Mem. Natl Inst. Polar Res., Spec. Issue, **51**, 153–163, 1996

Report

REPORT ON ATMOSPHERIC SCIENCE OBSERVATIONS AT NY-ÅLESUND, SVALBARD

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Abstract: Observations of atmospheric variables at Ny-Ålesund, Svalbard were started in 1991 at the Rabben observation station, in order to increase our understanding of global atmospheric change in the Arctic. The measured atmospheric components are the variations of greenhouse gases, clouds, precipitation and radiation; these are then compared to observations in the Antarctic. Observations of greenhouse gases, such as CO_2 and CH_4, are conducted by air sampling at the site once a week, in cooperation with the Norwegian Polar Institute. Large seasonal variation and north-south difference in the annual mean between Ny-Ålesund and Syowa Station, Antarctica of about 4 ppmv are observed for the CO_2 concentration. CH_4 also shows a large seasonal variation and large north-south difference. Surface ozone concentration is measured continuously at the station; clear seasonal variation and some drastic destruction at the polar sunrise have been revealed. Clouds and precipitation are observed with 37 GHz microwave radiometer for the column liquid water content, and 10 GHz vertical pointing radar for the ice water content and precipitation. Monthly variations of clouds and precipitation are obtained, and some seasonal differences in cloud properties are described. Analysis of surface radiation data observed for a long time by the Norwegian Polar Institute has revealed certain characteristics of the radiation budget at Ny-Ålesund.

1. Introduction

The Arctic is a place where several important processes which control the global climate occur, and where early evidence of the global atmospheric change might appear with great amplification. It is therefore important to make observations in the Arctic in order to increase our understanding of the global environment and climate change.

Since 1991, we have started observations of certain atmospheric parameters at Ny-Ålesund (79°N, 12.5°E), Svalbard. These observations have been carried out under the "International Cooperative Project on Global Environment Research in the Arctic (1990–1994)", in accordance with International Arctic Science Committee (IASC) initiatives. The project is a multi-disciplinary study composed of atmospheric, glaciological, oceanographic and ecological components. In this paper, preliminary results on the variations of greenhouse gases including surface ozone, clouds, precipitation and radiation are presented, and are compared to observations in the Antarctic.

As seen in Fig. 1, the Svalbard archipelago is located at 80°N, surrounded by oceans.

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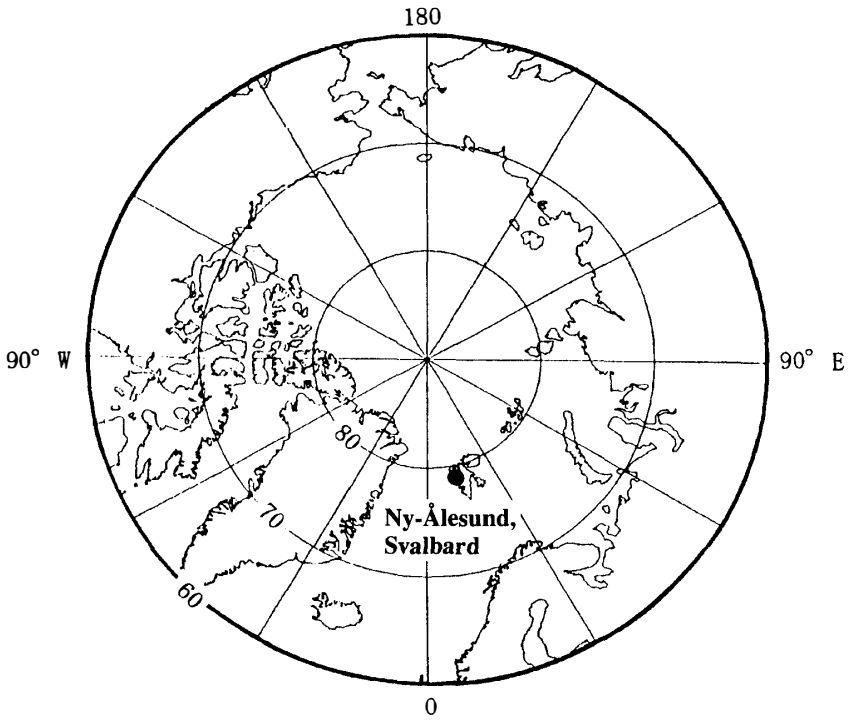

Fig. 1. Location map of Ny-Ålesund, Svalbard in the Arctic.

Even at 80°N, the islands are normally at the edge of seasonal sea ice due to warm currents in the Greenland Sea from the south, often influenced by the polar front. The climate of the islands is therefore maritime Arctic (VINJE, 1982; BARRY *et al.*, 1993; HISDAL, 1975).

2. Observations

Observations of atmospheric variables by the National Institute of Polar Research (NIPR) are all conducted at Japanese station called "Rabben". The station is located at the side of an air strip, close to the Kongsfjorden, about 1.5 km from the Ny-Ålesund town center. In recent years, Ny-Ålesund has become an international scientific center for Arctic research, mainly operated by the Norwegian Polar Institute (NP), with logistical support provided by KBKC (H. ITO, personal communication). Operational aspects of international cooperation are coordinated by the Ny-Ålesund Scientific Managers Committee (NySMAC). Our observations are performed under a cooperation agreement between NIPR and NP.

Instruments are located inside and outside the observation hut, as shown in Fig. 2. Measurements of greenhouse gases are conducted by flask sampling through the air intake situated at one side of the hut. *In situ* continuous measurement of surface ozone is made by a Dasibi Ozone Monitor, introducing air from another air intake. A microwave radiometer, pyranometer and infrared radiation thermometer are set on the roof of the hut. Vertical pointing radar is set on neighboring ground, with a parabolic antenna on the roof of a small shed containing a control and power unit. All the recording instru-

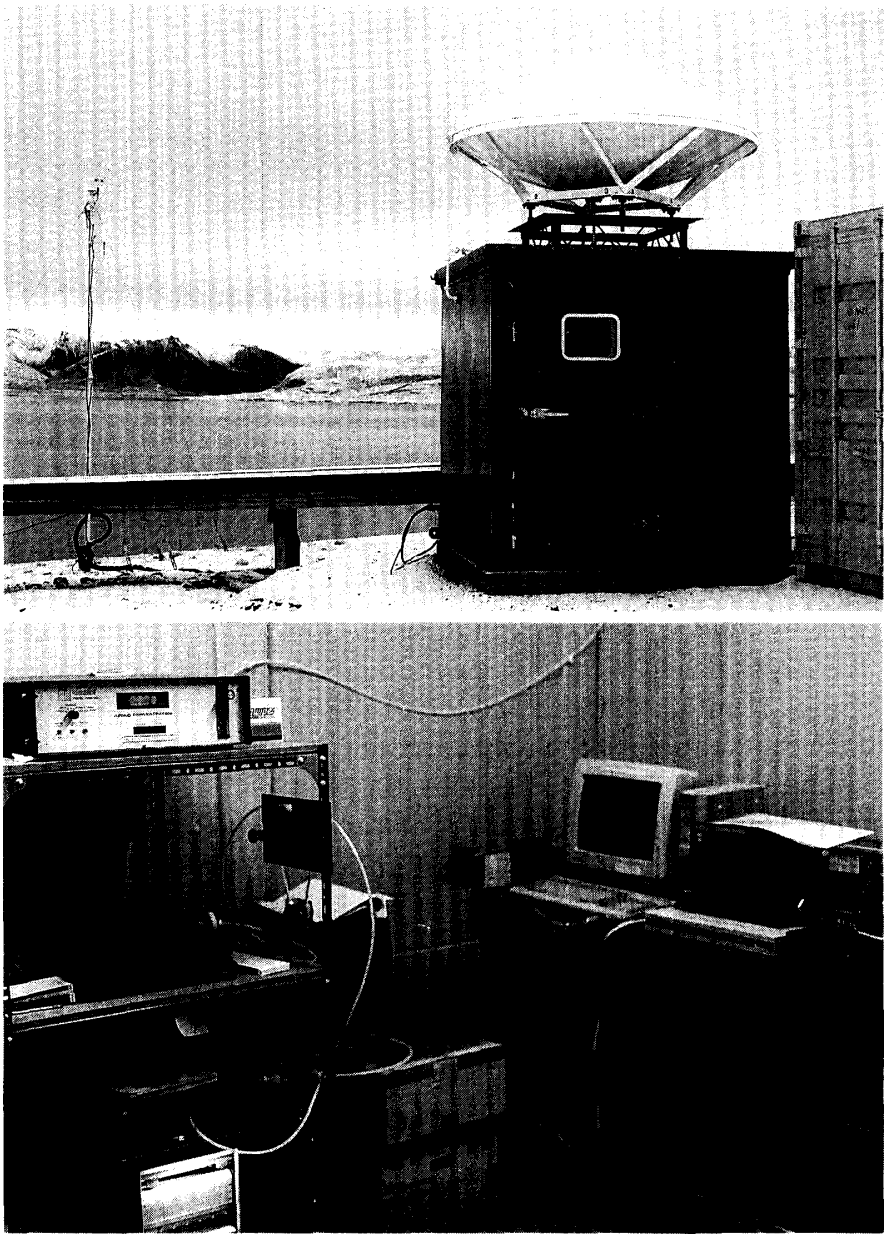

Fig. 2. Picture of air intake, meteorological sensors, vertical pointing radar and instruments in the observation hut.

ments are set inside the hut. Most of the air sampling (once a week) and the maintenance of the instruments are supported by NP staff.

3. Greenhouse Gases

Atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and carbon isotope ratio ($\delta^{13}C$) of CO_2 are analyzed at the home institution from air sampled in a flask once a week, following the method described in TANAKA *et al.* (1987). The flasks are made of stainless steel, with volume of about 800 m*l*, and the sampled air is pressur-

ized to about 10 atm.

3.1. CO_2

Figure 3 shows a three and a half year record of the atmospheric CO_2 concentration. Large seasonal variation with a peak-to-peak amplitude of about 18 ppmv can be seen, with a steep minimum in August and rather long plateau-like maximum from March to April. The annual mean of 1994 is 360.6 ppmv. It is found that the site is suitable for background monitoring, since all the data obtained at the station are shown in the figure, with no unrealistically high concentrations due to the contamination of station activity. Within the Arctic, compared to the data at Barrow, Alaska obtained by NOAA/CMDL (PETERSON and ROSSON, 1994), quite similar seasonal variation is seen. Also the annual mean values agree together within ± 2 ppmv. In this sense, the atmospheric CO_2 data at Ny-Ålesund are also generally representative of the Arctic.

CO_2 concentrations obtained at Syowa Station, Antarctica (AOKI *et al.*, 1994) are also shown in Fig. 3. Seasonal variation is greatly reduced, to a peak-to-peak amplitude of only about 1.1 ppmv, with the minimum in April and the maximum in October. The annual average in 1994 is 356.4 ppmv, which is about 4 ppmv lower than that at Ny-Ålesund. The larger annual average in the Arctic indicates that the main source of CO_2 is in the Northern Hemisphere (NH), and is probably anthropogenic. Since the seasonal variation of CO_2 concentration is mainly initiated by exchange between the atmosphere and terrestrial biosphere, the large seasonal variation in the Arctic suggests that most of the terrestrial biosphere is located in the NH. From the annual averages calculated from the data points in Fig. 3, only very small year to year increase is found; this is consistent with the smaller increase rate reported commonly for these years (PETERSON and ROSSON,

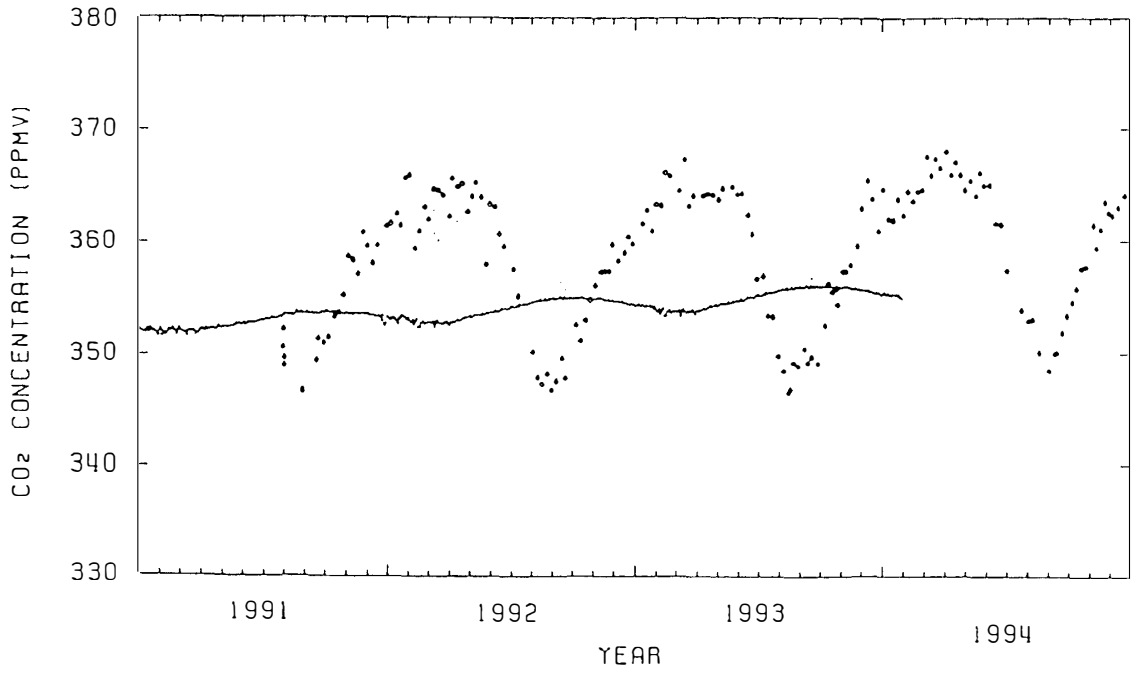

Fig. 3. Atmospheric CO_2 concentration at Ny-Ålesund, Svalbard from weekly flask sampling, compared with the daily mean record at Syowa Station, Antarctica.

1994).

Variation of carbon isotope ratio ($\delta^{13}C$) of CO_2 is measured. The amplitude of seasonal variation is about 1.2 ‰, the maximum appears in August to September and the minimum during December to March. The seasonal variation of $\delta^{13}C$ and CO_2 concentration correlate well. The ratio of the variation of $\delta^{13}C$ to the variation of CO_2 concentration is about –0.05 ‰/ppm, which indicates that this seasonal variation is mainly due to CO_2 exchange between the atmosphere and biosphere (NAKAZAWA *et al.*, 1993). Also, large oceanic uptake is assumed to be effective in the Arctic sea from the results of p-CO_2 measurements in the Greenland Sea (AOKI *et al.*, 1996).

3.2. CH_4

Atmospheric concentration of CH_4 obtained at Ny-Ålesund is shown in Fig. 4. CH_4 also shows a clear seasonal variation, together with larger divergence of points. The minimum concentration appears in July to August, and the maximum appears during the end of January to February. The amplitude of seasonal variation is more than 100 ppbv and the annual average in 1994 is 1828 ppbv. Unlike CO_2 concentration, CH_4 sometimes shows irregular high concentrations, sometimes as much as 1900 ppbv. Although CO_2 concentration does not show such a large deviation, it still correlates partly with CH_4 fluctuations. These irregular fluctuations in CH_4 and CO_2 seem to be associated with exchange of air masses, one from a highly contaminated and another from a less contaminated area. These short-term variations in CH_4 and CO_2 between two values have already been pointed out by HOLMEN *et al.* (1995) and LEJENAS and HOLMEN (1996) from the result at Zeppelin Mountain, Svalbard and from the data at Alert, Canada by HIGUCHI *et al.* (1987) and TRIVETT *et al.* (1996).

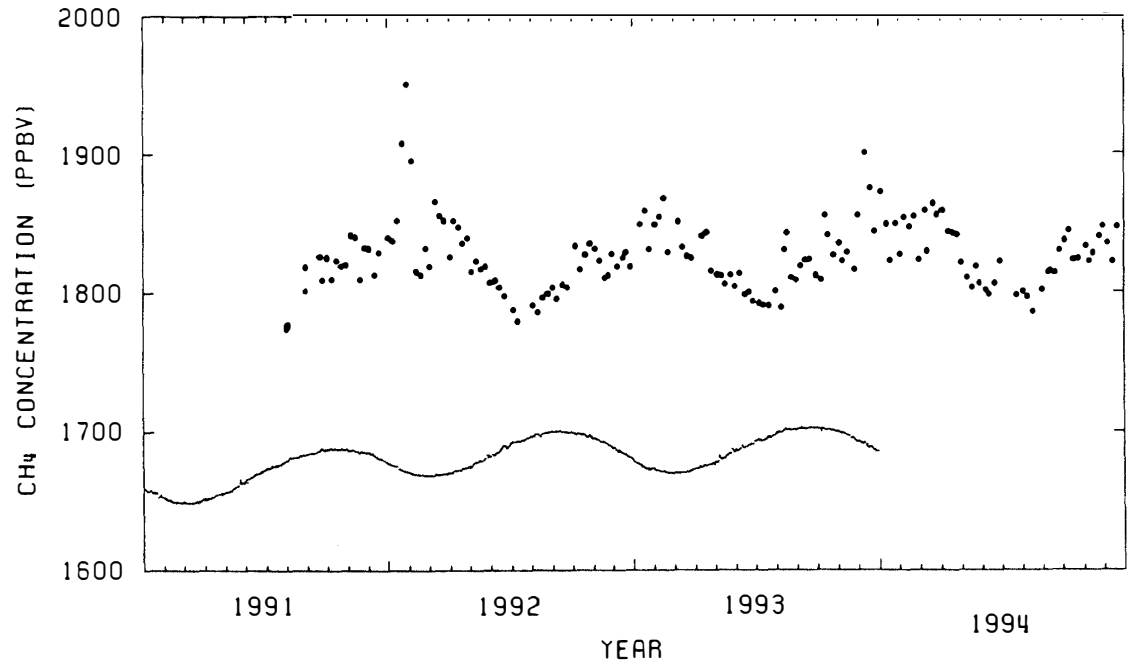

Fig. 4. Atmospheric CH_4 concentration at Ny-Ålesund, Svalbard from weekly flask sampling, compared with the daily mean record at Syowa Station, Antarctica.

The CH_4 concentration obtained at Syowa Station, Antarctica by continuous measurements from 1988 (AOKI *et al.*, 1994) are also shown in Fig. 4. The curve shows very systematic seasonal variation, with the minimum in March and the maximum in September, and amplitude of about 30 ppbv. The annual average of CH_4 at Syowa Station in 1994 is 1692 ppbv, which is about 140 ppbv lower than that at Ny-Ålesund. The north-south gradient of CH_4 concentration, more than 8% of the mean concentration, is much larger than that of CO_2 concentration, which is about 1%.

Since the annual increase rate of CH_4 at Syowa is about 10 ppbv on average, this large north-south difference in the annual average corresponds to a difference of more than ten years. This is certainly consistent with the fact that the main source of CH_4 is also in the NH. In the case of CO_2, we can explain the north-south difference as corresponding to a two to three year increase of CO_2 concentration, reflecting the time lag of atmospheric transportation between the northern and southern hemispheres (TANS *et al.*, 1989; NAKAZAWA *et al.*, 1991). This is because, while CO_2 is very stable in the lower atmosphere, CH_4 is not so stable, resulting in a shorter life time of about 10 years in the lower atmosphere due to dissociation by the OH radical during its transportation from north to south.

3.3. Surface ozone

Surface ozone is a good tracer for the atmosphere and one of the key species for atmospheric chemistry in the troposphere. Figure 5 shows the daily mean values of surface ozone concentration from the three-year measurements at Ny-Ålesund. Continuous measurements are made by the Dasibi Ozone Monitor with several checks and calibration conducted regularly (AOKI and YAMANOUCHI, 1994). Surface ozone also shows a rough seasonal variation, with high values in March to May and low values in June to

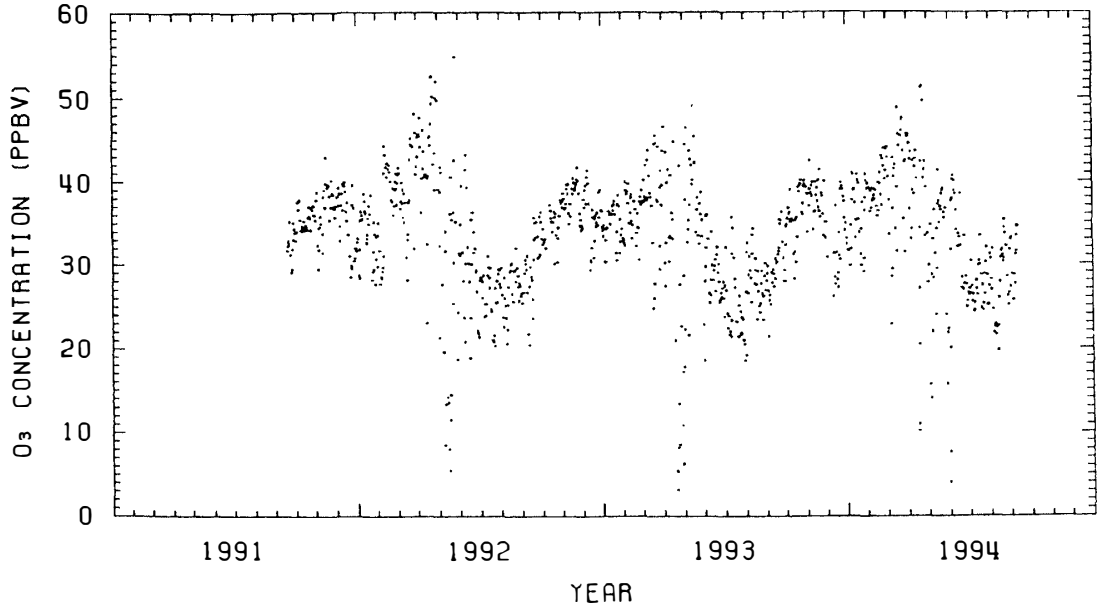

Fig. 5. Daily mean surface ozone concentration at Ny-Ålesund, Svalbard from continuous measurement.

July, and a peak-to-peak seasonal amplitude of about 20 to 25 ppbv. However, day to day fluctuation is extremely large in spring, with a very high peak appearing one day, followed by very low concentrations for a few days to about 10 days. Looking in detail, there is a secondary peak in November to December, and a dip in December to January. This semiannual oscillation can also be seen in the seasonal variation of CH_4 in Fig. 4. Thus some similarity is found in the general seasonal variations of CH_4 and surface ozone.

Compared to the Arctic, the surface ozone concentration measured at Syowa Station shows rather clear seasonal variation, and is about 10 ppbv lower on average (AOKI and YAMANOUCHI, 1994). Lower values appear around January and higher values appear in July to September. Seasonal variation is roughly symmetric, with relatively small fluctuations in the increasing stage during March to June, and larger fluctuations in the decreasing stage during August to December. This seasonal variation in the Antarctic is quite different to that observed in the Arctic. In the Arctic (Fig. 5), some isolated high values seen at the end of April to the beginning of May might be due to stratospheric air intrusion associated with the passages of cyclones.

Rapid decrease of surface ozone in spring is commonly observed at Ny-Ålesund and Syowa. Extremely low values are found during April to May at Ny-Ålesund and during August to October at Syowa. Figure 6 shows a few examples of such rapid depletion in the surface ozone at Ny-Ålesund during April 1993. The data plotted are hourly averages. The surface ozone concentration decreases to a minimum in a day or two, remaining low for a few days in some cases or only for a few hours in other cases, before returning to normal. In the Antarctic, this phenomenon was first observed by AOKI and YAMANOUCHI (1994), but in the Arctic, it was already known at a few sites, such as Pt. Barrow and Alert (BARRIE *et al.*, 1988; OLTMANS *et al.*, 1989). The mechanism of this abrupt depletion of surface ozone is not resolved yet; however, there is some evidence

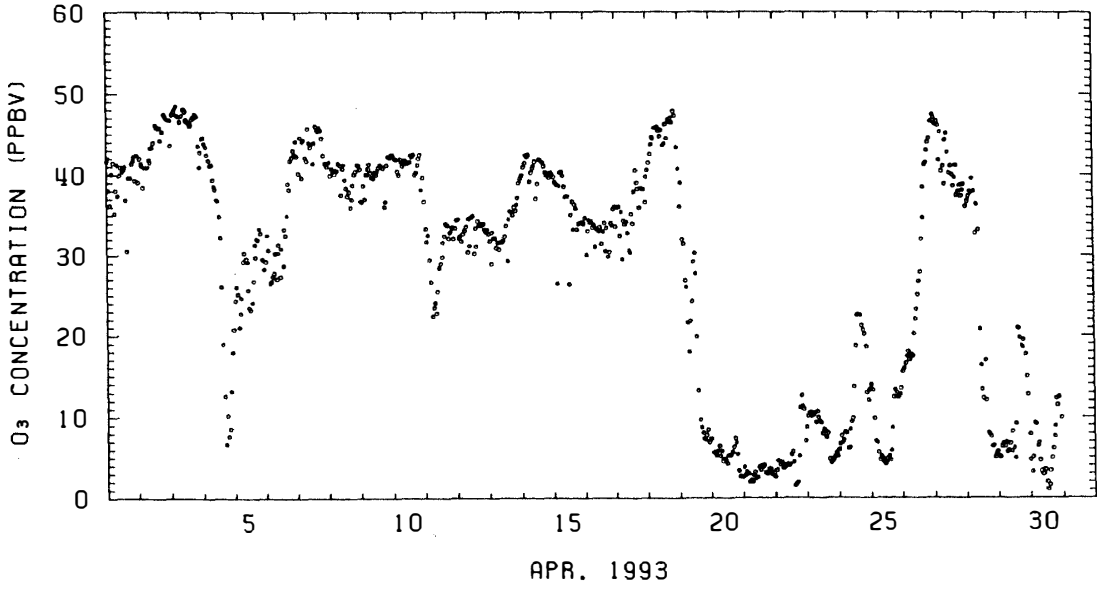

Fig. 6. Hourly mean surface ozone concentration at Ny-Ålesund, Svalbard from continuous measurement, April 1993.

relating the abrupt depletion to compounds originating from the marine biosphere. Though the time of occurrence of these phenomena is not identical in the northern spring and austral spring, the time of these phenomena from the sunrise is quite similar for the Arctic and Antarctic. The phenomena have been found to occur from about a month after the sunrise in both the cases. Compared to observations at 500 m above sea level (Zeppelin Mountain; SOLBERG *et al.*, 1996), and to the ozone sonde flight by Alfred Wegener Institute (GERNANDT, personal communication), the vertical scale of the ozone depletion is normally more than 500 m, but rarely more than 2 km. The horizontal scale is on the order of hundreds to about one thousand km, since the duration of the phenomena is about a few days. So, air with depleted ozone is limited to a thin surface layer of quite large horizontal scale.

4. Clouds, Precipitation and Radiation

Observations of clouds and precipitation are made using a microwave radiometer and vertical pointing radar. Microwave radiometer of 37 GHz is used for the column liquid water content, and vertical radar of 10 GHz is used for the ice water content and

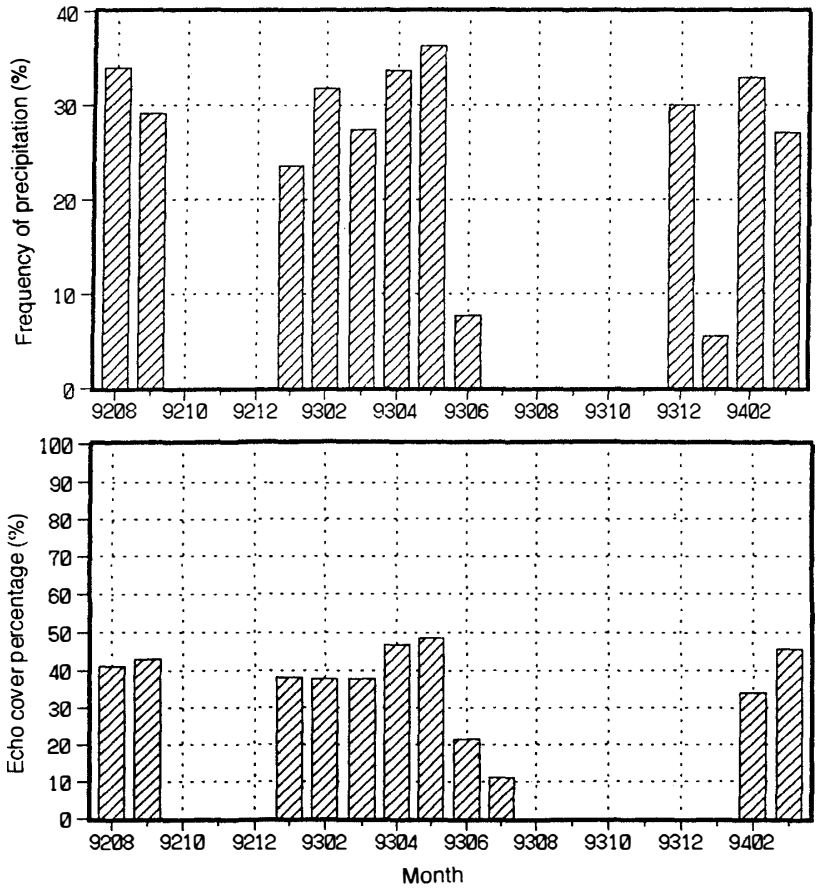

Fig. 7. Monthly variation of radar echo percentage and frequency of precipitation calculated from the radar echo obtained from vertical pointing radar.

precipitation from the radar echo. Figure 7 shows the monthly variation of radar echo percentage and frequency of precipitation calculated from the radar echo obtained from vertical pointing radar. These data are not quantitative estimates of clouds or precipitation, but show some indications. A detailed discussion of the radar echo is reported in a separate paper related to synoptic phenomena (WADA *et al.*, 1996). Also compared are the manually observed cloud amount and precipitation measured by gauge by the Norwegian Meteorological Institute (NMI; personal communication). Cloud amount shows a distinct seasonal difference, with low amount in winter and high amount in summer; this is very common in the Arctic (BARRY *et al.*, 1993).

On the other hand, radar echo percentage does not show such a large seasonal difference; it is much stable throughout the year. Most of the winter clouds are associated with echo, but not all the summer clouds are associated with echo. This means that a certain type of summer clouds do not precipitate or contain large ice particles, thus showing no radar echoes. This cloud type might be related to the Arctic summer stratus. In winter, clouds are not so frequent as in summer, but most clouds covering Ny-Ålesund are accompanied by precipitation. Those clouds are related to frontal cyclonic systems.

The surface radiation budget at Ny-Ålesund for one year, as an example, has been analyzed by YAMANOUCHI and ØRBAEK (1995) from data obtained for a long time by the Norwegian Polar Institute (HISDAL *et al.*, 1992). Figure 8 shows the daily average global solar radiation at the surface and solar insolation at the top of the atmosphere. Due to the disappearance of snow over the tundra surface, a drastic change in the surface albedo occurs in June from about 80% to 15%. This leads to global solar radiation smaller on average in the latter half of the year than the first half of the year because of reduction of multiple scattering between the surface and the atmosphere. No solar radiation is seen from the end of October to the end of February, during the polar night at Ny-Ålesund.

Figure 9 shows daily averaged downward longwave radiation. A great difference in

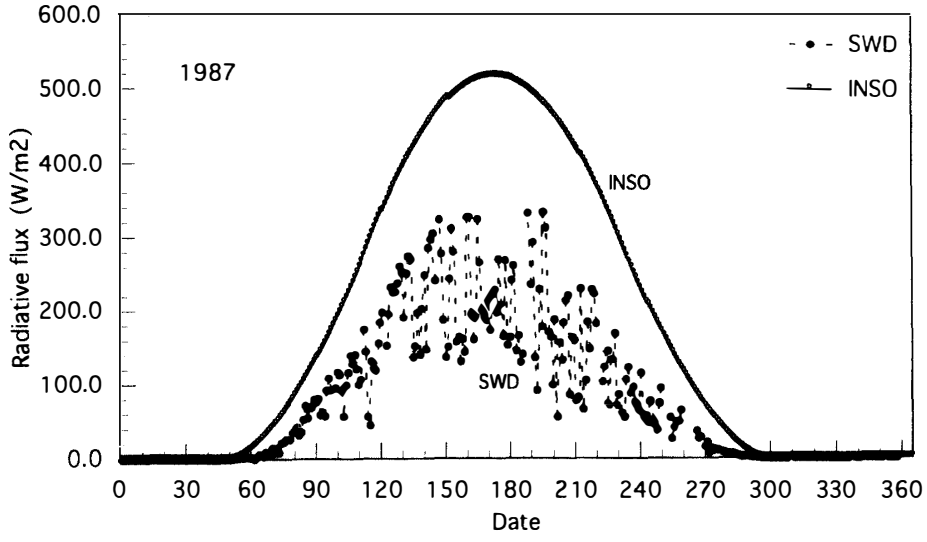

Fig. 8. Daily mean global solar radiation (SWD) at Ny-Ålesund, Svalbard in 1987, together with the solar insolation at the top of the atmosphere (INSO) (YAMANOUCHI and ØRBAEK, 1995).

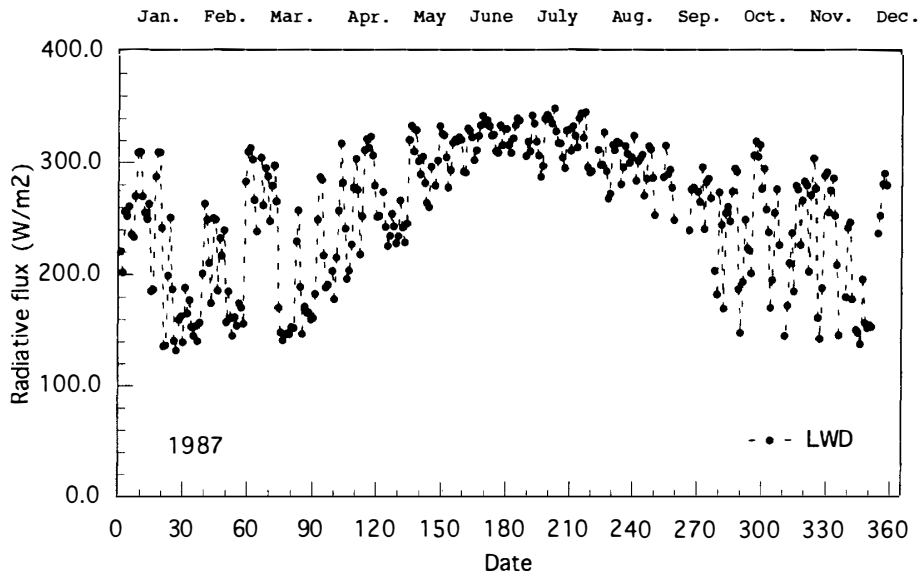

Fig. 9. Daily mean downward longwave radiation (LWD) at Ny-Ålesund, Svalbard in 1987.

the day to day variation between winter and summer is noticeable. Large day to day variation of up to 200 W/m^2 can be seen during October to March. Intermittent variation between large and small downward longwave radiation is due to a change in air mass over the region. A change in cloud cover only cannot account for such a large fluctuation as 200 W/m^2. This large change in the downward longwave radiation is caused by changes in air temperature and water vapor amount due to change in air mass. Large downward longwave radiation is found under a maritime air mass from the south, while small downward longwave radiation is seen under a dry and cold Arctic air mass coming from the northern Arctic Ocean. Cloud amount also differs according to the air mass. For example, high cloud amount is common for the maritime air mass, enhancing the downward longwave radiation. This relationship was clearly demonstrated by comparison with weather charts (YAMANOUCHI and ØRBEAK, 1995). On the other hand, in summer, the day to day variation of downward longwave radiation is very small, partly due to persistent heavy cloud cover and partly due to higher surface temperature when sky is clear.

Acknowledgments

The authors wish to express their sincere thanks to the staff of the Norwegian Polar Institute for their support in the observations. This study was part of the International Cooperative Project on the Global Environment Research in the Arctic (1990–1994), and also supported financially in part by Grant Nos. 03041089 (PI: O. WATANABE) and 05044065 (PI: N. ONO) under the International Scientific Research Program and Grant-in-Aid for Developmental Scientific Research (B) No. 07558076 (PI: T. YAMANOUCHI) from the Ministry of Education, Science, Sports and Culture of Japan.

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(Received December 29, 1995; Revised manuscript accepted April 5, 1996)