the Arctic

Not only Arctic Haze is introduced to the Arctic by atmospheric transport. Needless to say, ozone and its chemical precursors, as well as their degradation products are brought in by the same winds as sulphur dioxide and sulphate aerosols. The transport pattern varies according to season and to the meteorological situation, and the events with Arctic Haze and other pollutants alternate with periods in which the air masses are extremely clean.

Of particular concern in the Arctic are compounds that may influence the Arctic directly. Within this group, certain persistent organic compounds are particularly important because of their persistence and accumulation in Arctic food-chains. These compounds include both pesticides such as DDT, Toxaphene and Lindane, and industrial chemicals such as PCB's and chlorinated naphthalenes. These compounds are carried by the air and taken up by the ocean or other water bodies, and biologically enriched because of their high solubility in lipids. NILU is presently monitoring a wide range of persistent organic pollutants (POPs) as well as heavy metals in air at Ny-Ålesund.

Arctic "ozone holes"

The processes which since about 1980 are responsible for the occurrence of the so-called ozone hole in the Antarctic are also active in the Arctic. Stratospheric ozone depletion is known to be caused by chlorine originating from CFCs and related chemicals as well as by bromine from industrially produced Halons. It occurs in connection with the formation of cold, stratospheric clouds. The depletion is therefore highly dependent on the meteorological circulation pattern, particularly with the formation of isolated air packets characterised by the potential vorticity in the upper atmosphere.

NILU has several instruments in Ny-Ålesund which measure both the thickness of the ozone layer, as well as some of the chemical species which actually destroy ozone. The UV radiation reaching ground level is also measured.

Another ozone "hole" of a quite different kind has been studied in the Arctic for about ten years. Each spring episodes of extremely low ozone concentrations near the ground have been detected at Ny-Ålesund as well as other Arctic stations. This is not an environmental problem, but the phenomenon has been studied in detail during the last few years, as it is believed to impact the ozone budget on a large scale.

International co-operation and collaboration

Scientists from many nations are doing atmospheric research in Ny-Ålesund. NILU has a close collaboration with the group from the Meteorological Institute at the University of Stockholm, Sweden, which measures CO_2 and other species at the Zeppelin station, as well as with German, Japanese and Italian scientists who have their own atmospheric research facilities in Ny-Ålesund. In addition NILU

often arranges research campaigns in collaboration with scientists from all over Europe as well as from the United States.

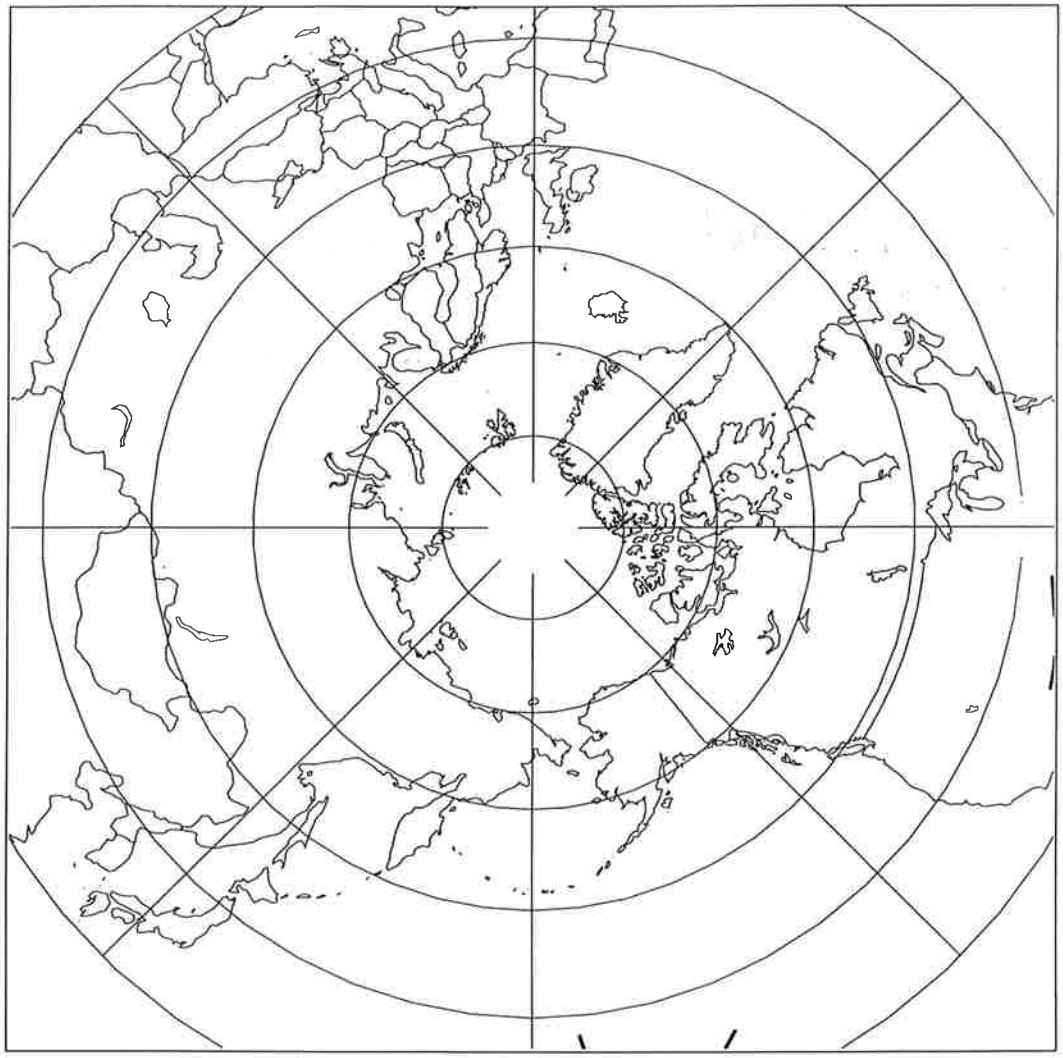

Figure 1. The northern hemisphere.

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1. Historical background of Arctic research

1.1 Introduction

Atmospheric Research in the Arctic sprang to life in the early 70's, when 'Arctic haze' was re-discovered during radiation measurements near Barrow, Alaska [e.g. *Shaw, 1994*; *Rahn et al.*, 1977]. This phenomenon, first described during the 1950's, refers to turbid layers of air which are found regularly over the pack ice in the Arctic during periods of clear weather. The layers are diffuse; many thousands of kilometers wide, 1-3 km thick, and can occur as single or multiple bands of different heights at nearly any level in the troposphere. They are invisible from the ground, but may limit horizontal and slant visibility within a layer to as little as 3-8 km. Their color is gray-blue in the anti-solar direction and reddish-brown in the solar direction, suggesting they are aerosol rather than ice crystals [*Mitchell*, 1956].

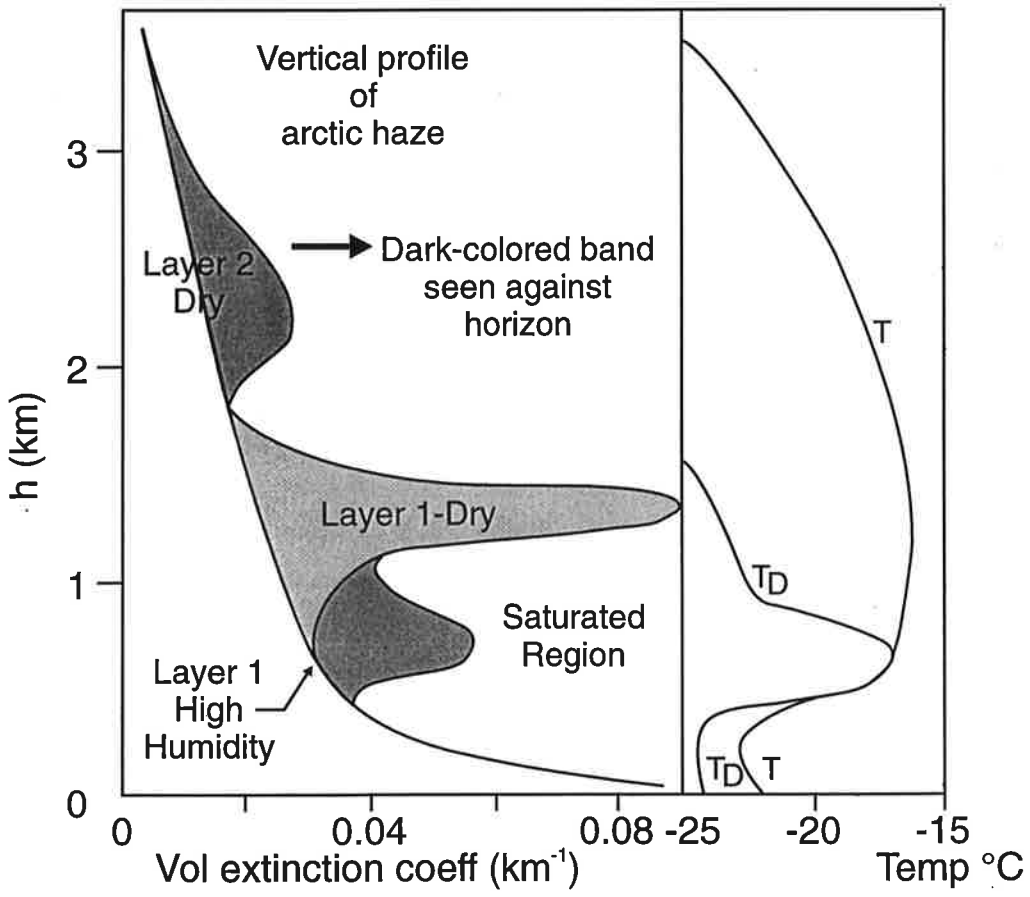

Figure 2. Altitude distribution of Arctic haze. The profile was made with a sun photometer from a small airplane [Shaw, *1994*].

Now, two decades later, as research interests are focusing on the depletion of the ozone layer, the tropospheric ozone budget and climate change, there is a renewed interest in Arctic haze due to its role in the climate system and global climate change.

1.2 Historical background of environmental research at Svalbard

The Svalbard islands are close both to the cyclonic activity in the North Atlantic and the Polar Basin. Observations in this area are particularly valuable in studies of the meteorological conditions governing the air pollution transport into the Arctic.

Inspired by similar work performed in the Alaskan Arctic, sampling of atmospheric aerosols was performed at Ny-Ålesund since 1973 [*Larssen and Hanssen*, 1980]. High-volume filter samples were analyzed using neutron activation analysis by Rahn [*Rahn et al.*, 1977]. Until 1981 some analyses were also performed at NILU. The results showed for the first time that polluted air was transported into the Arctic. Additional filter samples analyzed by Rahn for non-sea-salt (nss) sulfate showed episodic behavior that was not random, but due to extra-continental transport of pollutants [*Rahn et al.*, 1980].

After two phases of the OECD programme on Long Range Transport of Air Pollutants (LRTAP) in Europe, the European Monitoring and Evaluation Programme (EMEP) was started in 1979. This project included all European countries and was organized within the framework of the United Nations' Economic Commission for Europe (ECE). Bjørnøya, and later Ny-Ålesund were chosen as remote background station in the European site network established within EMEP.

Following these efforts a **first meeting on Arctic air pollution** was organized at NILU in April 1977 [*NILU*, 1980]. This first meeting established the importance of research on aerosols, as influences on climate and radiation became apparent. The first concepts of long range transport of pollution into the Arctic emerged; element analysis of filter samples and radioactive fallout as a tracer gave the first data to support these ideas. As main result of this meeting it was agreed to establish baseline values for various atmospheric parameters between 1977 and 1980, and pool this information to further scientific progress.

It was now emerging that the Arctic atmosphere was more influenced by human pollutant emissions activities than it was thought to be until then.

The **second meeting on Arctic air chemistry** was held at the University of Rhode Island, the proceedings were published in a special issue of *Atmospheric Environment* [15(8), **1981**]. It was called after unexpectedly large amounts of pollution aerosols in the Arctic were discovered. It addressed questions of the speciation and extent of Arctic pollution, the main polluting substances, sources and transport paths of this pollution, as well as deposition and effects on the Arctic. The main purpose of this meeting was to discuss and coordinate ideas and plans for future research.

Figure 3. Map of Spitsbergen.

A **third meeting** was held at the Atmospheric Environment Service (AES) in Ontario, Canada [*AES*, 1984]. The first results of the BP project (see below) were presented by several NILU scientists.

A number of important facts about Arctic air pollution were established at this meeting:

- The long range transport of polychlorinated hydrocarbons into the Arctic.
- The importance of black carbon.
- Arctic haze is accompanied by gaseous pollution
- USSR and Europe are sources for different layers of Arctic haze. This was shown by a number of different methods.

In the early 1980's several large research projects were focusing on Arctic topics. In the Norwegian Arctic two projects were of special importance. The first, AGASP, was an aircraft campaign organized by the American National Oceanographic and Atmospheric Administration (NOAA). The second, of much larger impact for the understanding of transport and chemical processes of the Eurasian Arctic was the so called BP programme, carried out by NILU and funded by British Petroleum Ltd. (BP) under an agreement between the Norwegian government and the oil companies.

During the spring of 1983 the first **Arctic Gas and Aerosol Sampling Program (AGASP)** was conducted across the Arctic. The research platform was a NOAA aircraft, which flew 144 flight hours on 12 individual research missions. Six of these missions covered the Norwegian Arctic, during three Svalbard was passed. The results of AGASP were published in a special issue of *Geophysical Research Letters* [11(5), **1984**], and included a number of papers from NILU scientists.

This research covered many topics, the main findings with respect to the Norwegian Arctic can be summarized:

- Sulfur pollutants exhibit an annual cycle in the Arctic with a winter maximum and a summer/fall minimum [*Joranger and Ottar*, 1984]. During the winter thin stratified layers of pollution are transported in episodes mainly from Russia. The Arctic aerosol shows a narrow and homogeneous size distribution which indicates that the aerosol is not subject to chemical reactions or further growth.

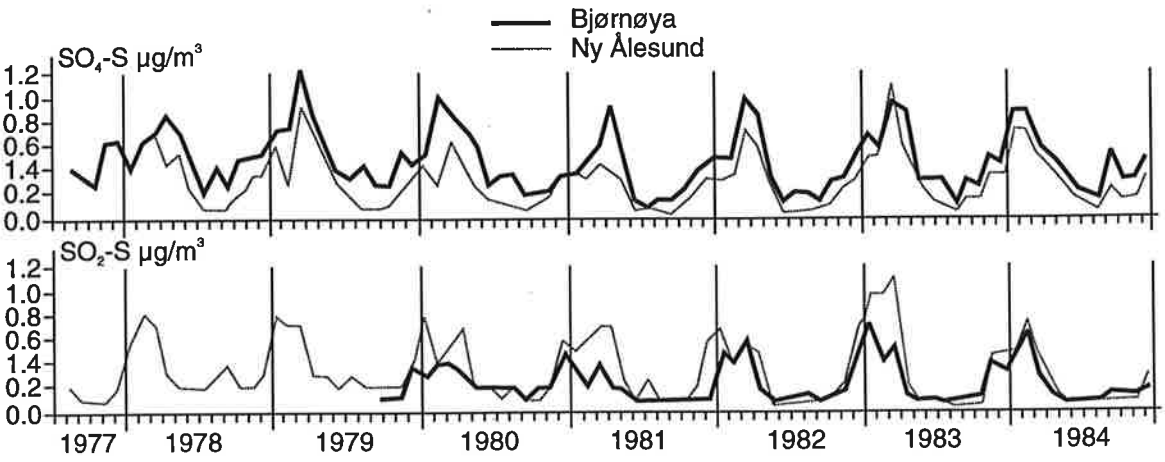

*Figure 4. The variation of the monthly mean concentrations of SO_2 and SO_4^{2-} at the Arctic stations Bjørnøya and Ny-Ålesund during 1977 to 1984 [*Joranger et al., *1986].*

- The first measurements of halocarbons and light hydrocarbons were reported for Spitsbergen [*Hov et al.*, 1984]. They showed the effects of both direct transport and different reactivity of a broad range of species.

- Based on the concentrations of Ni, Zn, and Pb measured in different aerosol size fractions and trajectory analysis, events of long range transport of pollution from the Kola peninsula into the Arctic were identified [*Ottar and Pacyna*, 1984].
- Analysis of snow samples revealed a spatial pattern that was consistent with orographic deposition of anthropogenic pollution transported into the Arctic [*Semb et al.*, 1984].
- Quasi-adiabatic transport proved to be a good concept to describe transport from polluted mid-latitudes into the Arctic [*Iversen*, 1984].

The results of the **BP programme** are published as a NILU report [*Ottar et al.*, 1986], which established much of our current understanding of Arctic atmospheric pollution and transport. The main points can be summarized as follows:

- Wintertime Arctic haze originates from anthropogenic pollutants emitted into the Arctic air mass. This phenomenon occurs in late winter and spring, and affects large parts of the Arctic and Sub-Arctic regions.
- The vertical extent of the Arctic haze layers is typically less than 1000m.
- In this cold and stable air mass deposition rates and photochemical activity are very low, anthropogenic pollutants are therefore found in concentrations comparable to those at the industrialized mid-latitudes.
- Atmospheric precipitation in the Arctic is generally low.
- Precursors of tropospheric ozone were found in Arctic air, mainly non-methane hydrocarbons (NMHC), which during spring and summer could contribute to the elevated background mixing ratios of ozone.
- Air flow into the Arctic often follows approximately isentropic trajectories outside of frontal zones where the latent heat release can be substantial. This finding was utilized in formulating an atmospheric dispersion model, which for example allows to pinpoint the original ground level temperature and latitude of the emissions. The model calculations indicated that the former USSR was responsible for about 80% of the ground level SO_2/SO_4^{2-} concentrations in the Arctic.

These results were important enough to warrant a continuation of most sampling efforts after the BP programme had officially ended. NILU proceeded to measure SO_2/SO_4^{2-} at both Bjørnøya and Ny-Ålesund. In addition sampling of persistent organic pollutants (POP), volatile organic compounds (VOC) and other species continued as well. The interests in aerosols shifted towards the understanding of the chemistry. Sampling for aerosols continued, the analyses were carried out by W. Maenhaut, University of Gent. Further aerosol studies were carried out by Maenhaut, who installed a PIXE cascade impactor for trace elements at Ny-Ålesund in 1990, and in 1991 a high volume sampler for trace elements and methane sulfuric acid (MSA).

A **fourth international symposium on Arctic air chemistry** was hosted by NILU at Hurdal, Norway in 1987. Again, a special issue of *Atmospheric Environment* was published [23(11), **1989**]. *Ottar* [1989] summarized the findings of the BP project, individual NILU researchers contributed on the following topics:

- *Iversen* [1989a; b] showed that quasi-stationary atmospheric flow systems on the planetary scale are responsible for long range transport of polluted air into the Arctic. He also presented results of a numerical modeling of SO_2 and particulate SO_4^{2-} flows.
- *Joranger and Semb* [1989] showed how scavenging and the formation of precipitation affected the SO_4^{2-} concentrations.
- *Hov et al.* [1989] presented measurements of light hydrocarbons from Ny-Ålesund. The measured concentrations of individual NMHCs agreed with their OH reactivity.
- *Maenhaut et al.* [1989] showed that the concentration of anthropogenically produced elements in the Arctic aerosol go through strong annual cycles.

The meeting concluded with a discussion of plans for an extended base-line monitoring station at Ny-Ålesund: today's Zeppelin station.

In the second half of the 1980's new discoveries were made about the Arctic atmosphere; The effects of precursor transport and the springtime formation of ozone was investigated. The Arctic VOC measurements were analyzed theoretically, applying a global 2-D chemical transport model [*Isaksen et al.*, 1985]. This work opened the view for tropospheric chemistry, which today determines much of the interest in the high Arctic atmosphere. One of the central hypothesis, the *in-situ* formation of tropospheric ozone through the buildup of PAN during winter and subsequent release of NO_x during spring, has not been experimentally evaluated until recently [*Beine et al.*, 1997].

A new phenomenon, spring-time ozone depletion in the Arctic marine troposphere was observed for the first time [*Barrie et al.*, 1988, *Bottenheim et al.*, 1990]. This topic has since then received much attention in a number of measurement campaigns (e.g. Polar Sunrise Experiments (PSE) in the Canadian Arctic, Arctic Tropospheric Ozone Chemistry (ARCTOC) in the European Arctic, including Ny-Ålesund).

The **fifth international symposium on Arctic air chemistry** took place in Denmark in 1993 [*Braathen and Joranger*, 1993]. The topics of this decade in Arctic atmospheric research are

- Greenhouse agents (CFCs, CH_4, N_2O, O_3, CO_2, aerosols)
- Photochemical oxidants (O_3, VOCs, PAN, NO_x, and reaction products)
- Total atmospheric columns of O_3 and NO_2 and other species of stratospheric interest
- Monitoring of background levels and transport of a range of gaseous and aerosol species in air and in precipitation
- POPs
- Meteorology and climate change

Since 1994 part of the measurements at Ny-Ålesund were reported to the Arctic Monitoring and Assessment Programme (AMAP).

2. Arctic 'background' air sampling – the Zeppelin station

Much of NILU's research in the Arctic is today centered at the Zeppelin station near Ny-Ålesund, Svalbard (78°54'29"N, 11°52'53"E, 474 m. a. s. l.). Ny-Ålesund is an old mining town on the Kongsfjord on the west coast of Svalbard. Mountains surrounding the location peak to 600 m. The mining operations stopped in 1963.

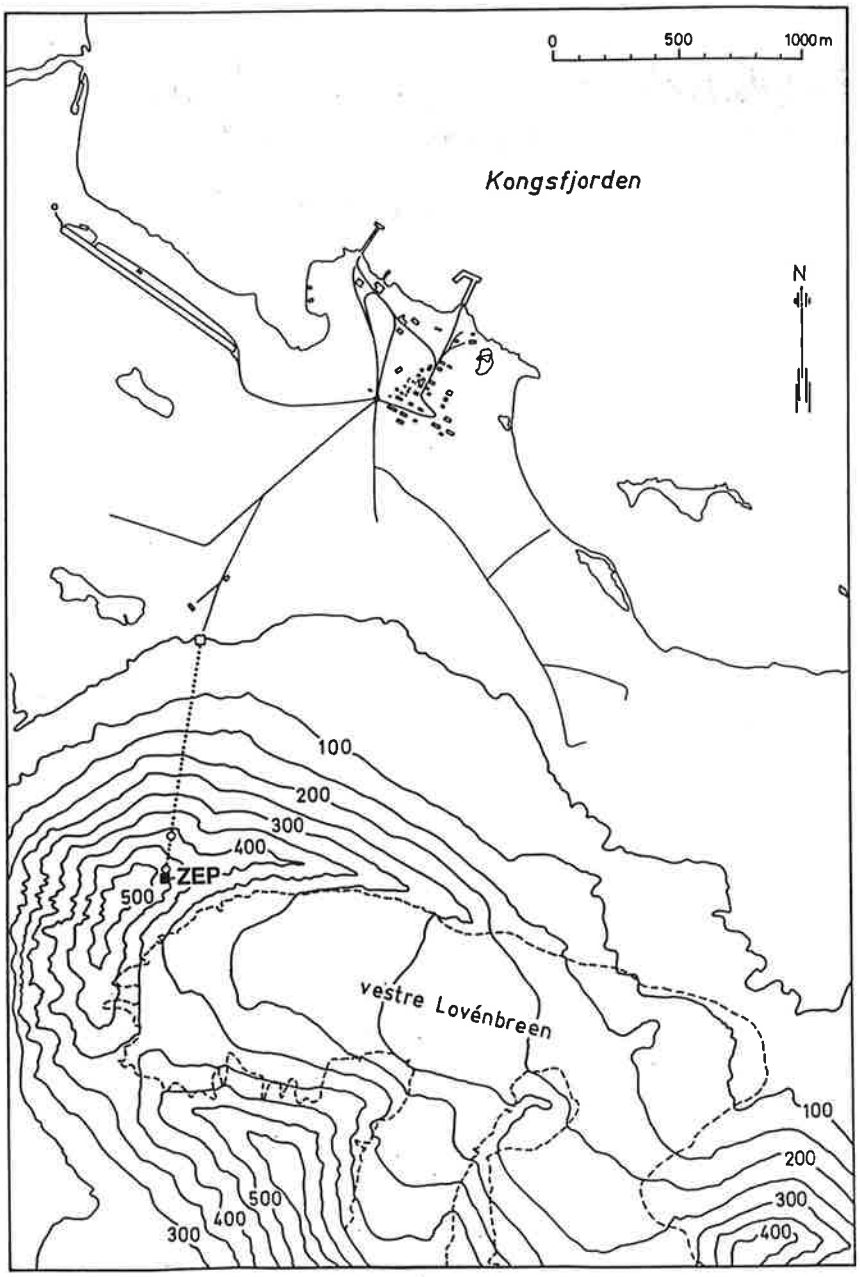

Figure 5. Ny-Ålesund and surroundings [Holmén et al., 1995].

Figure 6. The Zeppelin mountain station.

The operation of the NILU sampling site 'Badehuset' had increasingly revealed problems with local pollution, especially during periods of low winds and/or inversion. In October 1989 a new atmospheric research station on the Zeppelin mountain, Svalbard was put into operation. The station was planned and built for measurements of background air in the high Arctic troposphere [*Braathen et al.*, 1990]. It was located on top of the Zeppelin mountain to minimize impacts from the nearby village of Ny-Ålesund, and to permit sampling of free tropospheric air [*Hov and Holtet*, 1987].

Access to the station is possible via a dedicated electric cablecar. No combustion sources are located at the mountain top. Local contamination at the station is rarely seen [*Beine et al.*, 1996].

Since November 1989 the 'full EMEP program' was measured at Zeppelin: 24 h average SO_2, SO_4^{2-}, sum nitrates, and sum NH_4^+. The sampling at 'Badehuset' was stopped in January 1991, after the continuity of measurements at Ny-Ålesund had been demonstrated.

2.1 Continuous activities at the Zeppelin station

2.1.1 EMEP monitoring:

Zeppelin is a major background station for EMEP. Ozone and a number of ions are continuously measured both in the gas phase and in precipitation. NILU, as the Chemical Coordinating Center (CCC) within EMEP, provides data to the program. NILU has for example measured the longest record of SO_2 and SO_4^{2-} in the Arctic. Both species show consistently a decreasing trend over the years.

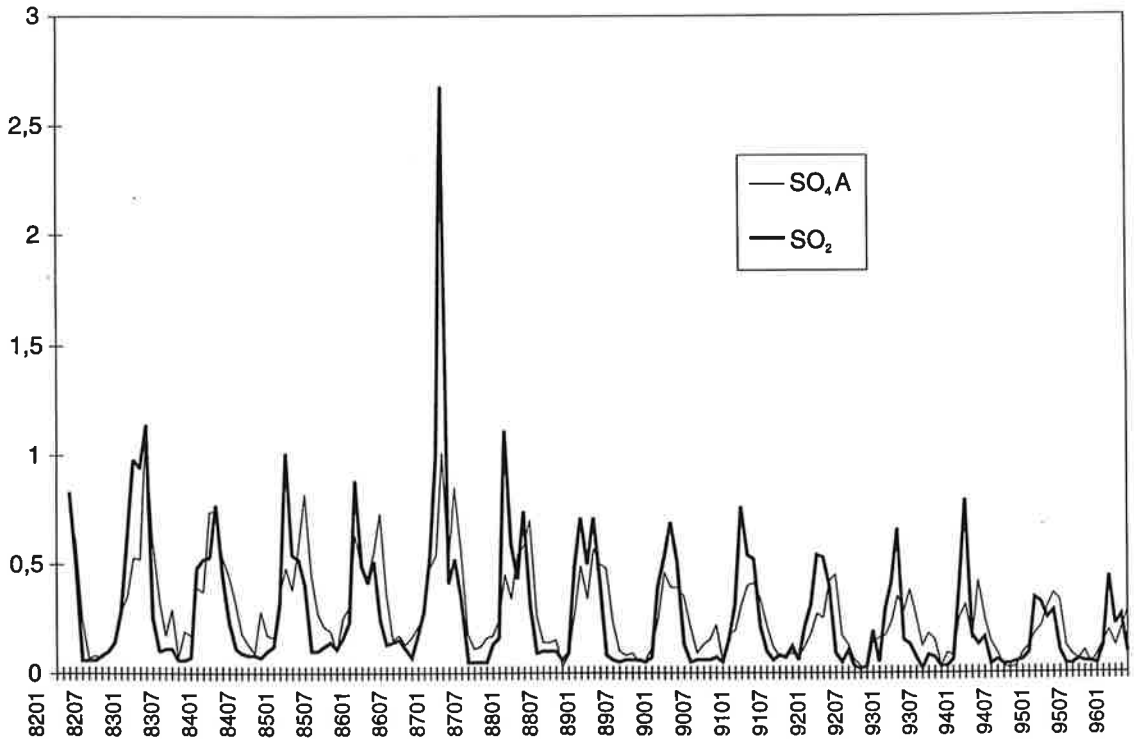

Figure 7. The monthly mean concentrations of SO_2 and SO_4^{2-} at Zeppelin.

Records like this one are important in the EMEP work to demonstrate trends and the hemispheric influence of in particular European and Russian emissions. Other data include for example VOC [*Solberg et al.*, 1996a], or MSA [*Maenhaut et al.*, 1997].

In addition to the EMEP monitoring activities a number of atmospheric chemistry research topics are advanced through the scientific work at Ny-Ålesund:

2.1.2 Stratosphere

A significant springtime thinning of the stratospheric ozone layer is also found over the Arctic region, even though the ozone reduction there and its spatial extent are smaller than over Antarctica. NILU monitors ozone in the stratosphere and the key species involved in ozone chemistry (e.g. NO_2) with a UV-visible spectrometer (SAOZ). This work is complemented by regular ozone-sonde measurements carried out by the Alfred Wegener Institut für Polarforschung.

2.1.3 Climate change: Greenhouse gases:

Understanding the sources and the distribution of trace gases that affect the infrared radiation balance in the atmosphere is essential to the quantity of global warming and the greenhouse effect. For this purpose NILU monitors the major greenhouse gases H_2O, CH_4, CFCs, tropospheric ozone, and CO_2 (measured by MISU), at the Zeppelin station to understand the cycles and trends of these species.

2.1.4 Climate change: Aerosols

As shown above, Arctic haze was first 'quantified' using sun photometer measurements. The radiative effects of aerosols are again in focus today: In mid-latitudes light is scattered and reflected by aerosols, which leads to a regional cooling of the atmosphere, thus offsetting 'global warming'. To understand global warming, and to predict future trends, all interactions between agents that influence the radiative forcing of the atmosphere must be quantified.

2.1.5 Photochemistry:

The background mixing ratio of tropospheric ozone has increased by more than a factor of two in the Northern Hemisphere over the last hundred years. This is a direct consequence of increased emissions of precursors such as nitrogen oxides and hydrocarbons. Ozone is a greenhouse gas and is harmful to human health and vegetation. Apart from measuring ozone itself, NILU conducts monitoring of the most important precursors to ozone, notably NO_x and VOC at Zeppelin. Together with measurements of radiative parameters (e.g. the photolytic rate constant of NO_2), this enables us to understand the processes governing the production and destruction of ozone.

Important current research topics in tropospheric photochemistry include the question of the spring ozone maximum in northern latitudes as well as the Arctic boundary layer ozone destruction during spring. Both these topics are investigated in Ny-Ålesund.

2.1.6 Current Research at Ny-Ålesund

An overview of all research programs conducted at Svalbard is published yearly by the Norwegian Polar Institute [see chapter 4].

At Ny-Ålesund NILU, partly in collaboration with other institutions, measures the following species under a number of programs. NILU thus follows the plans made in 1990 as outlined by *Braathen et al.* [1990]:

2.1.6.1 European Monitoring and Evaluation Programme (EMEP)

* Tropospheric ozone (continuous UV absorption instrument)
* NO_2, daily average (KI impregnated filter)
* SO_2, daily average (filter)
* nitrates (sum of gaseous and aerosol), daily average (filter)
* ammonium (sum of gaseous and aerosol), daily average (filter)
* Sulfate aerosol, daily average (filter)
* Nitrate in precipitation, weekly average
* Ammonium in precipitation, weekly average
* Sulfate in precipitation, weekly average
* Other ions in precipitation, weekly average

2.1.6.2 Tropospheric Ozone Research (TOR)

* Tropospheric ozone (continuous UV absorption instrument)
* C_2 - C_9 hydrocarbons, canister samples, GC/FID analysis
* Peroxyacetylnitrate (PAN) and peroxypropylnitrate (PPN) (automatic GC/ECD, 4 samples/hour)
* Halocarbons, canister samples, GC/ECD analysis
* NO, NO_2, NO_y, continuous chemiluminescence method for NO, NO_2 as NO following broad band UV absorption, NO_y as NO following reduction by CO on a gold catalyst.
* CO, continuous, GC, Hg replacement, detection by UV absorption
* $J(NO_2)$, continuous photometric method

2.1.6.3 Greenhouse gases

* Methane, canister samples,
* Chlorofluorocarbons, canister samples,
* Tropospheric ozone (continuous UV absorption instrument)
* CO_2, continuous, IR absorption (run by MISU)
* Particles, continuous, condensation nuclei counter, nephelometer (run by MISU)

2.1.6.4 Stratospheric ozone

* Column density of ozone, NO_2, O_4, H_2O, diode array spectrometer (SAOZ, UV/visible)
* Supporting measurements of ozone by lidar and ozone-sondes are carried out by the Alfred Wegener Institut in Ny-Ålesund.

2.1.6.5 Polychlorinated hydrocarbons

* Gaseous, polyurethane plugs
* Particulate, fiberglass filters

2.1.6.6 Particles

* High-volume samples, analysis for heavy metals at the University of Gent
* Size segregated aerosol sampling by Hauke cascade impactor
*

2.1.6.7 Meteorology

* Wind speed, direction, humidity, temperature, pressure are measured with various instruments.
* UV and total radiation is measured by Norsk Polarinstitutt (NP).

2.2 Scientific campaigns

The Zeppelin station is open for international collaboration. Through the years many campaigns have drawn researchers from different institutes to Ny-Ålesund, the earliest examples were, as shown above, AGASP and the BP project. Recently three projects have taken advantage of the collaboration with NILU.

2.2.1 ARCTOC

During 1995 and 1996 Ny-Ålesund was the site of the EU project 'Arctic Tropospheric Ozone Chemistry' (ARCTOC), which attempted to measure a number of species during springtime tropospheric boundary layer ozone depletion events. The main research activity took place in Ny-Ålesund close to sea level, where measurements of halogens and other species were carried out by DOAS. NILU performed VOC and ozone measurements at the Zeppelin station for this project.

2.2.2 University of Alaska

During the spring of 1994 the Geophysical Institute, University of Alaska conducted a springtime measurement campaign of NOx at the Zeppelin station. These measurements were supported by NILU with data on ozone, meteorology, $J(NO_2)$ and VOC, and by MISU with aerosol data.

2.2.3 CNR- Istituto sull'Inquinamento Atmosferico

Also during spring 1994 the Italian CNR-IIA conducted denuder measurements of both gaseous and aerosol species at the Zeppelin station. The samples were analyzed in a laboratory in Ny-Ålesund.

2.3 LSF

The 'Large Scale Facility programme' (LSF) is an EU project to ensure the mobility of researchers and the access to facilities such as Ny-Ålesund. Proposals for research projects can be submitted to one of four partners (NILU, NP, AWI, Statens Kartwerk), depending on the scope of the work. This year several institutes take advantage of the LSF and collaborate with NILU at Zeppelin:

- Institute for atmospheric pollution, CNR-IIA, Italy.
- Finnish Meteorological Institute, Finland.
- University of Bristol, School of Chemistry, U.K.
- University of Stockholm, Department of Meteorology (MISU), Sweden.
- University of Leicester, Department of Chemistry, U.K.
- University of East Anglia, School of Environmental Sciences, U.K.
- Max Planck-Institute for Chemistry, Germany.
- University of Heidelberg, Institute for Environmental Physics, Germany

3. Recent advances in knowledge

The following section of this report highlights some results that were published in recent years based on the measurements made at Zeppelin.

A unique long term record of the Arctic aerosol shows that non-sea-salt sulfate is correlated with anthropogenically derived heavy metals, such as arsenic [*Maenhaut*, 1997]. During the summer months a strong biogenic source for MSA can be detected in the fine particles [*Heintzenberg and Leck*, 1994]. The sources, composition, transport, and cycling of aerosols are today fairly well understood [*Pacyna*, 1995]. Aerosol measurements are the main verification for our understanding of transport in the Arctic [*Djupström et al.*, 1993], which often can be described by isentropic trajectories [*Iversen*, 1989a; b]. Aerosols currently partly offset a warming in the atmosphere. CO_2 has increased at Zeppelin in recent years by up to 4 ppmv/year. It has a clear annual cycle, with a summer minimum and a winter maximum [*Holmén et al.*, 1995]. Other greenhouse gases such as CFCs show a trend which is more slowly increasing in the 90's than in the 80's, reflecting reduced emissions.

Transported both in the gas-phase and adsorbed on aerosols, POPs are enriched in the Arctic with significant consequences for Arctic biota [*Oehme et al.*, 1996a; b; 1995a; b].

NILU's main scientific focus has been on Arctic photochemistry in recent years. As explained above, troposphere chemistry is strongly connected to ozone, which has been measured for many years in Ny-Ålesund. The interaction of ozone, VOC, NO_x, and other species in the Arctic atmosphere are well described in a number of publications.

3.1 Atmospheric aerosol composition

Unlike the measurement programs at other sites [e.g. *Barrie et al.*, 1994] NILU in collaboration with the University of Gent carries out a long term program to characterize the chemical composition of the Arctic atmospheric aerosol. High volume filter samples and samples from impactors are analyzed for SO_4^{2-}, methanesulfonate (MSA), NO_3^-, Cl^-, Br^-, and a number of cations by ion chromatography, as well as for 40 elements by neutron activation and particle induced X-ray emission (PIXE) [*Maenhaut et al.*, 1997]. It was found for example

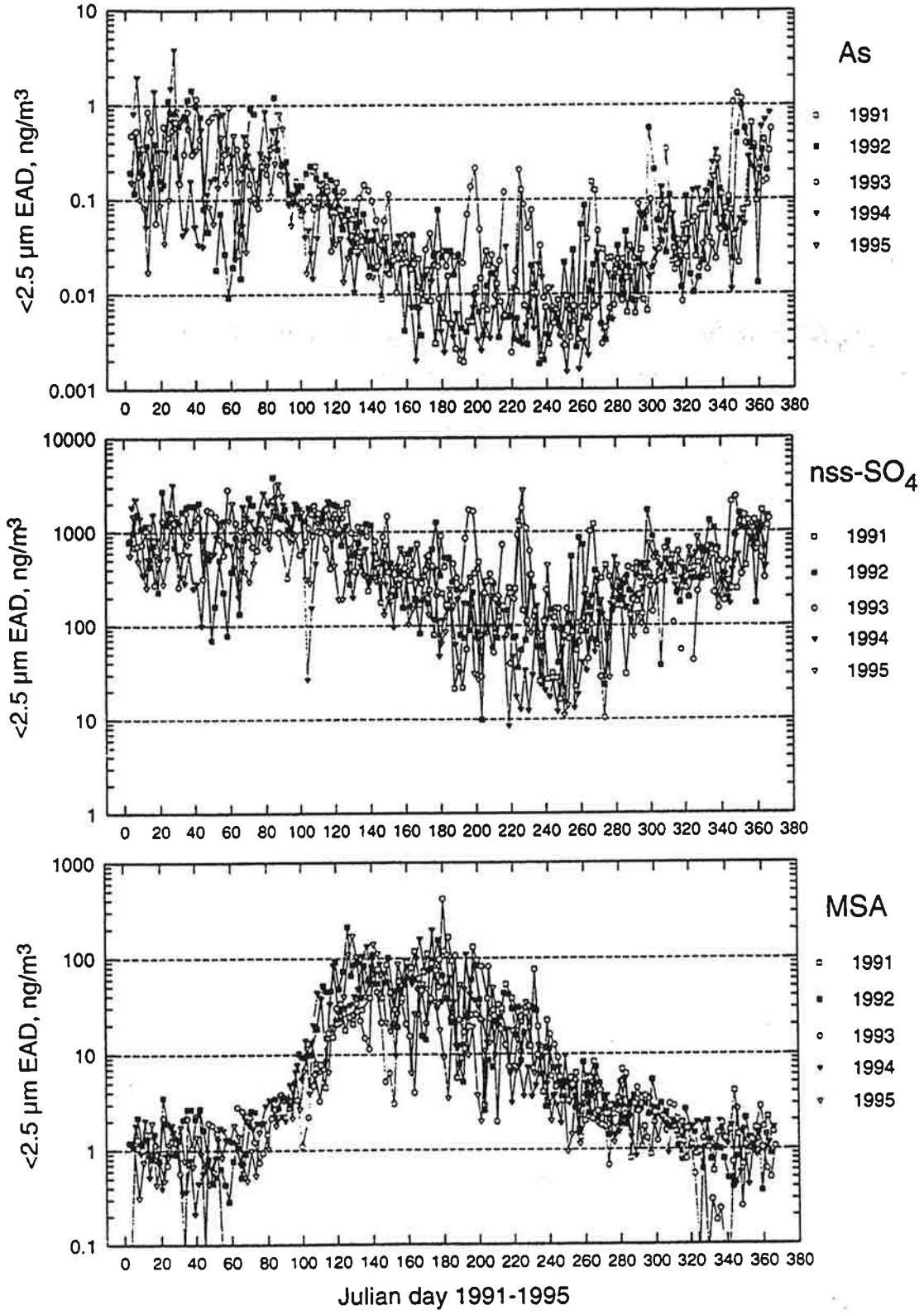

*Figure 8. Atmospheric concentrations (in the <2.5 µm size fraction) of As, nss-sulfate, and MSA as a function of sampling date (Day of Year) for the years 1991 through 1995 [*Maenhaut et al., *1995].*

that both sulfate and MSA are connected to fine particles (< 2.5 µm), and that this fine sulfate was virtually all nss-sulfate. Correlating those with episodes of high

concentrations of anthropogenically produced metals, e.g. As, the anthropogenic origin of sulfate is visible. MSA on the other hand shows no correlation with As, its seasonal cycle is almost opposite to that of sulfate, which is expected since MSA is entirely generated from DMS emissions by phytoplankton.

3.2 Aerosol

Pacyna [1995] has recently reviewed many aspects of Arctic air pollution. Pollution in the lower layers of the Arctic troposphere during winter originates from Eurasian sources. During summer European sources are more important. In altitudes of 4 - 5 km a mixture of pollution from a multitude of sources - both natural and anthropogenic - can be found. Less than 10% of the emitted pollution seems to be deposited within the Arctic, however, many sink processes are not fully understood. During the 1980's the concentrations of major pollutants such as sulfur species stayed constant, while a decrease, particularly in lead and fine particle concentration has been observed in the 1990's, and is probably a reflection of a decrease of emissions in some source regions.

Table 1. Average contribution from various sources to the atmospheric concentrations of elements in the Ny-Ålesund winter samples (percentages of observed atmospheric concentrations) [Maenhaut et al., 1989].

	Component 1 Pollution	Component 2 Crust	Component 3 Sea-salt	Sum of listed contributions
Na			70	70
Mg			129	129
Al	27	49	10	86
Si	19	49	32	100
S	45	20		65
K	34	28	62	124
Ca	11	38	81	130
Sc	53	60		113
V	121	22		143
Mn	95	40		135
Fe	85	45		130
Zn	96	33		129
As	115	33		148
Se	46	9		55
Br			78	78
In	109	24		133
Sb	87	33		120
I	35	14		49
Cs	60	40		100
La	48	48		96
Sm	32	49		81
Th	38	56		94

The fine particle fraction of the Arctic aerosol is of particular significance for Arctic haze and pollution. The fine particles are mainly composed of anthropogenic pollutants during winter, mostly sulfuric acid. They also contain high

concentrations of anthropogenic heavy metals and persistent organic pollutants (POPs). Coarse particles on the other hand are not connected to anthropogenic pollution and consist of clay minerals, soil, and sea salt.

The introduction of fine particles into the Arctic has also climatological consequences [see e.g. *Shaw*, 1994].

The Arctic aerosol during winter consists mainly of

- sulfate ~ 2 $\mu g/m^3$
- organic carbon ~ 1$\mu g/m^3$
- black carbon (soot) ~ 0.3 - 0.5 $\mu g/m^3$ (including associated water)
- water ~ a few $\mu g/m^3$
- others ~ a few tenths $\mu g/m^3$
- Nitrates are largely missing.

3.3 Fine aerosol particles (MISU)

The Department of meteorology, Stockholm University (MISU) installed instrumentation for continuous aerosol and CO_2 measurements at the Zeppelin station in 1990. The records of fine particles (radius < 1 µm) were analyzed with special emphasis on marine biogenic sulfur. A strong regional marine biological source of MSA and SO_4^{2-} was found during summer, while biogenic activity was essentially absent during winter. This source, however, became active as early as March over the Barents Sea and the North Atlantic [*Heintzenberg and Leck*, 1994]. Based on measurements of both aerosols and CO_2, transport patterns and sources for pollution were further investigated, with results that confirmed the findings of earlier studies [*Lejenäs and Holmén*, 1996].

3.4 Tropospheric photochemistry

3.4.1 Ozone

Ozone has an annual cycle with a summer minimum and a spring maximum. Ozone is lower during summer and higher during winter than at a mid-latitude station, for example Birkenes in the south of Norway. This shows that there is a pool of excess ozone in Europe during summer, and a deficit during winter, which reaches the south part of Norway, but not Svalbard.

Due to episodic ozone depletion events the spring maximum is not as pronounced as at continental northern hemispheric sites.

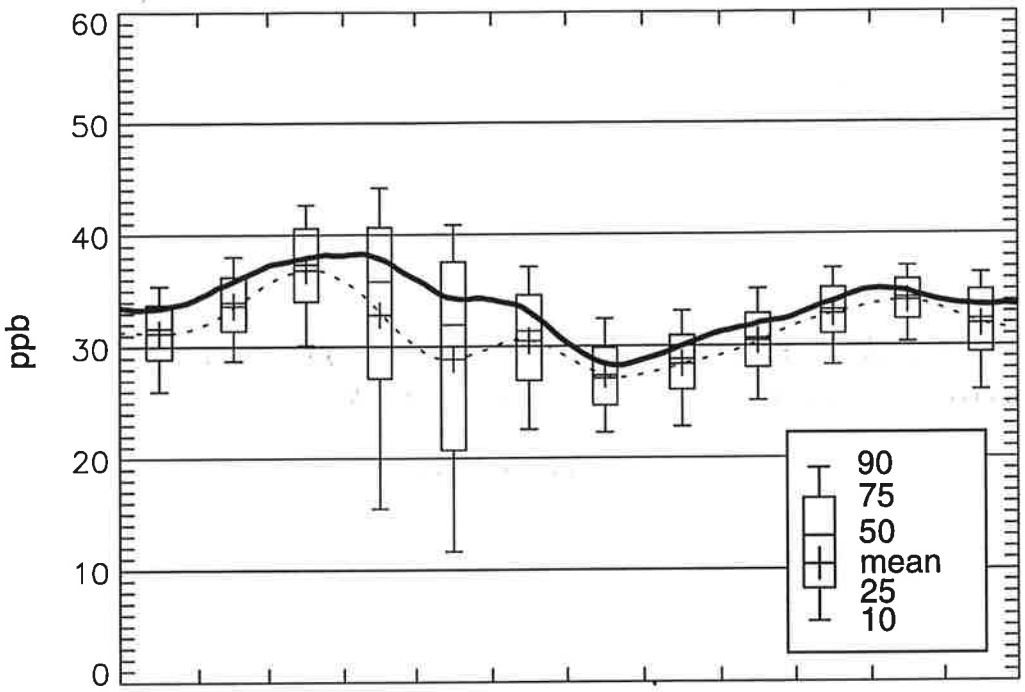

*Figure 9. Annual cycle of background ozone at Ny-Ålesund between 1989 and 1994 [*Solberg et al., *1997].*

3.4.2 NO_x

Accurate measurements of NO and NO_2 in the Arctic during winter and spring were not made until 1994 in a collaboration between the Geophysical Institute, University of Alaska, and NILU [*Beine et al.*, 1996]. These measurements, concurrently taken with measurements of ozone, PAN, and $J(NO_2)$ provided insight into the Arctic spring-time photochemistry [*Beine et al.*, 1997]. During the Arctic winter-spring transition, light and temperatures change dramatically the concentration of many NO_y species, which accumulate in the Arctic during winter and are thermally or photochemically processed to yield NO_x, which in turn can produce ozone. This process can help explain the ozone maximum that is seen in many continental northern latitudes sites during spring [*Oltmans and Levy*, 1994].

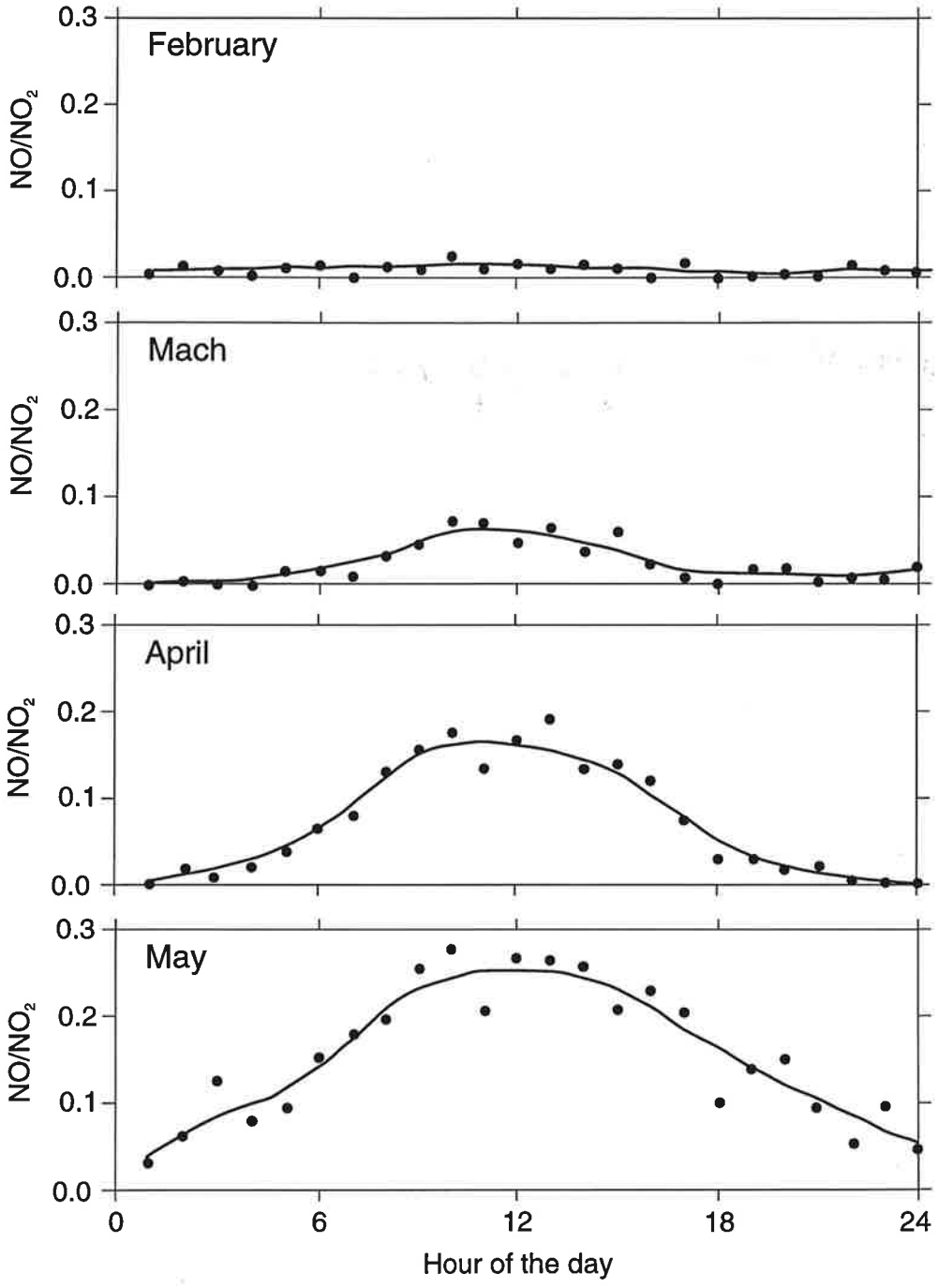

*Figure 10. The NO/NO_2 ratio at Ny-Ålesund measured during spring 1994 [*Beine et al., *1997].*

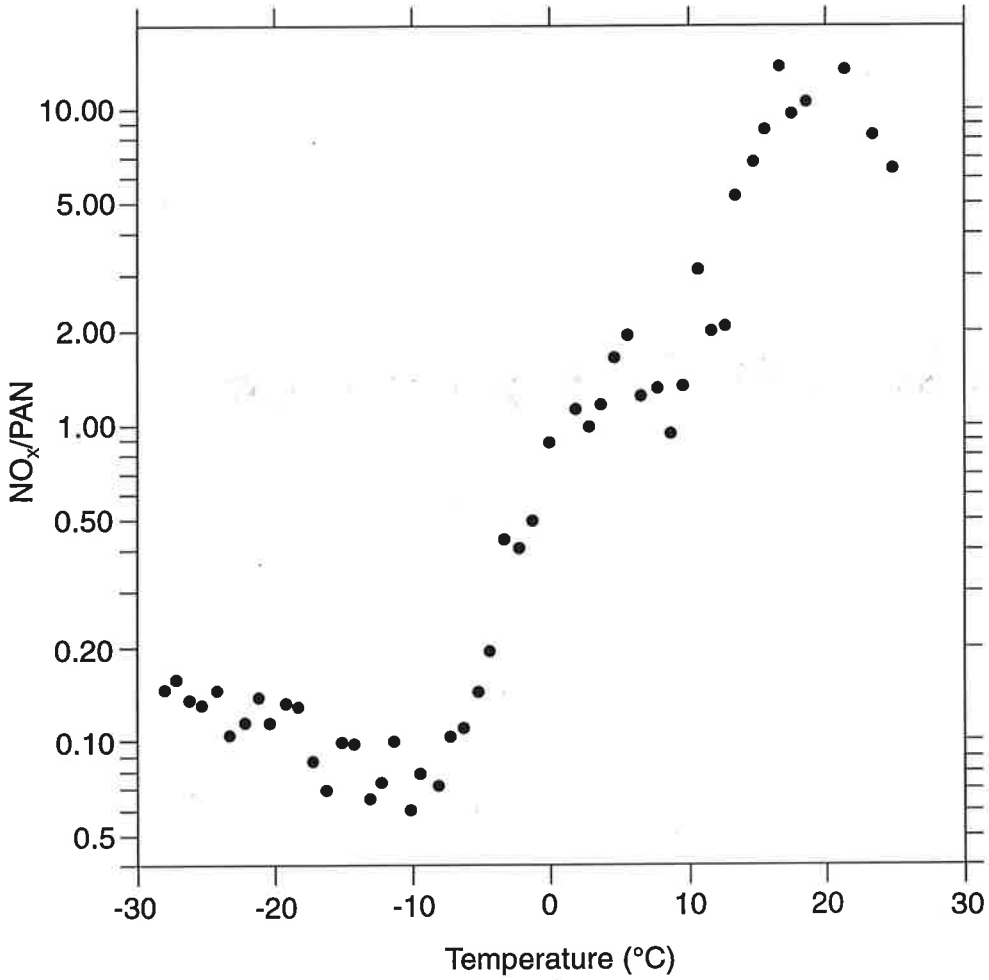

*Figure 11. The ratio of NO_x/PAN versus temperature. This figure shows combined measured values form Zeppelin (spring 1994) and Poker Flat, Alaska (spring 1995). The points show the mean NOx/PAN ratio for each °C [*Beine et al., *1997].*

3.4.3 NO_y and PAN

PAN was identified as the major NO_y component during spring, reaching mixing ratios as high as 800 pptv during individual episodes [*Solberg et al.*, 1997]. The annual PAN cycle reaches a maximum during spring. PAN is mostly transported into the Arctic over long distances, model results show however, that local photochemistry may produce up to 1 - 2 pptv/h PAN during April - May, arising mainly from acetaldehyde.

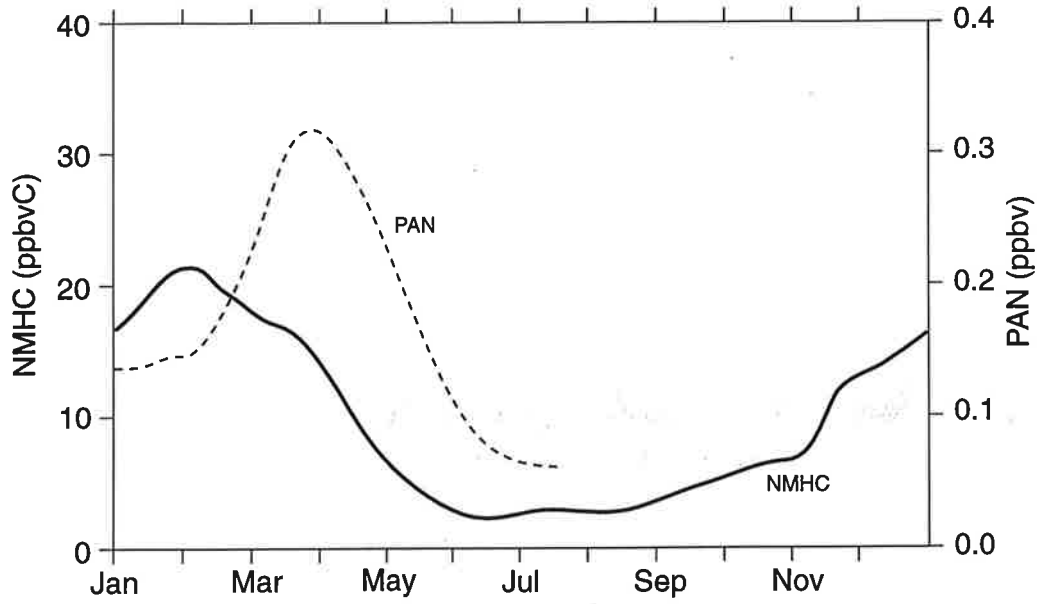

Figure 12. The seasonal cycle of PAN and NMHCs at Ny-Ålesund [Solberg et al., *1997].*

3.4.4 Tropospheric ozone depletion

Based of NILU's ozone, VOC, sulfate, and meteorology data *Solberg et al.* [1996b] analyzed ozone depletion events in the atmospheric boundary layer since 1989 on a climatological basis. The first measurements of NO_x during ozone depletion events taken with a high sensitivity instrument during the spring of 1994 were discussed by *Beine et al.* [1996].

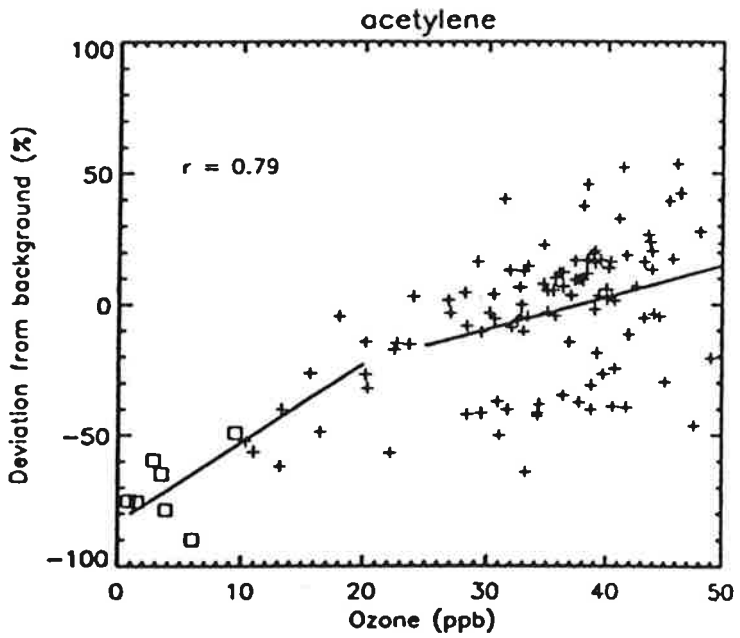

Figure 13. The relative deviation of acetylene from the background mixing ratio (in %) as a function of ozone mixing ratio during ozone depletion events in the Arctic marine boundary layer [Solberg et al., *1996b].*

These studies showed that tropospheric ozone depletion at Ny-Ålesund occurred within a cold boundary layer up to about one km height, which was capped by a thermally stable layer. The airflow arrived from north-westerly directions. Several individual hydrocarbons were reduced concurrently with ozone and it was shown that the depletion of these hydrocarbons must have occurred via reaction with halogen radicals rather than with OH. NO_x during the ozone depletion events was low.

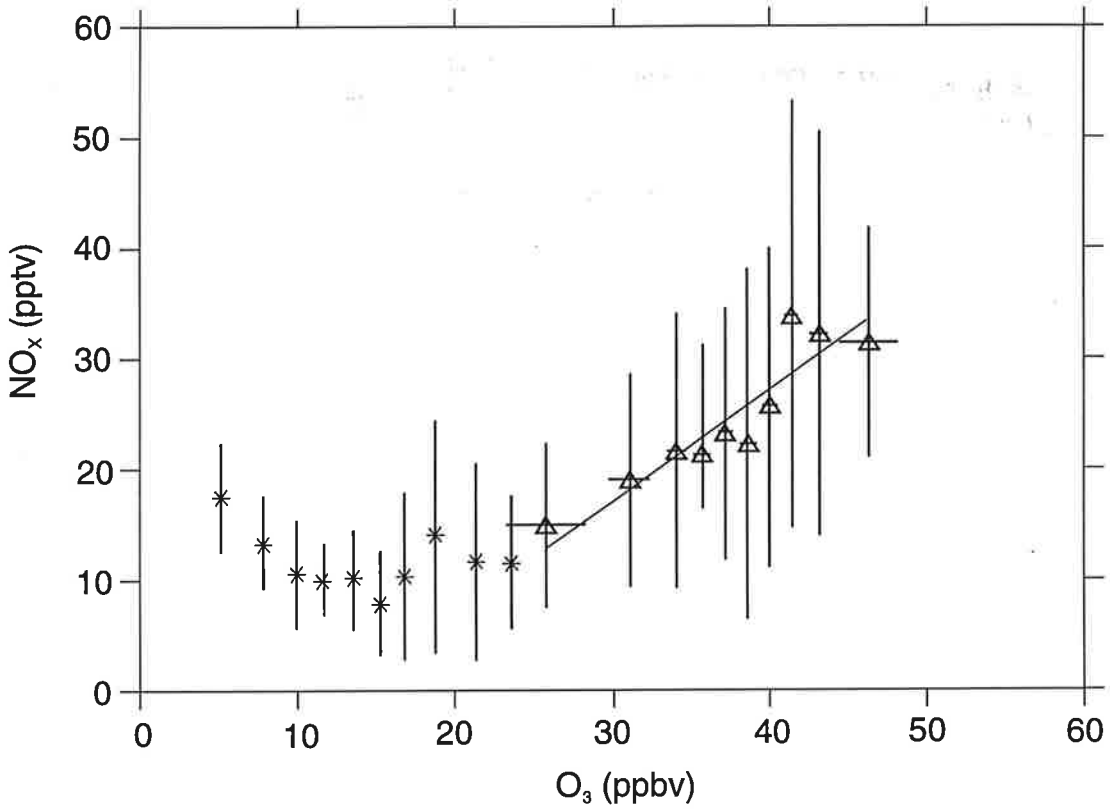

*Figure 14. NO_x during tropospheric ozone depletion events at Ny-Ålesund during spring 1994. Stars show ozone depletion, triangles show all other data [*Beine et al., *1996].*

3.4.5 VOC: NMHCs and Carbonyls

Within EMEP VOC are measured regularly at the Zeppelin station [e.g. *Solberg et al.*, 1996a]. It was shown that hydrocarbons originating from natural gas become well mixed in the Arctic, while fuel evaporation and combustion products show a latitudinal gradient, with lower concentrations at Zeppelin than further south. The sum of C_2 - C_5 NMHC shows an annual cycle with a summer minimum and a winter maximum of about 4 and 20 ppbC by volume, respectively.

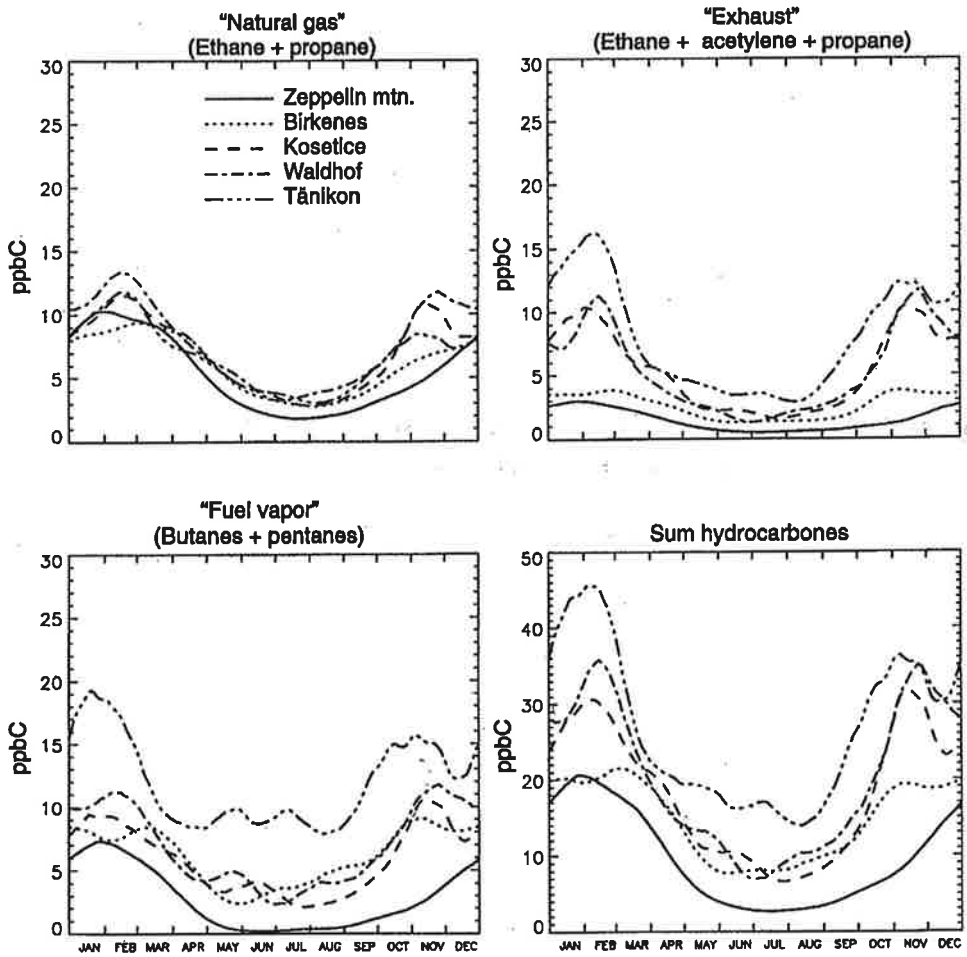

*Figure 15. Average seasonal cycle of the sums of different groups of hydrocarbons for several measuring sites [*Solberg et al., *1996a].*

Oxidized hydrocarbons contribute about 10 % to the sum of VOC at Zeppelin in winter. This fraction rises to 50% during the summer, consistent with the oxidation of NMHCs. Ethane and propane are the most abundant NMHCs, consistent with their OH reactivity [*Hov et al.*, 1989].

The annual cycle of hydrocarbons in the Arctic was already established following measurements in 1982/83 [*Hov et al.*, 1984].

3.5 CO_2

The MISU CO_2 data record from the Zeppelin station is of high quality and of sufficient length to investigate any trend. The overall growth rate of CO_2 varies between 0 and 4 ppmv/year. The record shows a clear annual cycle with a winter maximum and summer minimum [*Holmén et al.*, 1995]. During the entire year significant day-to-day variability exists. During winter episodes of high CO_2 mixing ratios are seen due to long range transport of pollutants from eastern Europe [*Lejenäs and Holmén*, 1996]. During the summer months, however, episodes of lower CO_2 mixing ratios are observed. During April to June these events result from intense CO_2 uptake by the waters of the North Atlantic ocean [*Engardt et al.*, 1996].

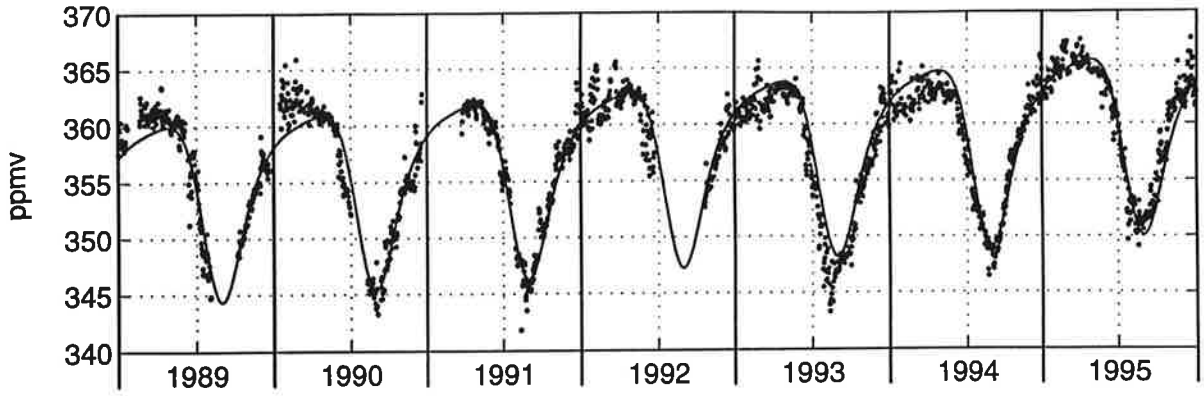

*Figure 16. Daily mean CO_2 mixing ratio [ppmv] measured at Ny-Ålesund 1989 through 1995. A linearly increasing harmonic function fitted through the entire data set is also shown [*Engardt and Holmén, *1997].*

3.6 Greenhouse gases

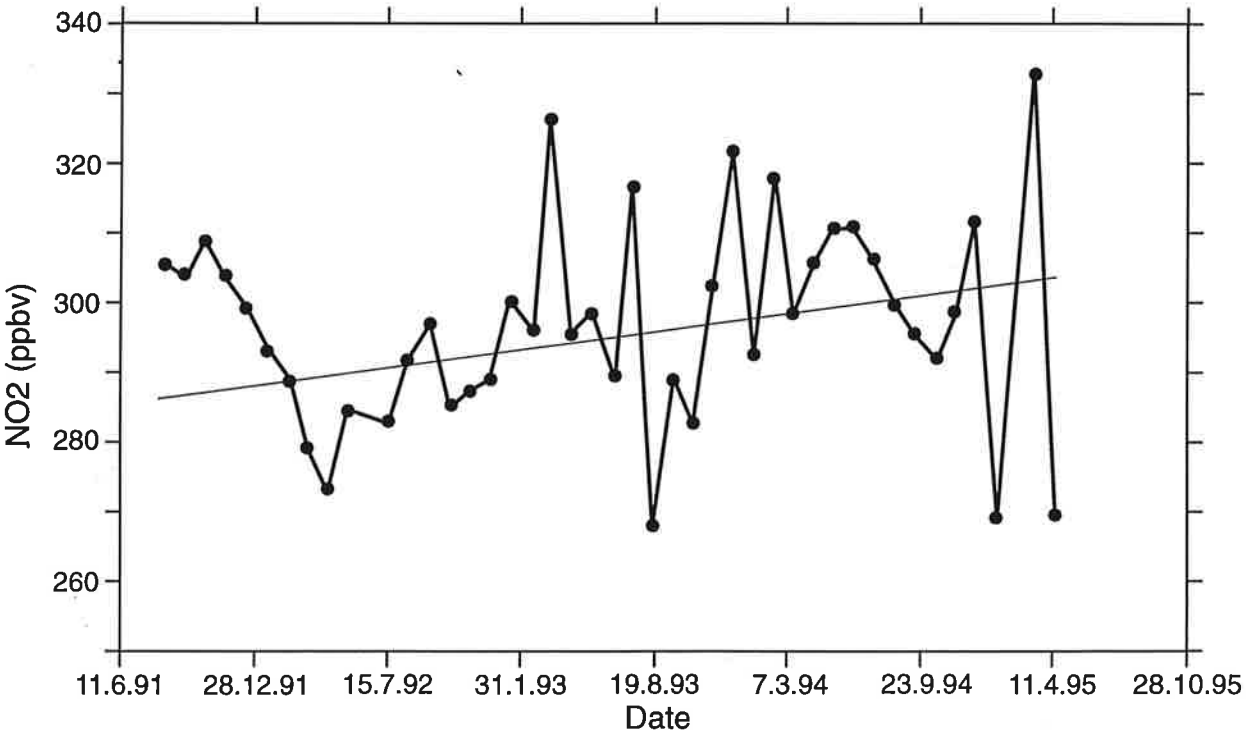

*Figure 17. Timeseries of N_2O at Zeppelin [Hermansen, pers. communication]. The average between 1991 and 1995 is 296.9 ppbv (± 5%). The trend of +2.7 ppbv/year is calculated using Theil's non-parametric regression [*Miller and Miller, *1984].*

NILU has measured CFCs at Zeppelin since 1990. Compared with measurements made in 1982 these species showed an average annual trend between 1982 and

1990 of 10.7 pptv/yr. The trend in the nineties is smaller, 7.3 pptv/yr. [*Hermansen and Solberg*, 1994], which reflects the success of curbing the emissions of these species.

Since 1991 N_2O has been measured at Zeppelin. Although the data show some scatter, a trend of +2.7 ppbv/year is visible.

3.7 POPs

Persistent organic pollutants (POP) have been measured at various times during the last 15 years at Ny-Ålesund. Identified species include pesticides, polychlorinated biphenyls, polyaromatic biphenyls, and, since 1995 toxaphens and dioxins [*Oehme et al.*, 1995a; 1995b; 1996a; 1996b; *Oehme*, 1991a; b]. POPs are brought into the Arctic via long range transport, due to their long life time volatile organochlorines show similar mixing ratios in the Arctic as in the mid-latitudes where the sources are found. Due to the physical properties of POPs they are enriched in the Arctic, with significant consequences for Arctic biota such as seals and polar bears.

3.8 Transport

The meteorological conditions for transport of air into the Arctic have been established since the middle of the 1980's [*Iversen*, 1989a; b; 1993]. Air flow in the Arctic follows to a large extent isentropic trajectories. The transport of air from Eurasian sources into the Arctic takes place in blocking situations [*Iversen and Joranger*, 1985], where the normal eastward propagation of cyclones stops and a transport of air takes place from mid-latitudes towards the pole. A number of meteorological scenarios where air is transported into the Arctic from Europe all the way to the Pacific is described in *Raatz and Shaw* [1984]. These authors identified anticyclones as playing a dominant role in air mass transport. This transport begins in areas where air is subsiding from upper levels (high pressure) and flows outwards to converge in frontal regions near cyclones (low pressure).

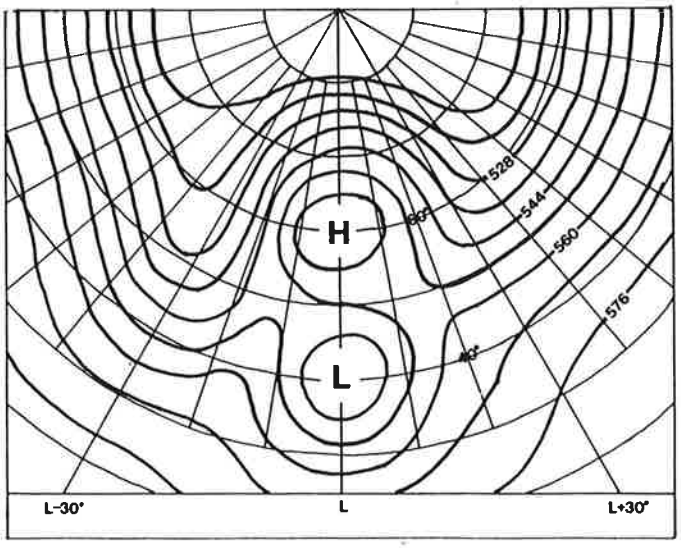

Figure 18. A prototype dipole blocking centered at longitude L as seen in the geopotential height field of 500 hPa in spring [Iversen, 1989a]..

Simultaneous measurements of Arctic haze events at Ny-Ålesund and two sites in Alaska showed that polluted Arctic air can be trapped in the region. Secondary aerosols, which deposit only slowly due to their small size, can be carried with Arctic air masses over the region [*Djupström et al.*, 1993].

3.9 Stratospheric ozone

Since 1990 a UV-visible spectrometer (SAOZ) measures the total column ozone and NO_2 routinely. Figure 20 shows the daily ozone measurements in 1994 and 1995 and NO_2 in 1995 in Ny-Ålesund. Readings cannot be made during the summer because of the high latitude of the station [*Høiskar et al.*, 1996; 1997].

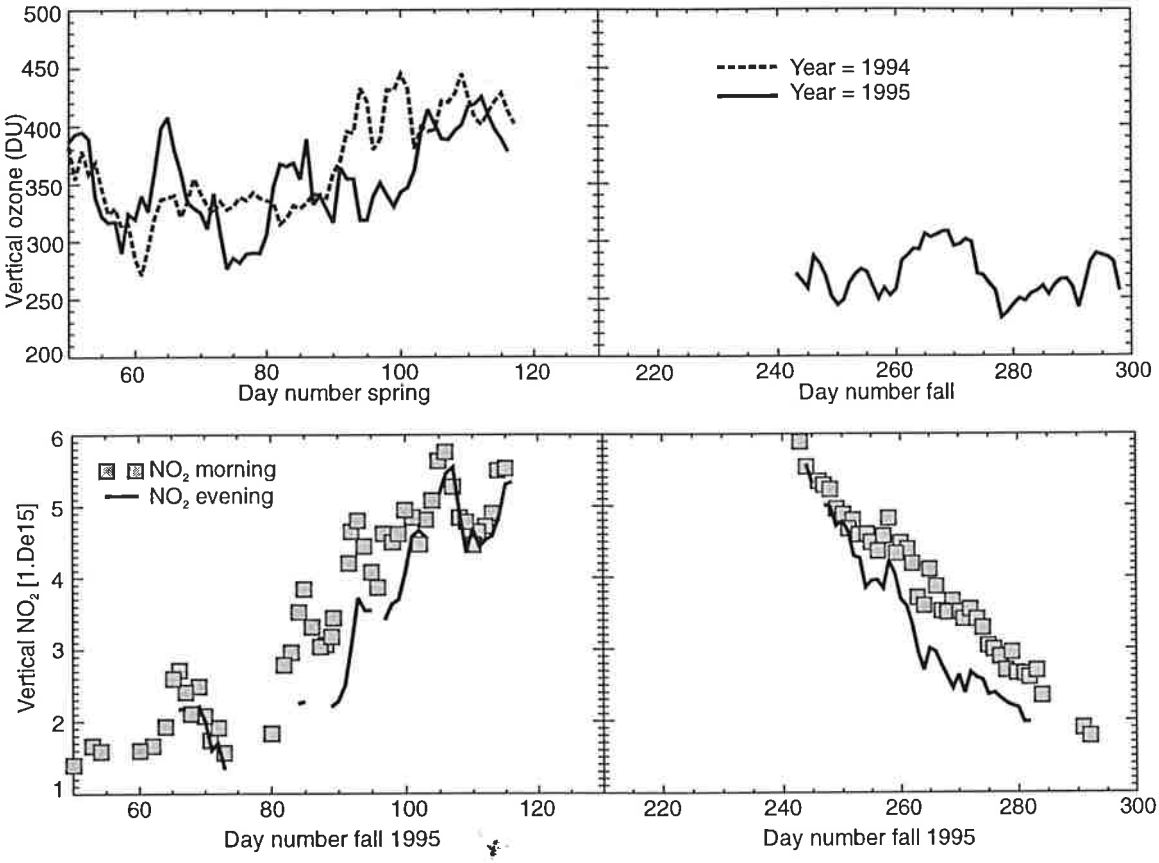

Figure 19. Total ozone and NO_2 measured at Ny-Ålesund during 1994 and 1995 [Høiskar et al., 1996].

Total ozone is also measured at various locations in Norway, including Ny-Ålesund, with multi-channel UV-filter instruments [*Dahlback et al.*, 1996].

3.10 Models

3.10.1 Tropospheric modeling:

Modeling efforts over the previous years have proceeded along two different paths. During the ARCTOC campaign a chemical box model was developed to interpret measurements of halogen species and low ozone events made during the campaigns in 1995 and 1996 [*Flatøy et al.*, 1996]. This particular model includes

gas phase as well as some heterogeneous chemistry. The work is in progress, so far only the sensitivity studies have been published.

A second strand is the work with transport models on a larger scale. A lagrangian numerical model was applied recently to simulate VOC concentrations and compare them to measurements taken at a number of sites, including Zeppelin [*Hov et al.*, 1997].

3.10.2 Stratospheric modeling

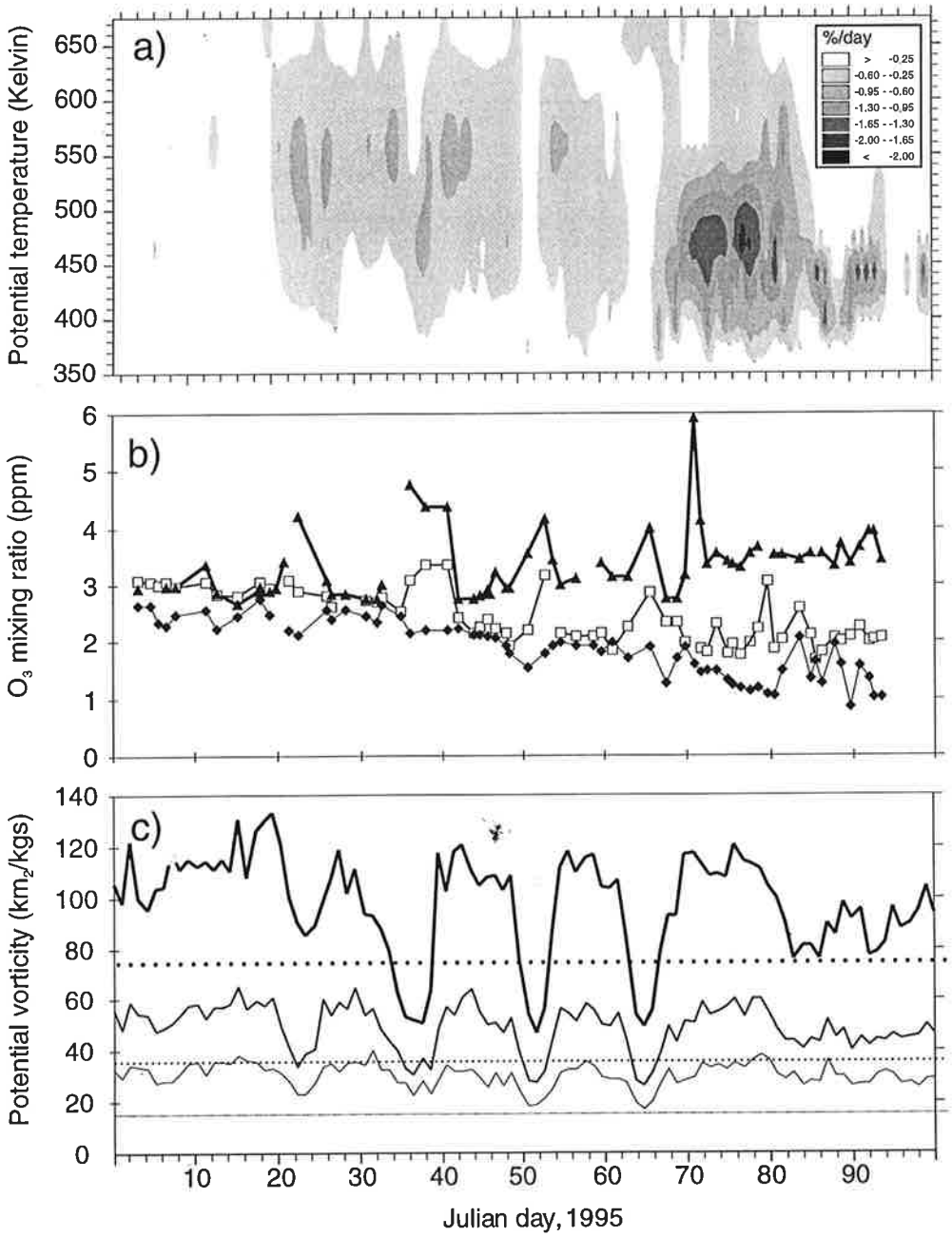

*Figure 20. Ozone loss in the stratosphere above Ny-Ålesund 1995 [*Fløisand et al., *1995].*

Stratospheric ozone is influenced by both dynamical and chemical processes, and this is reflected in stratospheric models. Ozone sonde data from Ny-Ålesund have been compared with chemical trajectory model calculations done at NILU [*Fløisand et al.*, 1995]. Figure 21 shows various factors that are connected to stratospheric ozone depletion; low potential temperatures and high potential vorticities.

Heterogeneous reactions of Cl species on Polar Stratospheric Cloud (PSC) surfaces have been studied [*De Haan et al.*, 1997] in a stratospheric chemical transport model.

3.11 Radioactivity

Since 1986 Ny-Ålesund is part of an alert-network to measure radioactivity in Norway [*Berg*, 1996].

3.12 Data collection and dissemination

NILU routinely monitors air and precipitation chemistry (e.g. O_3, nitrate, SO_2, SO_4^{2-}) at approximately 40 locations in Norway. The program is financed by various monitoring programs and NILU. Results are reported annually in data reports, which are available usually by June of the following year. Prior to these reports the data are usually not accessible. However, the preliminary data can be used upon request for specific projects, as long as it is being stated that the data are preliminary and owned by the Governmental Programme for Pollution Monitoring, i.e. SFT and NILU.

A reference to the data source is: Tørseth, K. Overvåkning av langtransportert forurenset luft og nebør. Atmosfærisk tilførsel, 1995. Kjeller (Statlig program for forurensningsovervåkning. Rapport 663/96), *NILU*, OR 38/96, **1996**.

Additionally, many data are available in various formats in a number of NILU data bases, one of them being NADIR. For example experimental data from EASOE and SESAME, as well ECWMF data on a 2.5° × 2.5° grid are available. For further information on NADIR see for example *Braathen* [1996], or contact nadirteam@nilu.no.

Furthermore, timeseries of the tropospheric mixing ratios of VOCs (carbonyl compounds and NMHC), CFCs, CH_4, N_2O, O_3, PAN, and meteorology are available on our database. For further information on data or for specific data requests please contact NILU.

4. The role of Ny-Ålesund in environmental policies

4.1 Conventions

The regional air pollution problems in Europe are today handled by the Convention on Long-range Transboundary Air Pollution under the UN ECE. The convention was signed in 1979 and most countries in Europe, the European Community, Canada and US have signed this convention.

There are four protocols under the LRTAP Convention; EMEP, Sulfur, Nitrogen Oxides, and Volatile organic compounds. Research in Ny-Ålesund is important for all the protocols.

The global air pollution problems, mainly those linked to the thinning of the stratospheric ozone layer and the increasing concentrations of greenhouse gases and aerosols, concern all countries in the world. The global environmental problems are handled by the UN and its sub-organizations UNEP and WMO.

In the *Vienna Convention* a global work plan for the protection of the ozone layer was adopted, with obligations specified and revised in proceeding protocols.

Ny-Ålesund is one of the main locations in the Arctic where the species affected by the protocols are monitored and researched.

4.2 Atmospheric Research in Ny-Ålesund [NP, 1996]

Four nations now have permanent facilities for atmospheric research in Ny-Ålesund; Norway, Germany, Italy, and Japan. These facilities were involved in a large number of projects during 1996:

NILU
- Measuring and modeling of mercury deposition in Arctic areas.
- Measurement of radioactivity in Norway
- Ozone soundings for the detection of ozone change
- European stratospheric monitoring stations in the Arctic II.
- Monitoring of pollutants in air on Svalbard.
- Aerosol and snowsampling during ARCTOC II
- Boundary layer measurements of halogen oxides, ozone, sulfur dioxide, nitrogen dioxide and radon.
- Monitoring of VOC at Zeppelinfjellet.
- Arctic tropospheric ozone chemistry.
- Stratospheric climatology using UV-visible spectroscopy.
- Monitoring program for long range transported polluted air and precipitation
- Arctic monitoring station

Alfred Wegener Institut, Germany (AWI)
- Balloon borne aerosol soundings and LIDAR measurements
- Tropospheric ozone LIDAR measurements
- Determination of heavy metals in aerosols and deposition samples
- Monitoring of ultraviolet solar radiation due to the ozone depletion
- Baseline surface radiation network, Part C: upper air sounding.
- High altitude balloon-borne ozone soundings
- Vertical ozone distribution in the Arctic atmosphere.
- Baseline surface radiation network, Part A: radiation balance.
- Baseline surface radiation network, Part B: synoptic observations.
- Measurements of the spectral aerosol optical depth with sunphotometer

- Influence of chemical and dynamical processes on tropospheric ozone variations in the Arctic.
- Atmospheric trace gas observations by emission spectroscopy measurements
- PSC occurrence and stratospheric temperatures.
- Stratospheric aerosol lidar measurements within NDSC.
- Stratospheric ozone loss determination.
- Measurements of the spectral aerosol optical depth in the Arctic atmosphere during polar night conditions.
- Atmospheric trace gas observations by the new FT-IR spectrometer.

The Norwegian Meteorological Institute (DNMI)
- Automatic weather stations
- Climatological scenarios in two basins on Svalbard

Institute for Environmental Physics, University of Heidelberg, Germany
- Aerosols and speciation of bromine and nitrogen compounds during ARCTOC II.
- Airborne measurements of boundary layer ozone and vertical profiles of tropospheric aerosols.
- Arctic tropospheric ozone chemistry (ARCTOC)
- DOAS measurements

Max-Planck-Institute for Chemistry, Germany (MPI)
- ARCTOC, DOAS and RO_x measurements.

Stockholm University, Sweden (MISU)
- Monitoring of CO_2 and aerosols on Zeppelinfjellet, Ny-Ålesund.

Nagoya University, Japan and AWI
- Balloon-borne stratospheric aerosol measurements
- Study of the polar cusp/cap dynamics based upon riometer, aurora, magnetic field, and ULF-VLF wave observations
- Tundra soil, vegetation, atmosphere climate interaction

National Institute of Polar Research, Japan (NIPR)
- Monitoring clouds, precipitation and atmospheric minor constituents.

Norwegian Polar Institute (NP)
- UV-monitoring in Ny-Ålesund.
- Long-term monitoring of the surface radiation budget in Ny-Ålesund.

University of Bremen, Germany
- NDSC and ESMOS/Arctic

University of California, Irvine, USA
- In-situ measurements of BrO in the boundary layer

University of Gent, Belgium
- Chemistry of size-fractionated atmospheric aerosols at the Zeppelinfjellet station, Ny-Ålesund.

University of Oslo
- Total ozone measurements by Dobson spectrophotometer.

4.3 International organizations and research agenda

Ny-Ålesund is an important background research location for a number of multi-national and international research programs. This research is coordinated and supported by a number of international organizations.

- AMAP (Arctic Monitoring and Assessment Programme)

- NySMAC (The Ny-Ålesund Science Managers Committee)

- IGBP (International Geosphere-Biosphere Programme)

  International Global Atmospheric Chemistry project (IGAC)
  NARE (North Atlantic Regional Experiment)
  PASC (Polar Atmospheric and Snow Chemistry)
  GLOCHEM (Global Atmospheric Chemistry Survey)
  MAC (Multiphase Atmospheric Chemistry)

  Global Change and Terrestrial Ecosystems (GCTE)

- UN (United Nations) Economic Commission for Europe (ECE)
  European Monitoring and Evaluation Programme for Long-Range Transboundary Air Pollution in Europe (EMEP)

- CEC (Commission of the European Communities)
  European Arctic Stratospheric Ozone Experiment (EASOE)
  Second European Stratospheric Arctic and Mid-Latitude Experiment (SESAME)
  Ozone Soundings as a tool for Detecting Ozone Changes (OSDOC)
  Arctic Tropospheric Ozone Chemistry (ARCTOC)

- WMO (World Meteorological Organization)

  GAW (Global Atmospheric Watch) is a program of the WMO.
  WMO World Data Centre for Greenhouse Gases (WDCGG)
  WMO World Ozone Data Centre (WODC)
  NDSC (Network for Detection of Stratospheric Change)

WCRP (World Climate Research Programme), is jointly sponsored by the WMO and the International Council of Scientific Unions.

ACSYS (Arctic Climate System Study)

SPARC (Stratospheric Processes and Their Role in Climate)

WMO Global Ozone Research and Monitoring Project

- European Science Foundation (ESF)

- Eureka

EUROTRAC (European Experiment on the Transport and Transformation of Environmentally Relevant Trace Constituents in the Troposphere over Europe)

TOR (Tropospheric ozone research)

GCE (Ground-Based Cloud Experiment)

EUROTRAC II

5. Outlook

This report shows how Arctic research at Ny-Ålesund has stimulated scientific questions and contributed to our understanding of the atmosphere on both the regional and global scale. NILU's work in Ny-Ålesund and specifically at the Zeppelin station on the many aspects of atmospheric chemistry is important with respect to the national and international research and environmental policy agenda.

Arctic research still poses a challenge scientifically and offers a number of surprises. So was for example the discovery of boundary layer ozone depletion completely unexpected. Even after a number of international campaigns the sources and mechanisms of this phenomenon are not fully understood, nor is it clear which consequences the ozone depletion might have for the ozone levels over Europe and the rest of the Northern Hemisphere.

There has been significant progress in the understanding of the chemistry of the Arctic atmosphere since the start of Arctic research in the late 1970s. The Arctic haze phenomena has been thoroughly documented to occur in particular in spring every year and connected to a higher likelihood of meridional transport from mid latitude pollution sources to the Arctic in spring than at other times of the year. Linked to the Arctic haze phenomena are higher concentrations of other pollutants, as e.g. volatile organic compounds and oxides of nitrogen in the spring, which may contribute to the springtime ozone maximum at remote locations in the Northern Hemisphere.

At the same time it has been seen how the polar stratospheric ozone depletion which first was seen over Antarctica during spring there, also takes place over the Arctic during spring, although to a lesser extent both in terms of duration in time,

spatial extent and severity in absolute terms. The Arctic ozone depletion is also clearly linked to occurrences of a stable vortex in the polar stratosphere, where polar stratospheric clouds are formed and halogens transformed from chemically inactive species to active species which cause significant ozone depletion. Continued research in Ny-Ålesund is essential to follow the development in the stratospheric ozone layer and the level of UV radiation. Full compliance with the international agreements is required if the depletion of stratospheric ozone is to be contained, and it is essential to continue and develop the monitoring capabilities of ozone and halogens to follow the situation. Ny-Ålesund is an essential site in this context.

Ny-Ålesund is a very remote, but yet accessible site and provides the boundary conditions for a very long range of environmental problems where emissions linked with population and industrialization are the causes. Climate change, ozone layer depletion, the global distribution of semivolatile organic compounds, continental scale problems linked to acidification, eutrophication and photochemical oxidants, the investigation of all these issues can be supported by the research in Ny-Ålesund. NILU is willing to play a major role in this activity.

The Zeppelin station is open for international collaboration. If interested, please contact Dr. F. Stordal. You can also contact Dr. H. Beine for tropospheric research, or Dr. G. O. Braathen for stratospheric research.

Acknowledgements

I am grateful for the help of many people - without it this report would not have been possible.

In particular I would like to thank Frode Stordal and Øystein Hov for discussions and valuable comments on the manuscript, and Arne Semb and Jan Erik Hanssen for discussions on the history of NILU's research in the high Arctic.

Results of their research at Ny-Ålesund were also contributed by Arne Dahlback, Britt Ann Kåstad Høiskar, Geir Braathen, Inga Fløisand, Jozef Pacyna, Kjetil Tørseth, Norbert Schmidbauer, Ove Hermansen, Sverre Solberg, and Terje Krognes. I am thankful for this help.

I'd also like to thank Elisabeth Hanssen, Finn Bjørklid and Kirsten Gram for their help in completing the final manuscript and all the figures.

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6.1 Special issues of journals and proceedings of conferences

1st workshop

Sources and significances of natural and man-made aerosols in the Arctic. Report on a workshop. Lillestrøm (1980) (*NILU TR 9/80*).

2nd workshop
Arctic Air Chemistry, (1981) Proceedings of the second symposium 6 - 8 May 1980, Ed.: K. A. Rahn. *Atmos. Environ.*, *15(8)*, 1345-1516,.

3rd workshop
Third symposium on Arctic air chemistry, (1984) Eds.: K. A. Rahn, L. Barrie. Ontario, Canada *Atmos. Environ. Service*, 218 pages,.

AGASP I
Arctic Haze, Ed.: R. C. Schnell. (1984) *Geophys. Res. Lett.*, *11(5)*, 359 - 472,.

4th workshop
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AGASP II
Arctic Haze, (1989) Arctic Gas and Aerosol Sampling Program II, Ed.: D. L. Albritton. *J. Atmos. Chem.*, *9(1-3)*, 1-397,.

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REPORT SERIES SCIENTIFIC REPORT	REPORT NO. OR 20/97	ISBN 82-425-0867-4 ISSN 0807-7207	
DATE 4 April 1997	SIGN. Øystein Hov	NO. OF PAGES 49	PRICE NOK 75.-

TITLE NILU's Atmospheric Research at Ny-Ålesund	PROJECT LEADER Terje Krognes
	NILU PROJECT NO. E-96043
AUTHOR(S) Harald J. Beine	CLASSIFICATION * A
	CONTRACT REF.

REPORT PREPARED FOR:

NILU

ABSTRACT

At Ny-Ålesund NILU is involved in many scientific projects that focus on global and regional atmospheric chemistry such as stratospheric ozone depletion, the greenhouse effect (from gases and aerosols), tropospheric ozone (*in-situ* production and depletion in the boundary layer), or the transport of pollutants from mid-latitudes (Arctic haze). This report presents a brief historical overview of NILU's research activities at Ny-Ålesund since 1973. This report, furthermore, shows and discusses the scientific results from the first years of operation of the Zeppelin station since 1989, and presents ongoing projects.

NORWEGIAN TITLE

KEYWORDS		

ABSTRACT (in Norwegian)

* *Classification*

- *A Unclassified (can be ordered from NILU)*
- *B Restricted distribution*
- *C Classified (not to be distributed)*