Air Pollution in Eastern Lapland: Challenge for an Environmental Measurement Station

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The Värriö environmental measurement station has been designed and constructed during 1991 and 1992. The measurement system consists of measurement units for gases (sulphur dioxide, ozone, carbon dioxide), particles, photosynthesis and irradiation. A meteorological station is also included. The preliminary measurement period was started on August, 1991. During the first year (1991–1992) some parts of the system were redeveloped and rebuilt. Full, continuous measurements started in August 1992. The system has been working quite reliably, with good accuracy. The preliminary results show that pollution episodes are observed when the wind direction is from Monchegorsk or Nikel, the main emission sources in Kola Peninsula.

Keywords automation, measurement, systems, photosynthesis, aerosols, SO_2, O_3, weather.
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1 Introduction

Lapland was considered as an remote and unpolluted area until the mid-eighties when political changes in the Soviet Union revealed new information about emissions from the Kola Peninsula, especially near the cities Nikel and Monchegorsk. It was finally realised that SO_2 emissions from both Nikel and Monchegorsk are of the same magnitude as the total emission from the whole of Finland (ca. 250 000 tn/year). The lack of information about air quality in the nearby regions of Finland, especially from unpopulated eastern Lapland, was widely acknowledged.

The air in eastern Lapland is clean when the wind is blowing from the North Atlantic over very sparsely populated areas. Also the emissions from the urban areas, from southeast and southwest, seem to have a minor effect on the air quality compared with the effect of the Kola Peninsula, since the southern sources are typically over 700 km away. Thus the air quality of eastern Lapland is characterized by very clean periods, which are broken by emissions from Nikel and Monchegorsk.

Most of the air quality monitoring in Northern Finland is done by the Finnish Meteorological Institute. One station working within the EMEP program (Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe) is located at Oulanka where sampling is carried out using filter packs. Also total deposited matter is collected. The gases monitored are NO_2 and ozone. There are also stations at Värriö where the sampling is carried out using filter packs and also total deposited matter is observed, and at Pesosjärvi and Vuoskojärvi where the total deposited matter is collected. Hillamo has also measured inorganic ion aerosol size distributions at Sevettijärvi (Hillamo et al. (1993)). There is one Russian-Finnish EMEP station at Jäniskoski (Tuovinen et al. (1993)). At the Norwegian stations at Jergul, Tustervatn, Ny-Ålesund and Svanvik the methods of measurements are quite like those of the Finnish EMEP stations (Pedersen et al. (1990), Schaug et al. (1991)). Although there are relatively large number of measurement stations in Northern Finland there has been a need of a station of a somewhat different kind, where the air quality and meteorology were measured more completely together with photosynthesis measurements.

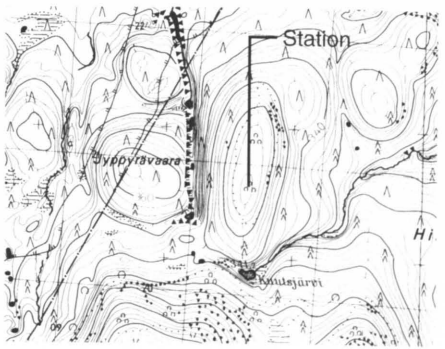

Fig. 1. Map of the station area.

A decision was made to construct a new environmental measuring station, consisting of measurement units for major pollutant gaseous species, aerosol particles, photosynthesis and irradiation, near the Värriö Subarctic Research Station in 1991. The measuring station is located in northern Finland, near to the Russian border at the height of four hundred meters from the sea level. The station area belongs to the Värriö nature park. Fig. 1 shows the surroundings of the station. One of the largest fjelds (rocky, barren plateaus) of the range of Värriö fjelds is located two kilometers south from the station. This range continues also to the north. In the east there is a plain covered by pine forest, in the west there are some isolated hills and a swamp area.

The aim of the station is to provide information of the air quality in eastern Lapland, to measure the response of trees to emissions, and to provide information for atmospheric chemistry and deposition in subarctic conditions. The location of the Värriö Subarctic Research Station is ideal for studies of pollution episodes coming from east and north-east direction. Monchegorsk is only 140 km east and Nikel some 200 km north of Värriö. Fig. 2 describes the largest sulphur dioxide sources in Lapland.

The main aim of this paper is present the current capacity and functioning of the Värriö environmental measurement station. In the present paper we also give outlines of future research possibilities with some examples.

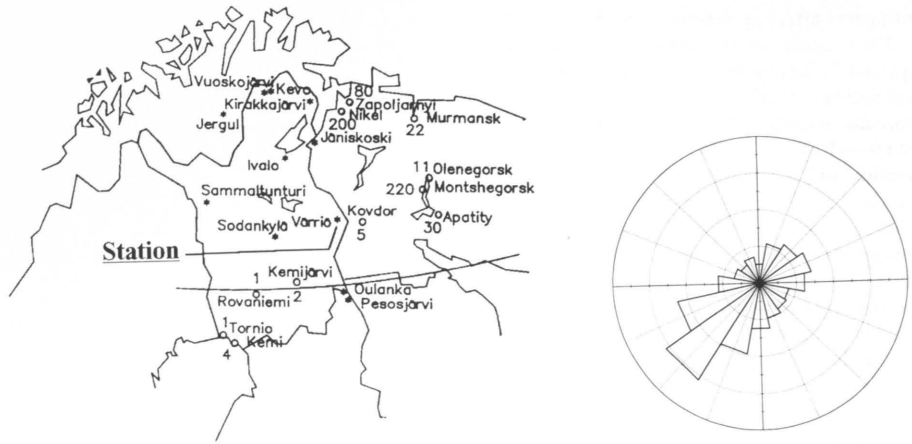

Fig. 2. Location of the Värriö environmental measurement station. SO_2 sources expressed in 1000 tn/year (Laurila 1992).

2 The Requirements for the Measurements

The sulphur dioxide emissions from Nikel and Monchegorsk are the apparent reason for damage to natural ecosystems close to them. The SO_2 emissions affect directly vegetation and also acidify soil. During transport a fraction of sulphur dioxide is transformed to sulphuric acid vapour, which together with water vapour forms new aerosol particles. Sulphuric acid vapour and aerosol particles, which contain sulphuric acid in the liquid phase, are important air quality characteristics (Hillamo et al. 1993).

The role of ozone as a potential agent causing forest damage is unclear (Sutinen 1992). The ozone concentrations in high latitudes have been observed to be high (Laurila and Lättilä 1993). During the winter time the mean values are close to 100 $\mu g/m^3$ and summer time somewhat less. Ozone is an important radical in the air and is a good indicator for atmospheric chemistry (see e.g. Seinfeld 1986; Finlayson-Pitts and Pitts 1986).

The deposition of gases and aerosol particles into a forest canopy gives rise to a gradient of concentration inside the canopy and in the free air above it. Thus measurements of vertical concentration profiles give an indication of the extent of deposition. However, for a quantitative interpretation of measurements a realistic model of canopy microclimate is needed. This problem is quite complicated since large changes in gradients of concentrations can occur over distances that are smaller than the typical turbulent eddy sizes.

The effects of air pollutants on forest growth are still unclear in the Värriö region. Since photosynthesis is the most fundamental metabolic process, it is selected as an indicator of toxic effects. Carbon dioxide exchange and transpiration (water vapour exhange) are very regular during the active summer season. Photosynthetic rate is determined by irradiance and transpiration by the water vapour concentration difference between the stomatal cavity and the ambient air. Irradiation and needle amount measurements can provide estimates of consumed carbon dioxide (CO_2 deposition). Measurements of transpiration rate can be utilized in estimations

of factors affecting gaseous deposition.

The weather conditions form a necessary background for interpretation of results. Most chemical and biological processes depend on temperature and humidity. The presence of rain and wet surfaces has also an effect on air chemistry, deposition and leaf surface reactions. Wind determines the transport in the atmosphere and measurements of wind velocity are important for interpretation of experimental data on concentration profiles.

The main requirement for the measuring station is versatility. The station for measuring concentration for one atmospheric pollutant is generally not useful. For environmental measurements also the identification of biological response is significant. Thus we have decided to measure at Värriö different concentration profiles (sulphur dioxide, ozone, aerosols, carbon dioxide, water), photosynthesis, irradiance and meteorological characteristics.

3 Värriö Station

3.1 General

The measuring station was constructed during the year 1991 and tested during 1992. A rather homogenous pine stand on the top of Kotovaara hill (67°46'N, 29°35'E, 390 m above sea level) about 1 km north from Värriö Subarctic Research Station was selected as a measuring site. The mean height of the trees on the site is 6.7 meters, the mean diameter 8.2 cm and the leaf area 4 m^2 per unit area of soil. The alpine timber line is about 400 m above sea level in the surroundings of Värriö Subarctic Research Station. Thus the stand has a clear arctic character.

The main function of the Värriö Station is to offer experimental information on characteristics of weather, irradiation, gases and particles. Measurements are performed at four different levels; at this moment the levels are 15, 9, 6.6 and 2 meters from the ground level. Everything is under computer control, so the station runs automatically. The station is visited by the personel two or three times a week in winter. The more intensive measurements during summer require daily checking of the system to quarantee a sufficient quality of measurements. More detailed checking routines are performed about four times a year. The general schematics of the station are presented in Fig. 3. The system can be divided into four subsystems. These are weather station, gas and particle concentration measurements, photosynthesis measurements and irradiation measurements. Weather, gas and irradiation data are collected with Delta-T DL2-dataloggers. The particle detection system is controlled with a special subsystem inside the control program.

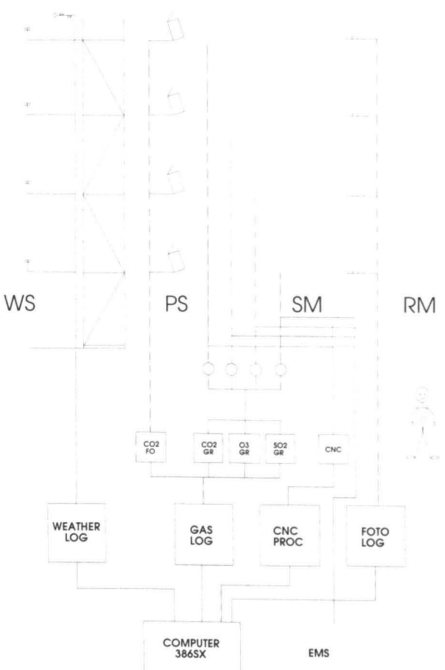

Fig. 3. General lay out of the station. WS – weather station, PS – photosynthesis mast, SM – gas and particle sampling mast, RM – irradiation measurement mast.

Table 1. Weather station.

Measured component	Sensor
Irradiation	
PAR	Li-Cor LI-190SB quantum sensor
Global	Minipyranometer
Reflected	Minipyranometer
Net	Phyto Net Pyrradiometer (mikrobalancemeter)
Rain	
Rainfall	Delta-T RG1 raingauge
Raindetection	Vaisala DPD 12 A preciptation sensor
Temperature and humidity	
Air temperature	Ventilated psychrometer, Pt-100 sensor
Humidity	Ventilated psychrometer, Pt-100 sensor
Ground temperature	Pt-100 sensor
Wind	
Wind speed	Vector A100R anemometer
Wind direction	Vector W200P windvane
Pressure	Druck DPI 260 barometer
Data handling	Delta-T DL 2 datalogger

Table 2. Gas and particle measurements.

Measured component	Sensor
CO_2	URAS 3G infrared analyzer, 0–20 ppm
SO_2	Thermo Electron 43 S fluorescence analyzer, 0–200 ppb
O_3	Thermo Electron 49 fotometric analyzer, 0–1 ppm
Particles	TSI 3760 Condensation Particle Counter, 0.014–3 µm

3.2 Weather Station

The weather station is located in a 15 meters high Aluscaff-tower. Wind speed, temperature and humidity are recorded at five different levels. Wind direction and radiation are recorded at the 15 meter level. Atmospheric pressure and rain are recorded at the ground level. Also ground temperature is measured. Components of the weather station are described in Table 1.

3.3 Gas and Particle Measurements

The sampling system is described in Fig. 4 and all the instruments are listed in Table 2. Air is sampled from four different levels with identical stainless steel piping. There exists a continuos, high flow (2 m/s) through the sampling pipes. For the gas analyzers the samples are at first pumped to the sampling bottles to achieve simultaneous sampling. After the bottles are filled, gas concentrations are measured starting from the fifteen meter sample. There is no sampling bottle for the particle sample to minimize losses. The submicron aerosol particle number concentrations are measured using a CNC (Condensation Nucleus Counter). Instead of CNC, it is also

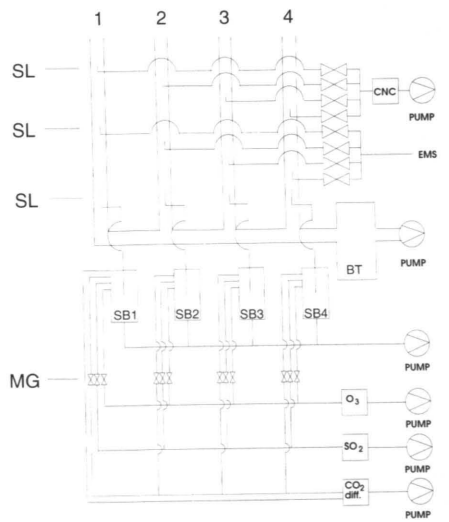

Fig. 4. Gas and particle flow system. 1–4 – Pipes for gas transportation, SL – sampling lines, SB1–SB4 – sample bottles, BT – Buffer tank, MG – Magnetic valves, CNC – Condensation nucleus counter, EMS – Electromobility spectrometer, O_3 – Ozone analyzer, SO_2 – sulphur dioxide analyzer, CO_2 diff – carbon dioxide difference analyzer.

possible to connect other particle detectors like EMS (Electromobility Spectrometer) to the sample line. Carbon dioxide measurement is different from the other gas measurements because only the concentration difference between the highest and other levels are measured in order to achieve a higher resolution.

One measurement cycle takes twenty minutes during which particle concentration profile is measured eight times, ozone and carbon dioxide profile twice and sulphur dioxide profile once although the highest level is measured twice. This is because of the different time constants between the instruments. The repeated measurements enable us to check the losses in the bottles. Carbon dioxide analyzer is calibrated once a week. Ozone and sulphur dioxide analyzers are calibrated twice a year using a calibration procedure by the Finnish Meteorological Institute.

3.4 Photosynthesis

The photosynthesis measuring system is similar to that constructed in the Forestry Field Station of University of Helsinki (Hari et al. 1990). It consists of 1–8 measuring cuvettes, a tubing system for air samples, and an infra-red gas analyzer. The twig to be measured is inserted through the base of a cuvette. The top of the cuvette and a hole in the bottom are open between the measurements. A fan in the hole generates 0.5 m/s air flow through the cuvette. In the beginning of a measurement cycle, the hole and the top of the cuvette are closed for seventy seconds by a pneumatic piston. After this the gas analyzer measures the cuvette CO_2 concentration every ten seconds. In the end of the cycle, the hole and the top are opened. In this way the overall environmental conditions of the twig in the cuvette remain very similar to those of the neighboring twigs. The daily number of measurement cycles varies from 40 to 120 depending on the number of cuvettes in operation.

3.5 Irradiance Measurements

Measurements of irradiance make it possible to estimate the photosynthetic production. The functional unit of the photosynthetic production is a single stoma and chloroplasts in the vicinity of it. Each stoma is feeding the chloroplasts in the mesophyl with CO_2. Diffusion is the flow mechanism and a complicated biochemical system binds energy from irradiance to carbonhydrates. The length scale of a stoma determines the desired dimensions of light sensor. However, the characteristic length of this functional unit is so small (ca. 50 micrometers) that light sensor of that size is quite expensive for multichannel purposes and vulnerable to disturbances in field conditions. Silicon fotodiodes (Siemens type BPW32, 1 mm in diameter) were selected as light sensors. Thirty six diodes were installed on six masts and connected to datalogger. The irradiance is measured 20 times at 5 seconds interval every 20 minutes in order to produce estimates of photosynthetic production by the canopy.

3.6 Control Program

A customized control program entitled VARMIT, written in the C++ language, is used for synchronizing the different measurement events and for collecting data from the loggers and storing it into ordinary ASCII files for further processing.

Basic structure of the control program is shown in Fig. 5. Each of the four different measurement subsystems is controlled by a dedicated, interrupt-driven RS232 serial port operating at 4800 bps. The display manager subsystem controls the maintenance of the user screen, and all data traffic to and from the hard disk goes via the disk manager subsystem. Program kernels tie these components together. Apparent concurrence among the separate subsystems is obtained at the application program level (the MS-DOS operating system does not support multitasking) by dividing the control operations into tiny elementary processes that can be entered and exited rapidly.

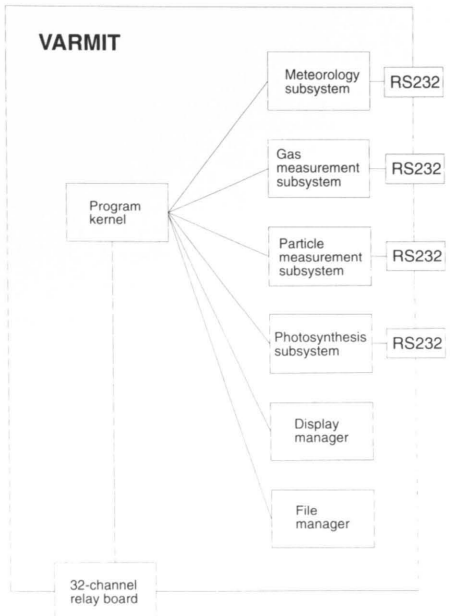

Fig. 5. Control program structure.

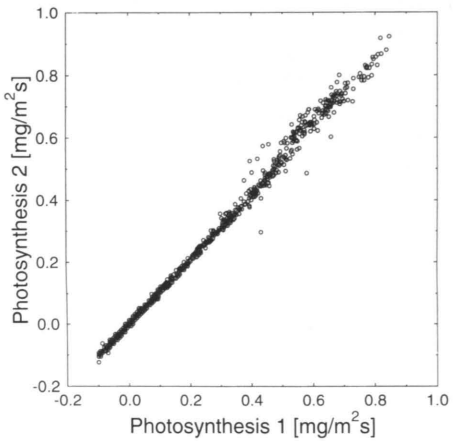

Fig. 6. The regression between measured photosynthesis during the first and second ten seconds periods after the closure of the cuvette measurements between 1.7 –23.7, 1992.

4 Results

The test operation of the measuring system started in August, 1991. During the first year the system was tested and improved. The continuous measurements were started in August, 1992. Since then the system has operated reliably, with some breaks due to thunderstorms and disturbances in the electricity.

The reduction of measuring noise has received major attention during the design and implementation. The measurements of photosynthesis is based on the CO_2 concentration changes in the cuvette. The six measurements of CO_2 concentration during a closure allow five measurements of photosynthesis. The cuvettes are located at the tops of the trees. The changes in irradiance, the main factor affecting photosynthesis, are small during successive ten-second-periods. The regression between measured photosynthesis during two successsive periods shows that ten seconds is sufficient to achieve a needed measuring accuracy (Fig. 6).

After August 1991 extensive data set has been obtained. The typical monthly variation of SO_2, O_3 and particle concentrations are shown in Fig. 7. In Fig. 8 the corresponding values for wind speed, wind direction, temperature and pressure are presented. The overall result is that typical sulphur dioxide concentration is near zero. However, when the wind is blowing from east or north, concentration increases. The particle concentrations follow SO_2 concentration peaks. The ozone concentration seems to be independent of these pollution episodes.

Typical examples of concentration differences between the values at 9 m and 2 m levels are shown in Fig. 9. The profiles for sulphur dioxide and particles are significantly greater than the carbon dioxide profiles. The relative concentration difference (the concentration difference divided by the ambient concentration) is typically two orders of magnitude larger for SO_2 than for CO_2. This indicates that SO_2 deposition mechanism differs from purely stomatal deposition mechanism of CO_2. Note that at night photosynthesis ceases and decomposition of organic soil

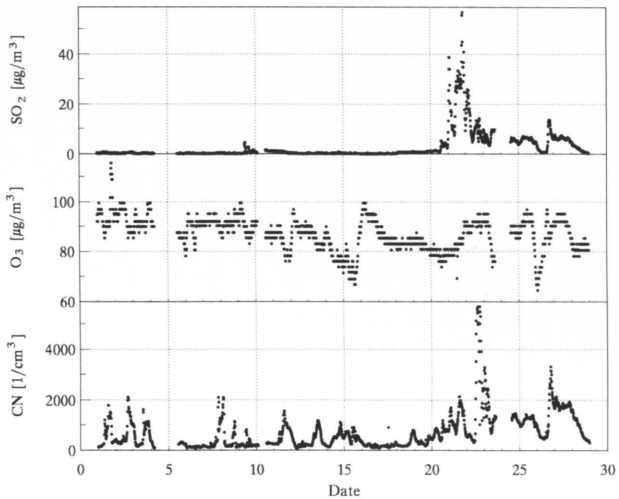

Fig. 7. Gas and particle (CN) concentrations during February 1993.

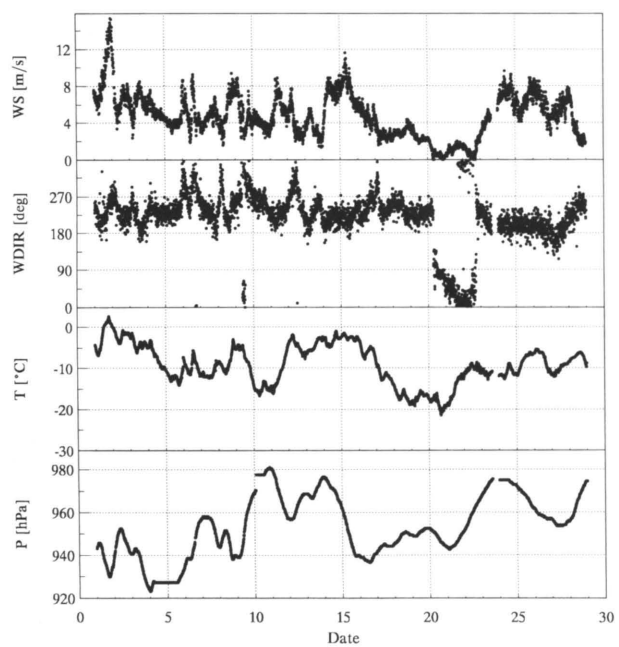

Fig. 8. Meteorological characteristics (wind speed, wind direction, temperature and pressure) during February 1993.

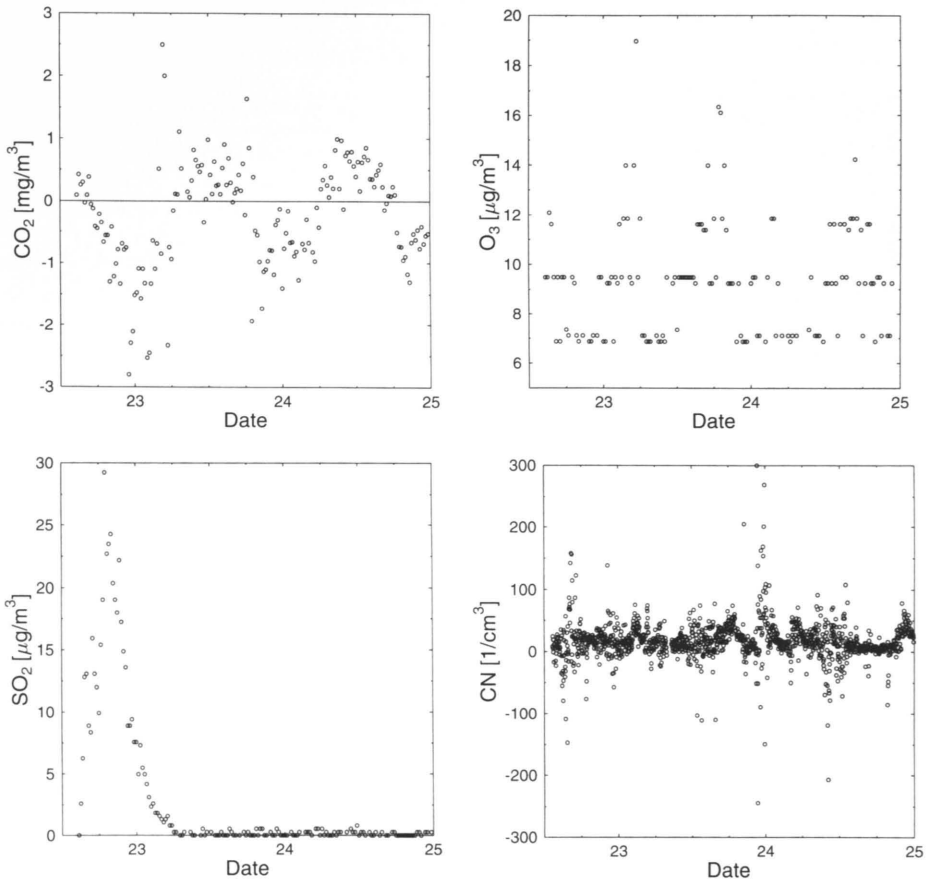

Fig. 9. The difference of gas and particle concentrations between 9 m and 2 m level during August 1992.

material and respiration by trees become noticeable reversing the direction of overall CO_2 flux.

Photosynthesis consumes and respirations produce CO_2. The cuvette measurements show us the difference of photosynthetic consumption and respiratory production. In Fig. 10 the CO_2 exchange as a function of irradiation is presented. The data covers time periods of eight days. The good measuring accuracy allows a reliable determination of the dependence of photosynthesis on irradiance.

The size distribution of aerosol particles have been measured during several intensive measurements (Aalto et al. 1992). Fig. 11 shows a typical example of background (or low polluted) size distribution and the case during pollution episode. The difference is apparent. During the low polluted period aerosol is typical aged background aerosol. Almost all the particles are gathered to the accumulation (0.1–1 μm) mode where the removal rates are the smallest. During polluted period aerosol is characterized by the large nucleation mode (0.001–0.1 μm) which is typical for fresh, anthropogenic aerosol.

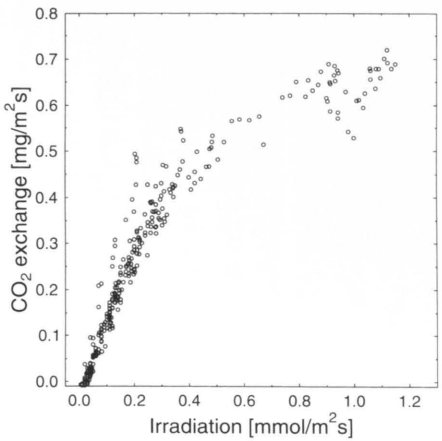

Fig. 10. CO_2 exchange versus irradiation during August 1992.

5 Conclusions

The Värriö environmental measurement station is working well. The precision of measurements seems to be excellent. During the first winter (1991–1992) there were some technical problems but after that the station has worked without any major interruptions. During the measured period several pollution episodes have been observed. The maximum concentration of SO_2 exceeds 200 μg/m^3 and that of ozone exceeds 180 μg/m^3. The maximum particle concentration is over 10 000 cm^{-3}. The sulphur dioxide and particle episodes occur when the wind blows from east or north.

In future the capacity of the station will be used for the investigations of the effects of pollutants to the forest growth in arctic conditions. Also the deposition fluxes of pollutants into trees and the formation of aerosol particles in arctic environment will be studied.

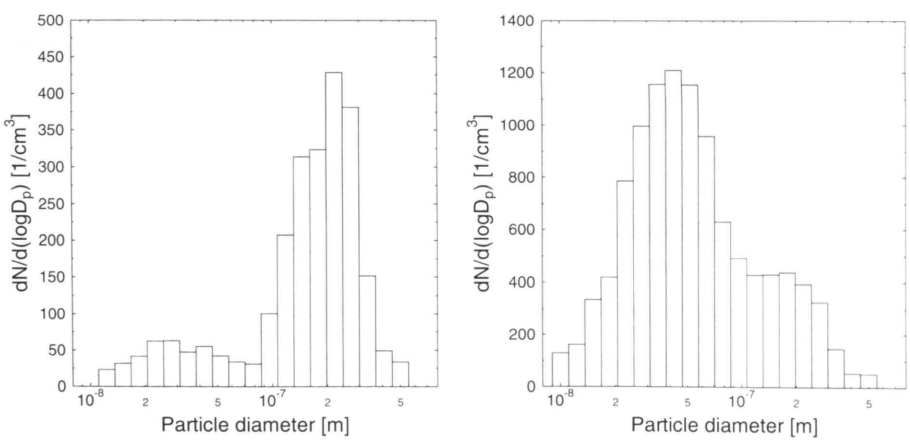

Fig. 11. Particle size distribution during clean period and contaminated period 31.3.1992.

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