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Scientific Note

AN OVERVIEW AND PRELIMINARY RESULTS FROM THE ARCTIC AIRBORNE MEASUREMENT PROGRAM 1998 CAMPAIGN

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Abstract: The Arctic Airborne Measurement Program (AAMP) was planned to investigate the transport, exchange and chemical processes of gas and aerosol in the Arctic atmosphere in early spring, and further to understand their roles in global change. An instrumented aircraft, Gulfstream II (G-II) twin-jet plane, was used for airborne measurements in the troposphere and lower stratosphere of the Arctic. For the AAMP 1998 campaign, G-II was equipped with CO_2 and O_3 concentration monitor systems, gas and aerosol sampling systems, aerosol particle counters, and the PMS 1D and 2D airborne particle probes. The aircraft was flown from Alaska, USA to Svalbard, Norway passing over the North Pole, and on the reverse route, in the first half of March 1998. The approximate cruising altitude was 12 km for long-range flights. Vertical profiles of gas and aerosol concentrations were obtained over Spitsbergen, Svalbard and Barrow, Alaska. A convective cloud system associated with a polar low was observed over the Norwegian Sea. Another cloud observation was made for marine boundary layer clouds over the open sea off Spitsbergen. Most of the instruments on-board G-II worked well, and measurements were successfully acquired during the AAMP 1998 campaign.

1. Introduction

The Arctic is a key region where global climate change appears clearly and where the unstable air-sea-snow system causes global changes by a feedback mechanism. Gases and aerosols are key elements of climate change and related phenomena such as global warming, ozone depletion, Arctic haze, etc. Thus, international research efforts have been made for Arctic science. The National Institute of Polar Research (NIPR) promotes atmospheric research in the polar regions, and has maintained an Arctic research station since 1991 at Ny-Ålesund (78.9°N, 11.9°E), Svalbard, in collaboration with the Norwegian Polar Institute. The station has been used mainly for sampling and

continuous measurements of atmospheric minor constituents (YAMANOUCHI *et al.*, 1997). Previous results from these measurements at Ny-Ålesund have suggested that seasonal variations of greenhouse gases reflect transport and chemical processes in the atmosphere. In the troposphere, surface ozone depletion has been also observed in the springtime (WESSEL *et al.*, 1998). These measurements, however, have been made at the surface of a single site, and the results from measurements may not be representative of the Arctic region. Wide-range observations involving not only surface measurements but also airborne measurements are essential to understand the phenomena and expand our knowledge of Arctic science. Thus, the Arctic Airborne Measurement Program (AAMP) was planned to investigate the transport, exchange and chemical processes of gas and aerosol in the Arctic in early spring, and further to understand their roles in global change (AERC, 1997; SHIOBARA *et al.*, 1998). In AAMP, a trans-Arctic long-range flight was planned. Such flights have been carried out successfully in previous international campaigns; e.g., AGASP (SCHNELL, 1984). The AAMP 1998 flight by a jet plane consisted of not only long-range flights between Japan and Svalbard via Alaska but also vertical sounding flights over Alaska and Svalbard.

In this paper, an overview of the AAMP 1998 campaign and some preliminary results from the Arctic flight will be presented and discussed. More detailed discussion on the results will be described in separate papers to be presented by the AAMP participants.

2. Outline of AAMP

Research objectives of AAMP are as follows:

1) To elucidate the spatial distribution and variability of atmospheric minor constituents, continuous in-situ measurements of CO_2 and O_3 concentrations and air sampling for N_2O and CH_4 analyses were made. Isotopes of carbon and oxygen in CO_2 and CH_4 were also analyzed.
2) To elucidate the long-range transport and transformation processes of aerosol and gas, the variability in the size distribution and chemical composition of aerosols were measured. Air was also sampled for analyses of gases related to physical and chemical processes, such as SO_2 and carbonylsulfide.
3) To elucidate the spatial distribution of tropospheric aerosols and their radiative effect on the radiation budget in the atmosphere-surface system, vertical soundings of aerosol concentration and size distribution were carried out.
4) To elucidate the structure of atmospheric disturbances and cloud microphysical processes, precise microphysical measurements using particle-sizing probes were acquired.

To attain the objectives, a trans-Arctic long-range flight including the polar vortex region was essential since the polar vortex has an important role in circulation and transport of the Arctic atmosphere. An instrumented jet plane was planned for the AAMP mission to fly in the troposphere and lower stratosphere of the Arctic. In the AAMP 1998 campaign, the aircraft was actually flown from Alaska, USA to Spitsbergen, Svalbard passing over the North Pole in the first half of March 1998. During the campaign, intensive ground observations were also carried out at Ny-

Ålesund, Svalbard. The ground-based measurements are described in WADA *et al.* (1997).

3. Instrumentation

A Gulfstream II (G-II) twin-jet plane was used as the airborne platform for the AAMP 1998 mission. The G-II aircraft, outfitted for atmospheric research flights, was commercially leased from Diamond Air Service Co. (DAS), Nagoya. The aircraft was equipped with instruments for measuring atmospheric trace gases, aerosols and cloud droplets, and sampling devices. Instrumentation of G-II for the AAMP 1998 flight is briefly described. Abbreviations for instruments in the text below and in Fig. 1 correspond to those in Table 1. An airborne system using an NDIR analyzer, Li-COR LI-6262, has been developed by MACHIDA *et al.* (1995) for continuous measurement of CO_2 concentration (CO_2 NDIR). This system was modified for use in the AAMP flight. A continuous measurement system for ozone concentration (OZONE) was based on a Dasibi-type ozone monitor, Dylec Model 1100. Air and aerosol sampling systems (ASS/AGSS/IMPACTOR) were installed in the cabin. Figure 2 shows an inside view of the G-II aircraft cabin. Since the cabin is pressurized during flights, air intake tubes were carefully arranged to avoid contamination of the cabin air. Air leak from tube fittings was checked by a leakage detector. Two optical particle counters (OPC) were installed to measure the number concentration of aerosols with diameter $D > 0.3\mu m$. An OPC, MetOne Model 237B, was placed near AGSS in the cabin. Another OPC, originally developed for balloon-borne measurements (IWASAKA *et al.*, 1997; WATANABE *et al.*, 1997), was rebuilt for airborne measurements. This OPC was placed in a non-pressurized space under the cabin floor. The Particle Measuring System (PMS) FSSP-300, FSSP-100, and 2D gray probes (OAP-2D-GA/GB) were suspended under the wing for sizing airborne aerosol and cloud particles. Data from

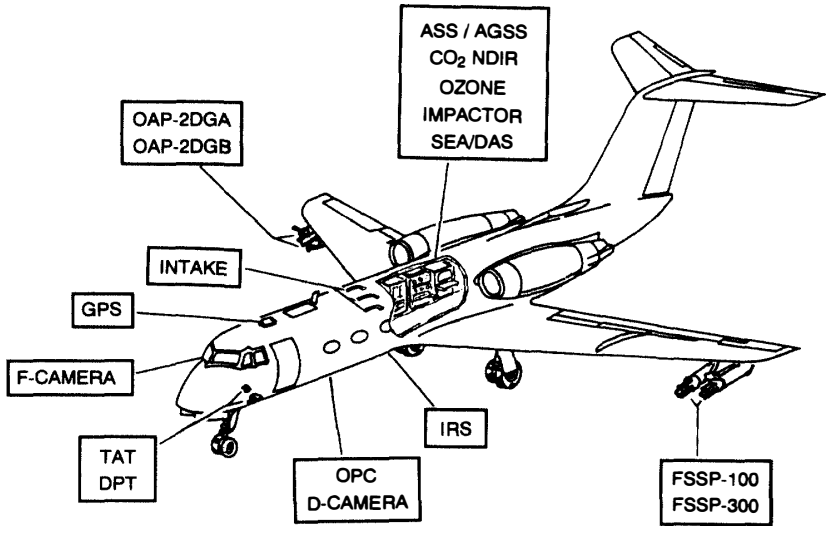

Fig. 1. Instrumentation of the G-II aircraft for the AAMP 1998 campaign. Abbreviations correspond to those in the text and Table 1.

Table 1. AAMP 98 instrumentation.

Abbreviation	Instrument/model/characteristics
AGSS	Aerosol-gas sampling system for SO_2 and sulfate aerosol measurements
ASS	Air sampling system for CO_2, CH_4, N_2O, CO, COS, CS_2 and isotopes
CO_2 NDIR	CO_2 NDIR analyzer, Li-COR LI-6262, for continuous measurement
DPT	Hygrometer, EG&G Model 137-C3, for DPT measurement
D-CAMERA	Downward-looking video camera-recording system
F-CAMERA	Forward-looking video camera-recording system
FSSP-100	PMS FSSP-100 for sizing 2–47μm-diameter particles
FSSP-300	PMS FSSP-300 for sizing 0.3–20μm-diameter particles
GPS	Global Positioning System, Trimble 2100T
INPACTOR	Aerosol impactors for electron-microscopic analysis
INTAKE	Air intake
IRS	Inertial Reference System, Honeywell HG1050
OAP-2DGA	PMS OAP-2D-GA2 for sizing 10–640μm-diameter particles
OAP-2DGB	PMS OAP-2D-GB2 for sizing 50–3200μm-diameter particles
OPC	Optical particle counter for 0.3–5μm-diameter aerosols
OZONE	Ozone monitor, Dylec Model 1100, for continuous measurement
SEA/DAS	Data acquisition systems, SEA M200 and DAS GII DRS
TAT	Thermometer, Weed Model 9816, for TAT measurement

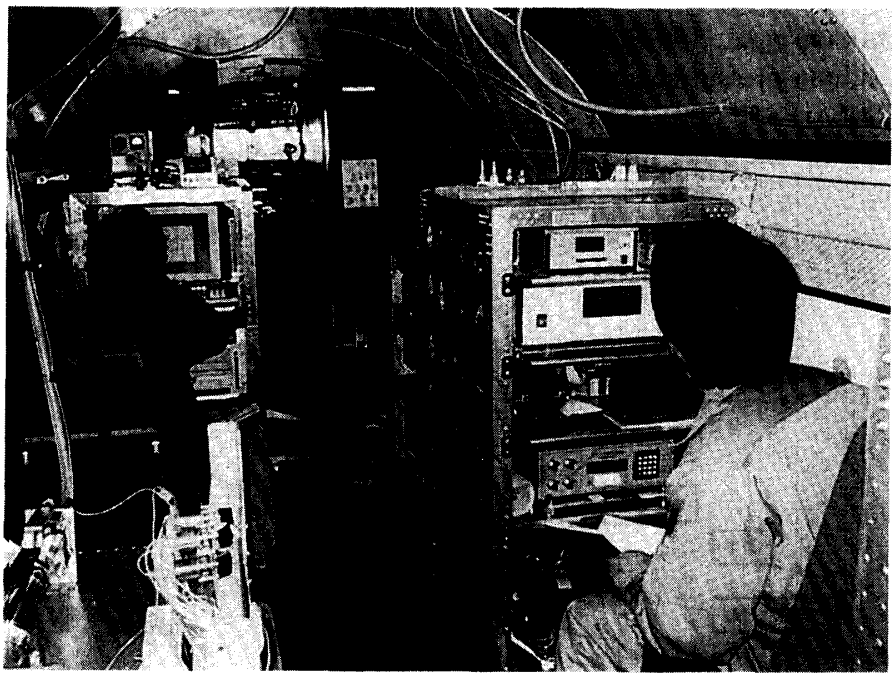

Fig. 2. An inside view of the G-II aircraft cabin from the rear to the cockpit. An ozone monitor and an NDIR-CO_2 analyzer are placed on the upper and lower stages, respectively, of the rack in the right side. The SEA M200 data acquisition system is placed in the left-side rack.

the PMS probes were acquired by a data acquisition system, Science Engineering Associates (SEA) Model 200. Total air temperature (TAT), dew point temperature (DPT), static and dynamic pressures, and other flight information from an inertial reference system (IRS) and the global positioning system (GPS) were recorded in another data recording system prepared by DAS. Downward and forward viewing images were recorded by two video camera-recording systems (D/F-CAMERA).

4. Observations

The AAMP 1998 flight consisted of long-range flights between Japan and Svalbard via Alaska and vertical sounding flights over Alaska and Svalbard. The air route of the AAMP 1998 flight is shown in Fig. 3, and all flights during the campaign are summarized in Table 2. Nagoya Airport (35.3°N, 136.9°E) was the departure place in Japan. The G-II aircraft took off Nagoya on 6 March, and landed at Petropavlovsk-Kamchatski (53.0°N, 158.3°E), Anchorage (61.2°N, 150.1°W) and Barrow (71.3°N, 156.8°W) on the way to the final destination, Longyearbyen (78.2°N, 15.4°E), Svalbard. The Longyear Airport was the base for the G-II flight operations in Svalbard. The approximate cruising altitude and speed were 12 km and 800 km/h, respectively, for the long-range flights (Flt Nos. 1-4, and 8-11). Normally it took about 20 min to reach the cruising altitude after take-off. Vertical sounding flights for gas and aerosol profile measurements were conducted up to about 12 km high over off Spitsbergen, Svalbard on 8 and 10 March (Flt Nos. 5 and 7, respectively), and over Barrow, Alaska on 12 March (Flt No. 9). These flights consisted of spiral ascending

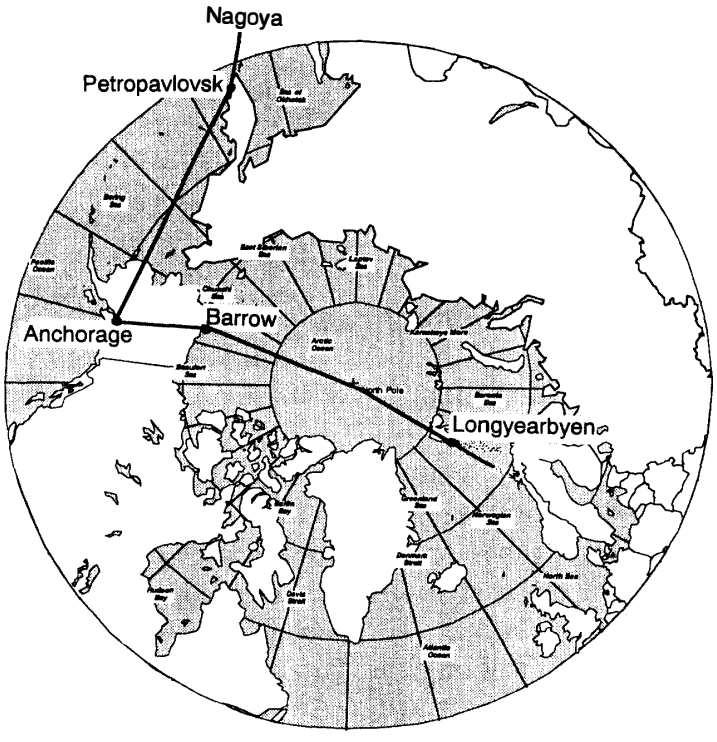

Fig. 3. Air route of the AAMP 1998 flight in the Arctic region.

Table 2. AAMP 98 flight summary.

Flt No.	Flight area	Flight type	Date	Dep.-Arr. (UT)	Flt hours
1	Nagoya-Petropavlovsk	Long-range	3/5, 6	2340-0310	3:30
2	Petropavlovsk-Anchorage	Long-range	3/6	0435-0845	4:10
3	Anchorage-Barrow	Long-range	3/6, 7	2340-0300	3:20
4	Barrow-Longyearbyen	Long-range	3/7	0505-0945	4:40
5	Off Spitsbergen	V-sounding	3/8	1040-1340	3:00
6	South of Svalbard	V-sounding	3/9	1000-1335	3:35
7	Off Spitsbergen	V-sounding	3/10	1015-1150	1:35
8	Longyearbyen-Barrow	Long-range	3/12	1500-1940	4:40
9	Barrow-Anchorage	Long-range	3/12	2100-2340	2:40
10	Anchorage-Petropavlovsk	Long-range	3/13, 14	2340-0355	4:15
11	Petropavlovsk-Nagoya	Long-range	3/14	0530-0930	4:00

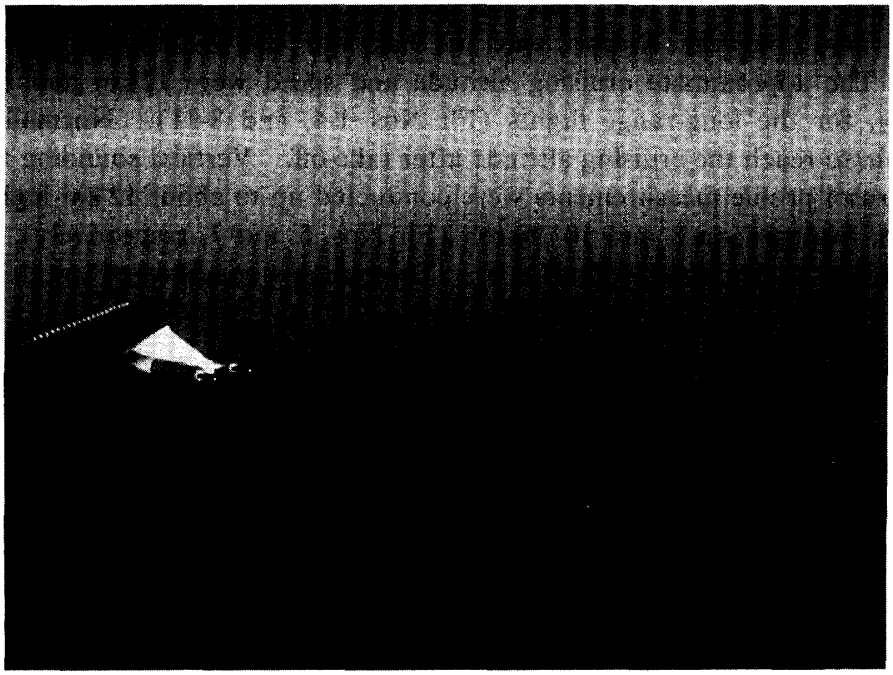

Fig. 4. A marine boundary layer cloud field observed from the 10 March flight (Flt. No. 7) over the open sea, 50 km northwest of Spitsbergen, Svalbard.

or descending at the rate of $\pm 150-300$ m/min. The approximate air speed was 500 km/h for the spiral flight. The 10 March flight (Flt No. 7) included observation of a marine boundary layer cloud (Fig. 4). Another observation flight on 9 March (Flt No. 6) was conducted mainly for cloud structure and microphysics of a convective cloud system associated with a polar low over the Norwegian Sea around 73° N and 7.5° E. After the flight operations based at Longyear Airport, the G-II aircraft took the same route back to Japan, and landed at Nagoya Airport on 14 March. Most of the instruments worked well, and measurements were successfully acquired during the campaign.

5. Results and Discussion

5.1. Atmospheric conditions

Atmospheric conditions during the campaign are briefly described here. Figures 5a and 5b are aerological maps of the 200 hPa height on 7 and 12 March, respectively, published by the German Weather Service (DWD, 1998). Since the cruising altitude for the long-range flight was 12 km of pressure height, *i.e.*, 195 hPa in pressure, these maps are close to the flight altitude. Looking at the figure along the flight path, the contours were largely wound around the Kamchatska-Bering Sea-Alaska area while the contours over the 80°N area were closed around the North Pole. From these figures, it is suggested that the polar vortex was maintained during the campaign although the maps do not show where the polar vortex was located. Precise analyses of the potential vorticity are necessary to know whether Svalbard was situated in the polar vortex. Figure 6 shows vertical profiles of the static air temperature which was obtained by subtraction of the dynamic heating effect from TAT measured on-board G-II for vertical sounding flights (Flt Nos. 5 and 9). A strong temperature inversion was found near the surface at Barrow (Fig. 6b) whereas there was no surface inversion over the sea off Spitsbergen (Fig. 6a). This is a characteristic difference of the meteorological condition between Barrow and Spitsbergen. Since the tropopause existed around 10 km height as shown in the figure for the campaign period, the aircraft had actually flown in the lower stratosphere during the trans-Arctic long-range flight between Alaska and Svalbard.

5.2. Trace gases

Figure 7 shows the variation of CO_2 and O_3 concentrations during the Barrow-to-Longyear flight on 7 March (Flt No. 4). A negative correlation between the two concentrations is obvious in the figure. Generally the stratospheric CO_2 and O_3 concentrations are lower and higher, respectively, than those in the troposphere. In Fig. 7, there is a large variation of concentrations from 74°N to 80°N on the Alaskan side (left-hand-side), in contrast to a stable section between 80°N on the Alaskan side and 80°N on the Svalbard side (right-hand-side). The concentrations of CO_2 and O_3 varied between 362–366 ppmv and 0.1–0.5 ppmv, respectively, in the 74°N–80°N region while those in the stable region were 361–362 ppmv and 0.4–0.7 ppmv, respectively. A similar variation was also observed in the aerosol particle concentration measured by an OPC on the same flight. The aircraft had flown at the constant pressure height of 11900 m $\pm$ 30 m, *i.e.*, 195 hPa during the flight between 73.0°N on the Alaskan side and 79.9°N on the Svalbard side. This result reflects the atmospheric transport process from lower latitude to the Arctic region. The observed large variation suggests that the air came from lower altitude where CO_2 and O_3 concentrations were expected to be higher and lower, respectively, than the flight altitude.

Tropospheric CO_2 and O_3 concentrations, which were measured from vertical sounding flights over Svalbard, were about 369 ppmv and 50 ppbv, respectively. It was also found from these flights that the concentrations of CO_2 and O_3 changed discontinuously at the tropopause height. It is suggested that vertical exchange between

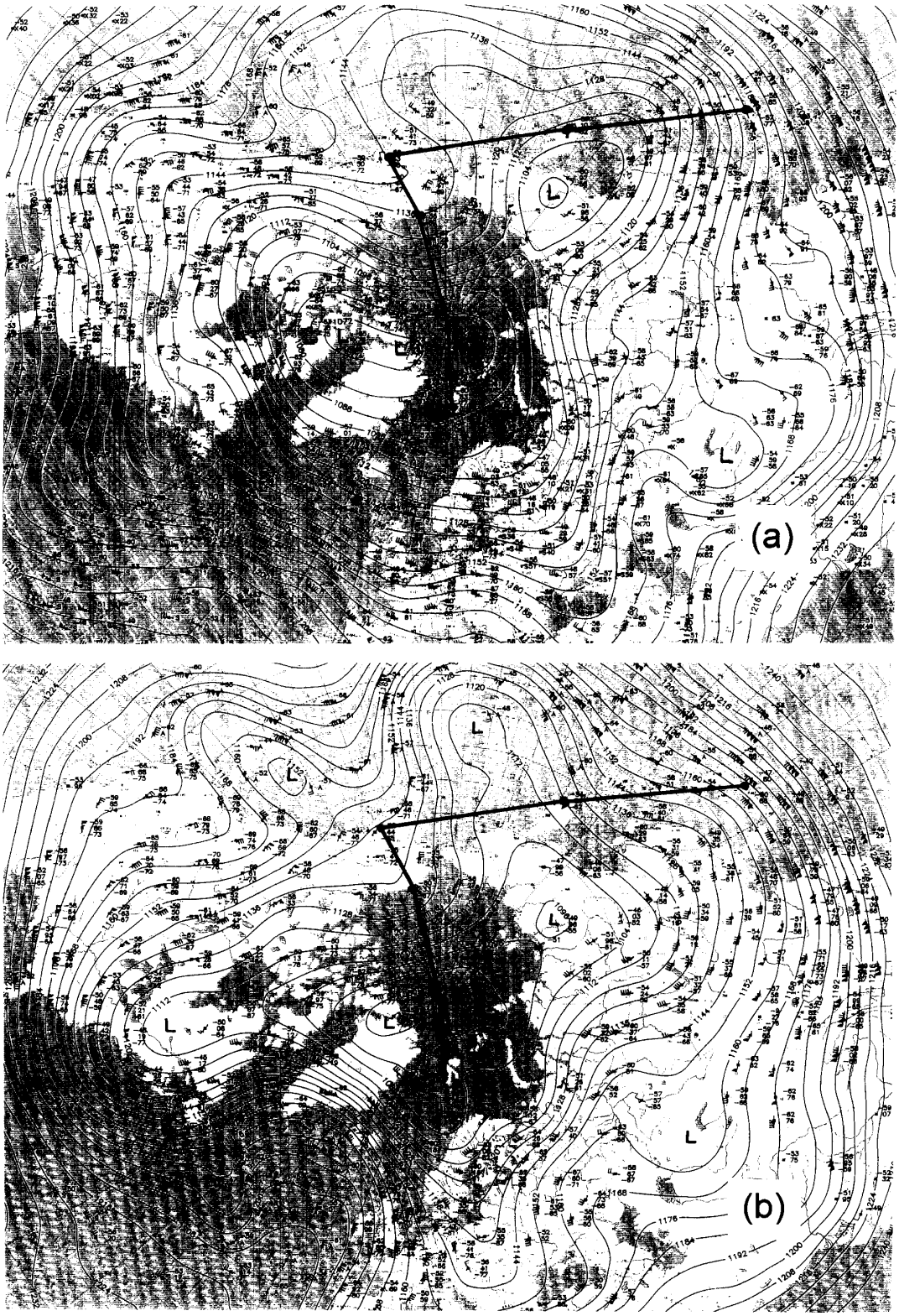

Fig. 5. Aerological maps of the 200 hPa height, (a) 12Z 07 March 1998 and (b) 12Z 12 March 1998, published by the German Weather Service. The bold line indicates the air route of the AAMP 98 long-range flights.

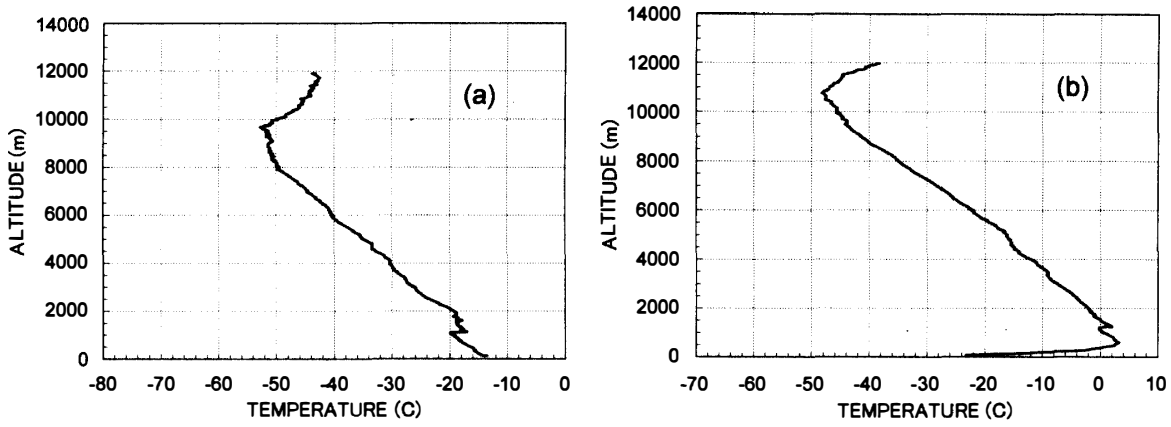

Fig. 6. Vertical profiles of the static air temperature measured on-board G-II, (a) 8 March 1998 over off Spitsbergen, Svalbard (Flt. No. 5) and (b) 12 March 1998 over Barrow, Alaska (Flt. No. 9).

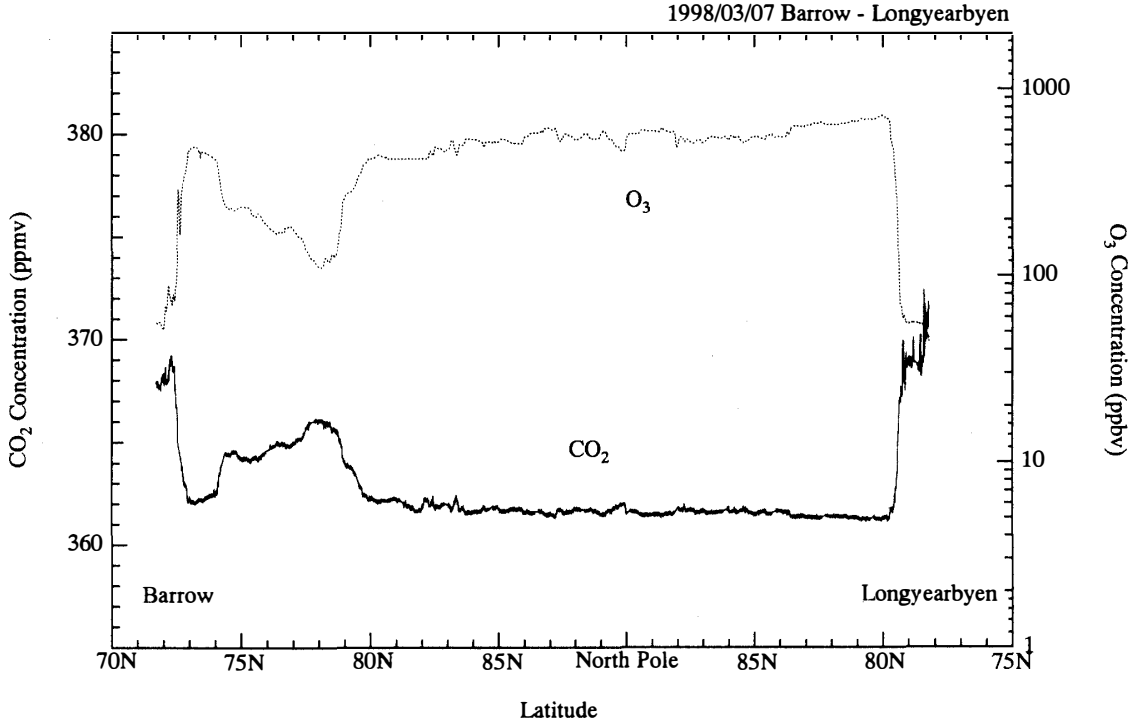

Fig. 7. Concentrations of CO_2 (solid line, left-side scale) and O_3 (broken line, right-side scale) during a trans-Arctic long-range flight from Barrow to Longyearbyen (Flt. No. 4). Large variations at both edges in the figure are due to ascending and descending flights in the troposphere.

the stratosphere and the troposphere was obstructed.

From analyses of air samples, concentrations of CH_4 and N_2O were 1.6–1.9 ppmv and 0.28–0.32 ppmv, respectively, during the AAMP flight. A positive correlation was also found in the variation of CH_4 and N_2O concentrations. This fact agreed with the result from balloon-borne measurements of the Arctic stratosphere carried out over Kiruna, Sweden in March 1997 (Aoki *et al.*, 1998). The result indicates degradation

of both gases by photochemical process in the stratosphere.

5.3. Aerosols

Arctic haze is generally known as a characteristic phenomenon of tropospheric aerosols in the Arctic (*e.g.*, SHAW, 1995). In the AAMP flight, the Arctic haze was usually observed and seemed optically thick. For example, Fig. 8 shows a vertical profile of aerosol concentration measured by OPCs near Spitsbergen on 8 March (Flt No. 5). In the figure, there is some clear difference between the concentrations measured by OPC1 placed in a non-pressurized space and OPC2 in the pressurized cabin. OPC2 might underestimate the concentration larger than OPC1 due to the loss of particles in a long tube. In the present status, it is difficult to discuss quantitatively on the concentration because corrections for the sampling volume and efficiency are not complete yet. Certainly in a qualitative sense, it is obvious from measurements with both OPCs that thick layers of Arctic haze existed near the ground, 2–3 km and 7–8 km high on 8 March. There were no higher clouds but relative humidity was high in the 7–8 km layer. Also in other cases during the campaign, Arctic haze was often multiply layered and sometimes the highest layer reached close to the tropopause around 9 km.

It was found from chemical and microscopic analyses of aerosol samples that sulfate aerosols were dominant in the stratosphere and free troposphere, and sea salt particles existed in the lower troposphere (HARA *et al.*, SHOJI *et al.*, personal communi-

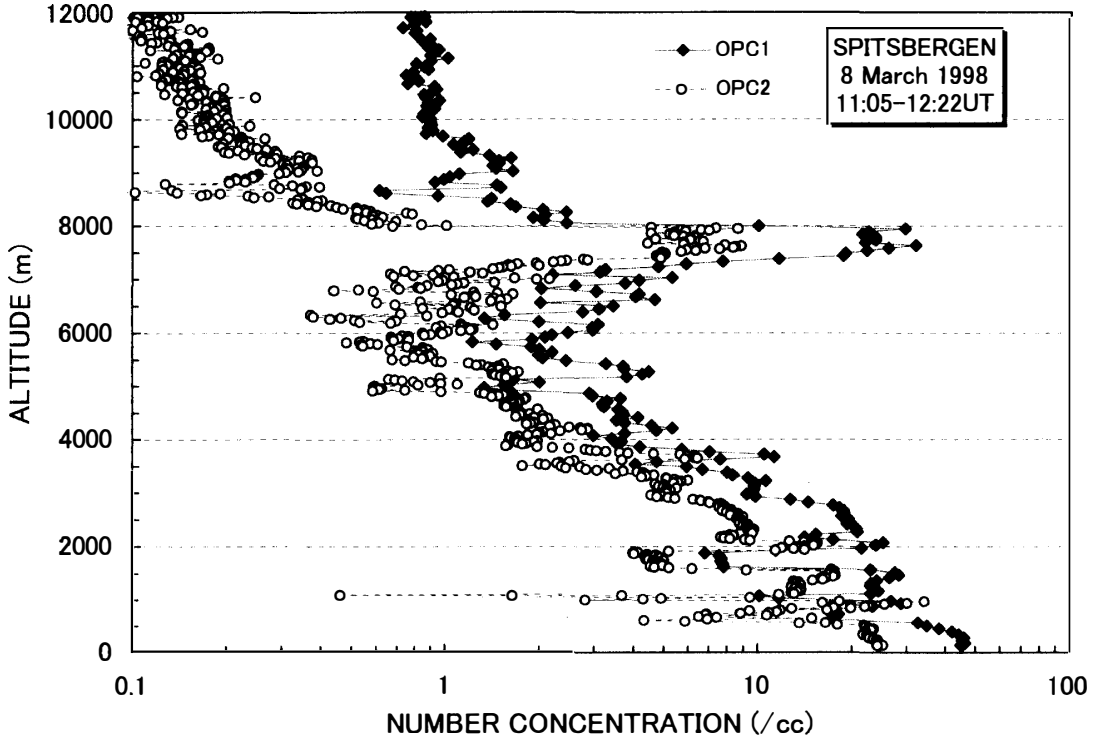

Fig. 8. Vertical distribution of aerosol particle number concentrations ($D > 0.3$ μm) measured by OPC1 placed in a non-pressurized space (closed diamonds with the solid line) and OPC2 in the pressurized cabin (open circles with the dashed line), from a descending flight (Flt. No. 5) near Spitsbergen on 8 March 1998.

cation).

Carbonylsulfide (COS) is generally thought to be a source of sulfur in stratospheric aerosols except for those of volcanic origin. A gas-chromatographic analysis was made for air samples to detect COS, and concentrations of 440–500 pptv were obtained for the AAMP flight. The COS concentration was lower in the stratosphere than in the troposphere. This fact suggests that sulfur in the stratospheric aerosols might be supplied by the tropospheric COS.

5.4. Clouds

Two different types of clouds were observed in the AAMP 98 campaign; convective clouds associated with a polar low, and marine boundary layer clouds. In the convective clouds over the Norwegian Sea on 9 March, it was observed that cloud droplets were mainly formed in the lower troposphere and carried up to the upper atmosphere by strong updrafts accompanied with conversion to ice particles. A marine boundary layer cloud field was observed over the open sea, 50 km northwest of Spitsbergen on 10 March (Fig. 4). The cloud top and base heights were 700 m and 150 m, respectively. The distance between cloud lines was roughly estimated to be 1.5–2 km from video images taken by a downward-looking video camera. Results from cloud-physics measurements with the PMS 2-D probes indicated that ice particles were dominant in this cloud, while super-cooled water droplets were observed as well (ASUMA *et al.*, in preparation 1999).

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