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AIRBORNE OBSERVATION OF WATER VAPOR AND AEROSOLS ALONG MIZUHO ROUTE, ANTARCTICA

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Abstract: Airborne observations of water vapor and aerosols using a dew point meter and optical particle counters were made along the route from Syowa Station (69°00′S, 39°35′E) to Mizuho Station (70°42′S, 44°20′E). Vertical flights were made around Syowa and Mizuho Stations, horizontal flights along the route were made at a height of 3800 m a.s.l., which is the altitude of Dome Fuji Station, and return flights from Mizuho Station to Syowa Station were made along the slope at about 300 –500 m height from the ground snow surface. A typical result, on December 25, showed gradual increase of water vapor amount and some decreases of aerosol concentration from the coast to the inland area along the 3800 m flight. On August 30, strong enhancement of aerosol loading was found in the 700 to 900 hPa layer, related to the passage of a strong low pressure system. Particle size distribution was steeper in summer and flatter in winter, indicating an increase of large particles and decrease of smaller particles in winter.

1. Introduction

Antarctic aerosols exist only in very low concentration; however, their role in the climate and physical and chemical processes in the atmosphere is very important (SHAW, 1988). Aerosol particles contribute to the formation of clouds, and scatter solar radiation. Behavior of atmospheric aerosol particles is one of the main targets of the study of the geochemical cycle of atmospheric constituents in the Antarctic. Since the Antarctic is removed from some major sources of aerosols, knowledge of transportation process and spatial distribution is crucial to the evaluation of their behavior. Water vapor is also an important and fundamental component of the atmosphere, controls the energy budget and water cycle; however, its behavior is not clear, especially in the Antarctic. Measurements of aerosol particles in the Antarctic have already been made for years (*e.g.*, ITO, 1985; SHAW, 1988); however, information on their vertical and horizontal distribution is very limited (HOGAN, 1979; HOGAN *et al.*, 1982). Around Syowa Station, ITO *et al.* (1986a) carried out airborne measurements of the vertical profile of Aitken particle concentration in 1984, and IWASAKA *et al.* (1985) described the

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individual aerosol particles obtained from airborne sampling of large particles. Also, balloon-borne observations of aerosol particles in the troposphere and stratosphere have been made (*e.g.*, ITO *et al.*, 1986b).

Airborne observations were carried out in 1997 along the route between Syowa Station and Mizuho Station, aiming to derive vertical and horizontal distributions of aerosol particles and water vapor from the coast to the interior of the Antarctic continent. The observations were made under the project on "Atmospheric Circulation and Material Cycle in the Antarctic" conducted by the Japanese Antarctic Research Expedition (JARE) since 1997 (YAMANOUCHI *et al.*, 1999). The aim of the project is to clarify the transport and transfer of atmospheric minor constituents related to the atmospheric circulation. At Syowa Station and at the inland Dome Fuji Station, located 1000 km from Syowa Station, extensive in situ and sounding observations of aerosols and water vapor were carried out during 1997 under the project (HIRASAWA, 1999; HAYASHI, 1999). Observations of the number-size distribution of aerosol particles (IWASAKA *et al.*, 1997, 1998) and chemical composition of size-segregated aerosols (OSADA *et al.*, 1998; HARA *et al.*, 1998) are continuing as part of the aerosol monitoring program at Syowa Station. The aim of this paper is to describe a meridional cross section between Syowa and Mizuho Stations by airborne observations.

2. Observations

The aircraft used was a Cessna A185F Skywagon, JA3889, with a reciprocating gasoline engine. The plane was equipped with two optical particle counters (OPCs), models TD-100 and TD-500A (Sigma Tech Co.; both use a laser beam as a light source), which measure particles with diameters larger than 0.3 μm and 0.07 μm, respectively. The air intake was set in the middle of the right wing to avoid contamination from the exhaust. Then the sample air was introduced into the cabin with a tigon tube with a inner diameter about 7 mm and length about 3.5 m, and branched off to two counters. The air flow rate was 1000 m*l*/min and 500 m*l*/min, respectively, for TD-100 and TD-500 OPCs. A dew point meter (Buck Science Research Co., Model 1011D), humidity sensor and thermometer (Väisala Co., humicup) were installed on the side window of the plane to monitor the state of the ambient air. Also, a barometer (home made) was installed on the plane. Data obtained by these instruments were sampled once per minute and collected with one personal computer through a digitizer. Since these observations originally had been planned to be made using another larger plane, a Pilatus Porter PC-6, it was hard work to install all these instruments in the smaller cabin. The operator was obliged to check the instruments in tight space.

The plane ascended over sea ice around Syowa Station, and flew horizontally from over Syowa Station to over Mizuho Station along the traverse route (Fig. 1) at an altitude of 3800 m above sea level, at the altitude of Dome Fuji Station. At Mizuho Station, the plane descended closely to the surface and then returned at an altitude about 300 to 500 m above the ice sheet surface (gradual descent, Fig. 2). On one day, flight leg was chosen in the opposite direction, gradual ascent along the ice sheet surface from Syowa to Mizuho Station, direct ascent at Mizuho and then level flight at 3800 to Syowa Station, in order to cut down flight hour.

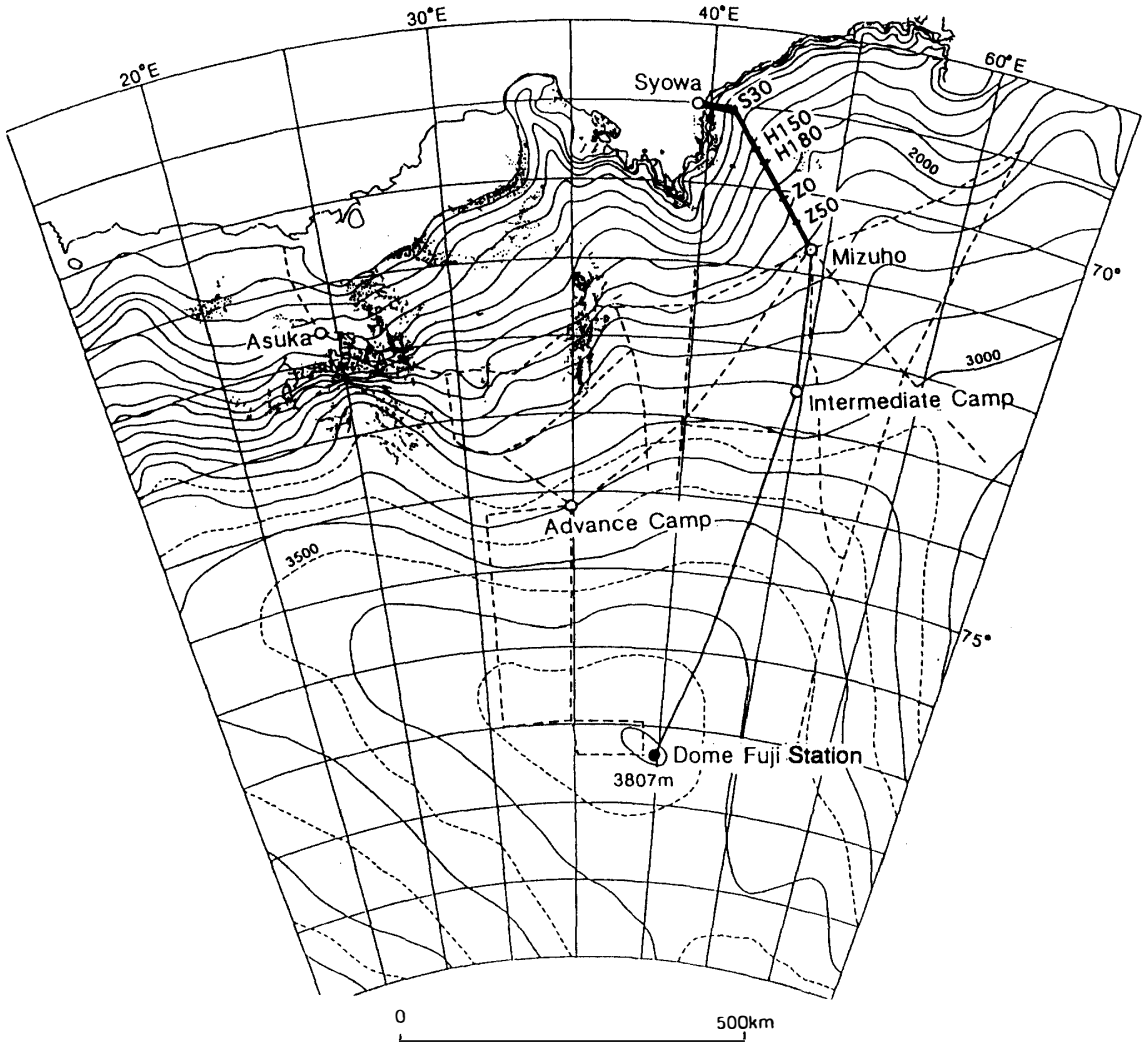

Fig. 1. Flight route of airborne observation. The observations were carried out between Syowa Station and Mizuho Station.

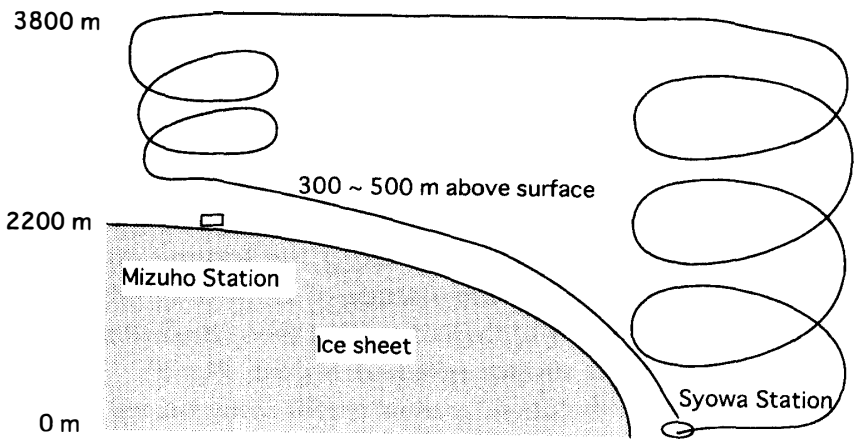

Fig. 2. Schematic diagram of vertical and horizontal flight patterns of airborne observation.

The observation flights were performed 7 times, on March 11, May 15, August 30, October 14, December 2 and twice on December 25, 1997.

3. Results and Discussions

Among seven flight observations made during the year, the flight on December 25, which was typical, and another on August 30, which was atypical are described in detail in the following sections. Results of all of the flights are then used to discuss seasonal variations.

3.1. Flight on the morning of December 25

As a typical example, results obtained from the flight on the morning of December 25 are explained in detail. Figure 3 shows variations of air pressure, temperature, humidity, dew point and number concentrations of aerosols with diameters greater than the indicated value (from 0.07 to 1.0μm). Water vapor decreased with ascent, stayed nearly constant along the horizontal flight, and increased slightly in the latter half of the horizontal flight. It then increased greatly with descent at Mizuho Station and remained high along the down slope flight. Aerosol particle concentration decreased on the ascent, slightly increased along the horizontal flight until around H150, and then decreased with some variation until Mizuho Station. On the descent, it showed a peak, varied greatly until around Z30, where humidity was also higher, then remained nearly constant until landing. Along the 3800 m horizontal flight, an anti-correlation is seen between water vapor and aerosol concentration; that is, water vapor increased when aerosol concentration decreased approaching Mizuho Station. This relation is also seen in other examples.

Vertical profiles for all the flight legs are shown in Fig. 4. Temperature decreased linearly to about 600 hPa, the altitude of the horizontal flight was made, and vertical distributions above Syowa Station and above Mizuho Station with the descent and return flight along the slope were parallel to one another. To determine the absolute amount of water vapor, water vapor mixing ratio is drawn in this figure. Due to decrease of air temperature, water vapor mixing ratio decreases rapidly along the ascent. The range of the mixing ratio during horizontal flight at an altitude of 3800 m is between 0.2 and 0.5 g/kg. The descent at Mizuho Station shows large variations in the mixing ratio, and also large variabilities continue during the down slope flight, indicating difficulties in keeping a constant altitude above the surface. Vertical profiles of the aerosol particle concentration show rather constant distribution, except for some high concentration layers seen during the descent at Mizuho Station and along the down slope flight, and a decrease from 600 hPa to 650 hPa. The high concentration layers at Mizuho Station might be due to the influence of drifting snow near the surface.

All the particle size distributions, shown in Fig. 5, are similar in shape, in spite of the region or height. When the size distribution is approximated by

$$\mathrm{d}N/\mathrm{d}\log D \propto D^{-\beta},$$

where N is particle number concentration (cm^{-3}) and D is particle diameter, the exponent β is about 4 for particles with diameter larger than 0.2μm. Below 0.2μm, the

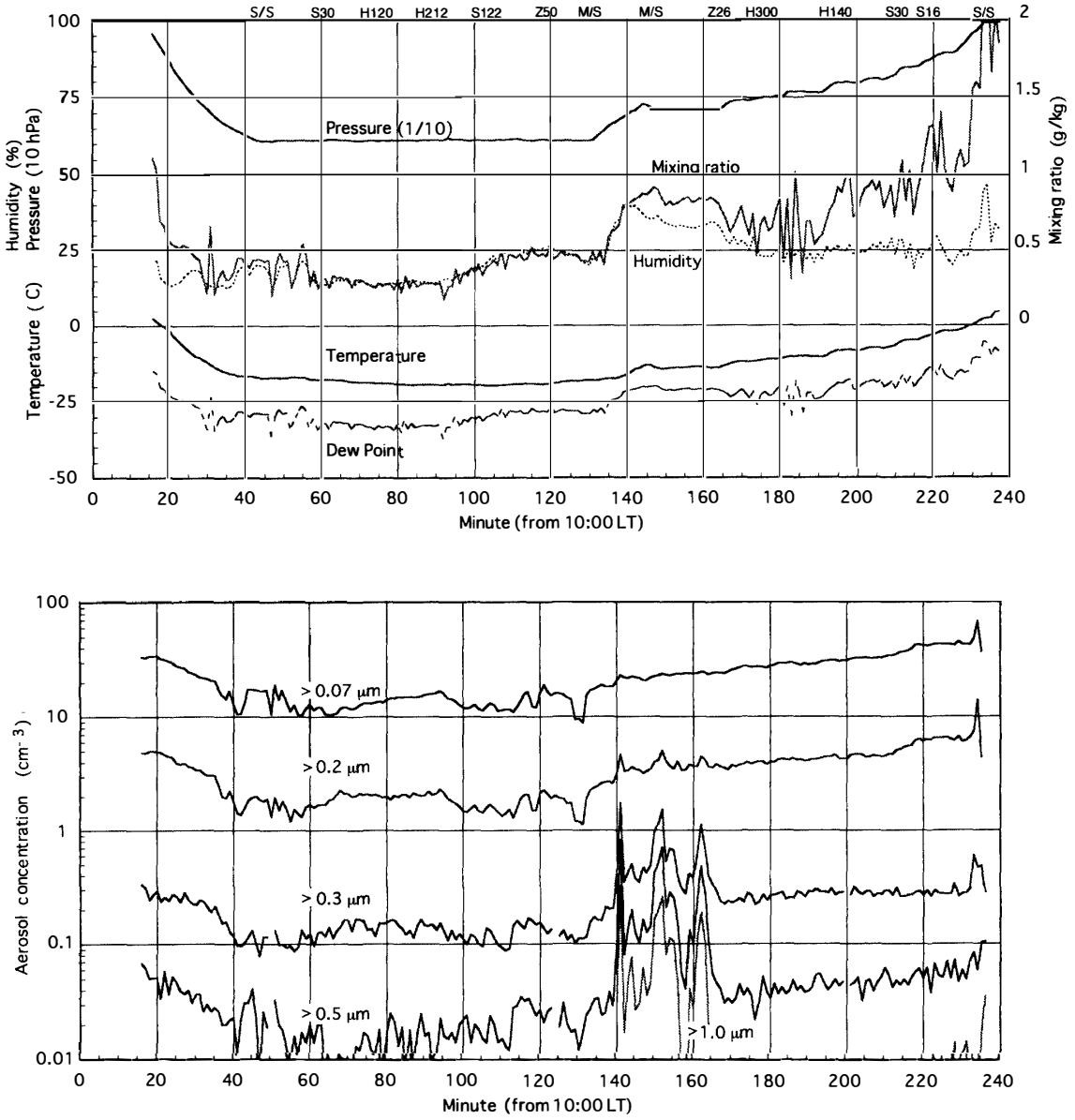

Fig. 3. Variations of air pressure, temperature, humidity, dew point, water vapor mixing ratio and number concentrations of aerosols with diameter greater than indicated values (from 0.07 to 1.0 μm) measured on the morning of December 25, 1997.

dependence on D is weakened and a peak is seen around 0.1 μm (ITO, 1985).

In order to assess the characteristics of the air mass and constituents, a scatter diagram of water vapor mixing ratio against aerosol particle concentration is shown in Fig. 6. In some part of the 3800 m horizontal flight leg, a vague anti-correlation is seen as in Fig. 3. Points from the ascent and from the 3800 m flight leg are distributed within a similar area, which indicates that these two parts of the atmosphere belong to the same air mass.

Also, potential temperature was calculated for the horizontal flight at an altitude of

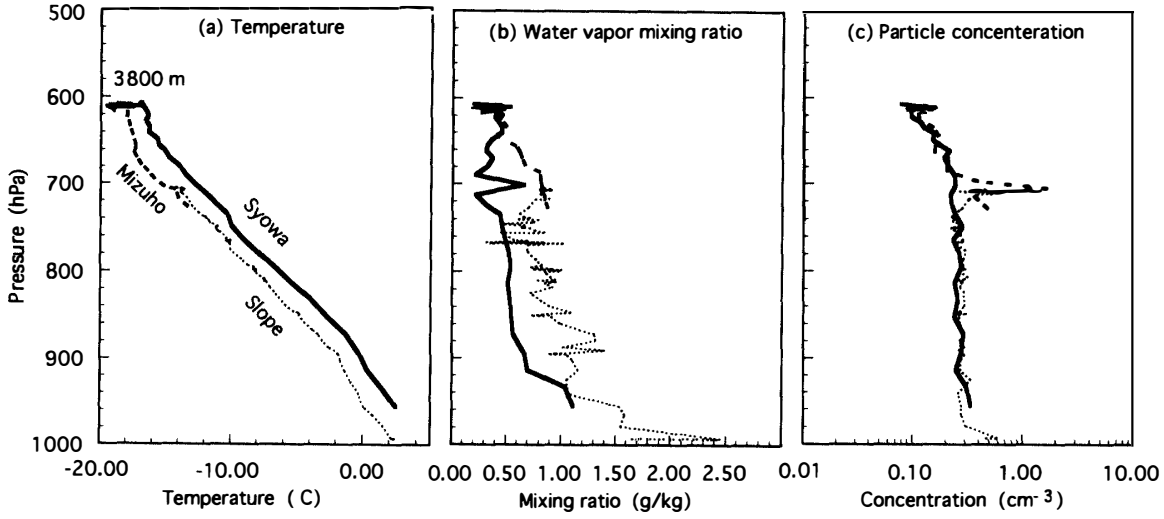

Fig. 4. Vertical profiles of temperature, water vapor mixing ratio and number concentrations of aerosols with diameters greater than 0.3 μm on the morning of December 25, 1997.

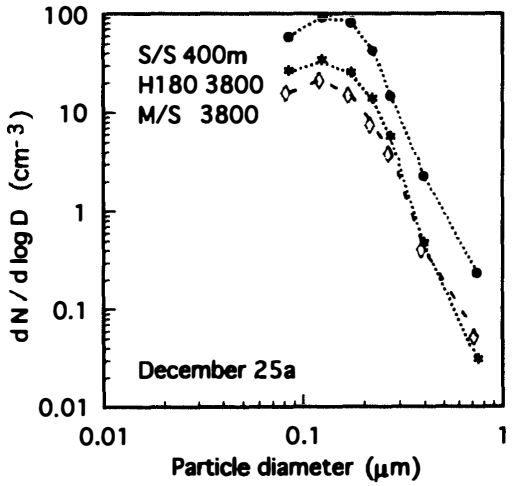

Fig. 5. Number-size distributions of aerosols at several locations on the morning of December 25, 1997.

3800 m. If the potential temperature changed noticeably during the horizontal flight, the variation of water vapor amount or aerosol particle concentration could be explained from the difference in the layer of the atmosphere. However, the variation of potential temperature is only within 3 degrees for the whole range from Syowa to Mizuho Stations. Even though water vapor mixing ratio increased nearly twice between 80 and 120 minutes (around H180–Z50), potential temperature remained within 1 degree.

3.2. Flight on August 30

Very large variance of aerosol concentration is seen in the flight on August 30. Figure 7 shows variations of air pressure, temperature, humidity, dew point temperature and aerosol number concentrations along the flight route. Air temperature gradually

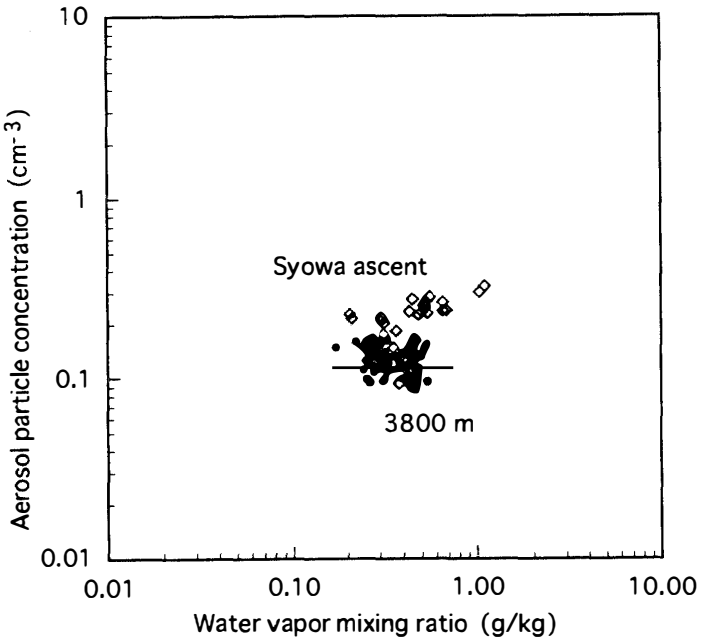

Fig. 6. Scatter diagram of water vapor mixing ratio against number concentrations of aerosol particles with diameters greater than 0.3 μm on the morning of December 25, 1997. Solid circles are for the horizontal flight at an altitude of 3800 m and white squares are for the ascent flight around Syowa Station.

decreases and then is nearly constant on the horizontal flight at an altitude of 3800 m above sea level. At Mizuho Station, temperature increases and then decreases for a while during descent, and varies gradually along the down slope flight. Water vapor amount once increases and then decreases during the ascent at Syowa Station. Then it is approximately constant for a while, and then increases slightly approaching Mizuho Station. The latter increase is similar to the result on the morning of December 25. On the decent over Mizuho Station, water vapor once decreases and then increases, and then at the end of down slope flight it increases greatly around point S30. Variation of aerosol number concentration is large. On the ascent above Syowa Station, aerosol concentration shows a very large peak, and then along the horizontal flight, it is also large at the beginning and then gradually decreases, and finally increases again approaching Mizuho Station. Aerosol number concentration continues to increase on the descent at Mizuho Station, and is stable along the down slope flight until the large increase at the end of the flight. These large peaks on the ascending and down slope flights correspond to the peaks of water vapor increase. The decrease along the horizontal flight approaching Mizuho Station corresponds to the water vapor increase.

Vertical profiles for all the flight legs are shown in Fig. 8. Temperature profile has a slight difference between the ascent above Syowa Station and descent at Mizuho Station. A large decrease of temperature, the surface inversion, is seen at Mizuho Station. The plane descended close to the surface and intruded into the surface inversion layer very close to the surface. Then, the plane maintained its altitude and left the inversion layer to a layer where the temperature distribution is quite similar to

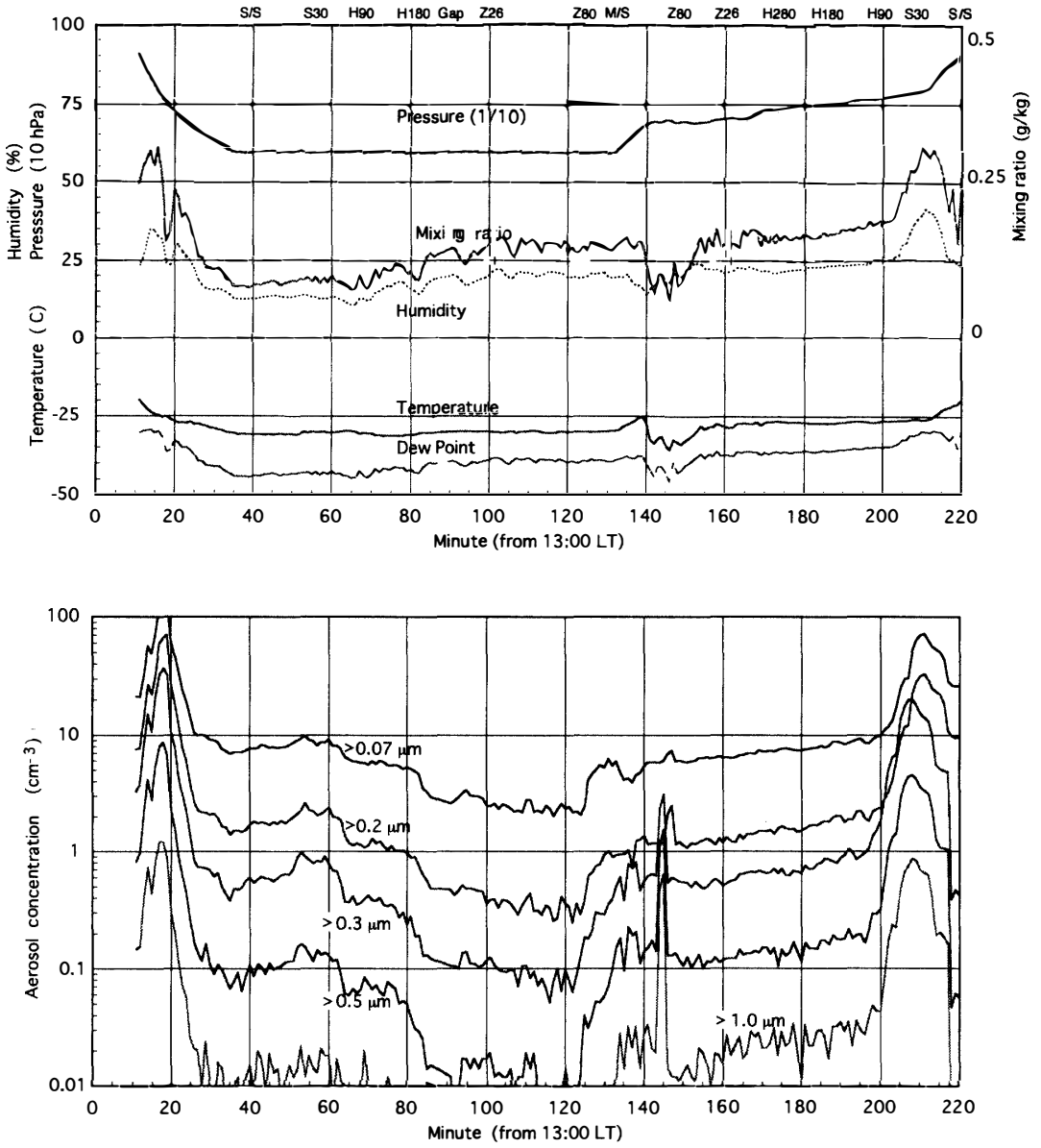

Fig. 7. Variations of air pressure, temperature, humidity, dew point, water vapor mixing ratio and number concentrations of aerosols with diameters greater than indicated values (from 0.07 to 1.0μm) measured on August 30, 1997.

that above Syowa Station. As expected from the time series in Fig. 7, the vertical profile of water vapor mixing ratio is very complicated with large variations. Generally, a layer with large water vapor mixing ratios exists above the surface, from about 900 hPa to 700 hPa, with a sharp drop around 750 hPa above Syowa Station, and a layer with large water vapor mixing ratio is also seen at low altitude during the down slope flight. At upper level, a higher mixing ratio exists in the vertical profile obtained at Mizuho Station. A very pronounced profile is seen in the aerosol concentration. A high concentration layer exists between 900 and 700 hPa with a peak at 750 hPa around Syowa Station. This large aerosol loading layer generally corresponds to the moist

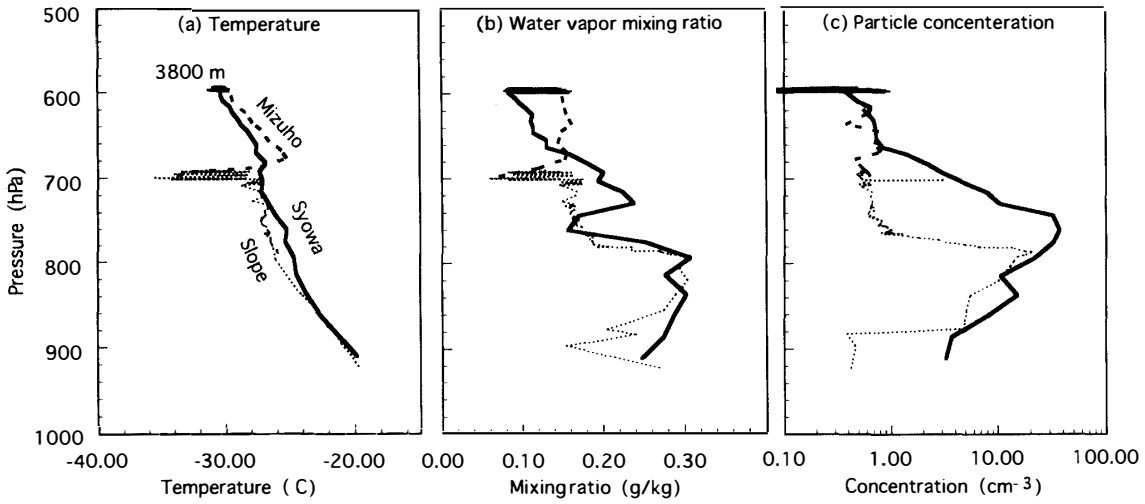

Fig. 8. Vertical profiles of temperature, water vapor mixing ratio and number concentrations of aerosols with diameters greater than 0.3 μm on August 30, 1997.

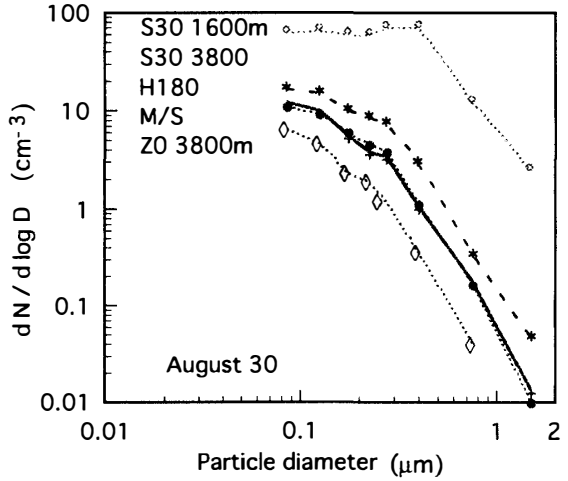

Fig. 9. Number-size distributions of aerosols at several locations on August 30, 1997.

layer; however, the water vapor mixing ratio shows a sharp drop within the layer. Above 650 hPa on the ascent flight and above 770 hPa along the down slope flight, the concentrations show steady variation, but still a factor of 2.5 larger than that in the morning of December 25 shown in Fig. 5. The results also show a large variation of more than one order of magnitude on the horizontal flight at an altitude of 3800 m.

Size distributions at several altitudes from the ascent flight around Syowa Station and several points along the horizontal leg are shown in Fig. 9. Size distributions show very large differences as compared to those on December 25, and some differences within each distribution on the same date. The number concentration of larger particles is noticeably large, and the slope of the size distribution is flat. An extremely flat size distribution with a diameter less than 0.4 μm is seen at the high concentration layer as in 1600 m layer at point S30.

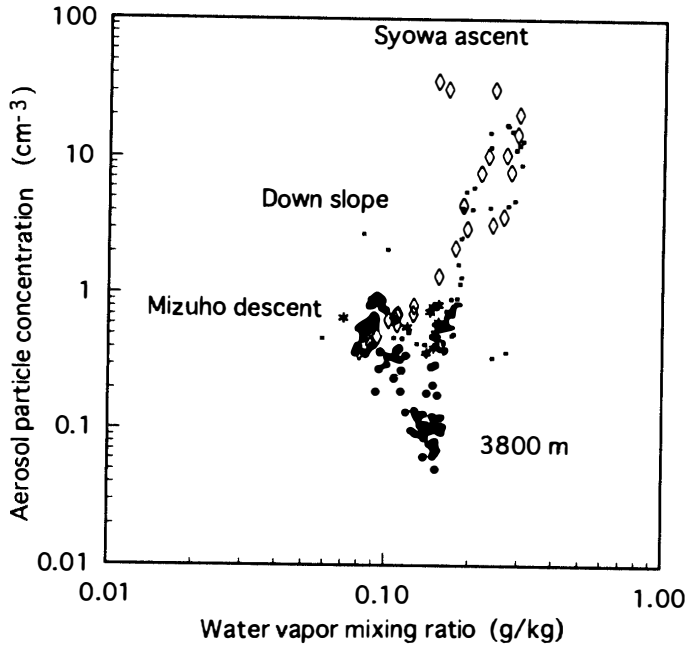

Fig. 10. Scatter diagram of water vapor mixing ratio against number concentrations of aerosol particles with diameters greater than 0.3 μm on August 30, 1997. Solid circles are for the horizontal flight at an altitude of 3800 m; white squares are for the ascent flight around Syowa Station; asterisks are for the descent flight at Mizuho Station and small dots are for the down slope flight.

A scatter diagram of water vapor mixing ratio against aerosol concentration is drawn as Fig. 10. Points from the ascent flight around Syowa Station and some points (bottom) from the horizontal flight at an altitude of 3800 m constitutes distinct clusters. However, some points from the horizontal flight at an altitude of 3800 m (near the coastal area) constitute the same cluster formed by points on the ascent flight above Syowa Station. The two clusters show different tendencies, the one from ascent flight and the one from the horizontal flight show vague correlation, indicating an air mass with high aerosol concentrations and high water vapor mixing ratios. Another cluster indicates an air mass with background aerosol loading, as seen in Fig. 6. Points from the descent at Mizuho Station and the down slope flight are distributed within the former clusters, indicating that air at Mizuho Station and air near the slope is rather similar to that around Syowa Station. Together with Figs. 7 and 8, intrusion of aerosols seems to occur with a wedge shape and the front of the air with high aerosol loading climbs up the slope at least to near Mizuho Station.

This result indicates that a very special event, intrusion of an airmass with high aerosol loading, occurred. A high concentration of aerosols occurred on August 28 at the surface, following the passage of a low pressure system as shown in Fig. 11, consisting of sea level pressure and 500 hPa height charts by the Japan Meteorological Agency (JMA analysis). It was snowing with blowing snow and strong wind on August 27 and 28; it became clear with drifting snow on August 29; and then it became clear with no drifting snow on August 30. At the same time, during August 28 and 29,

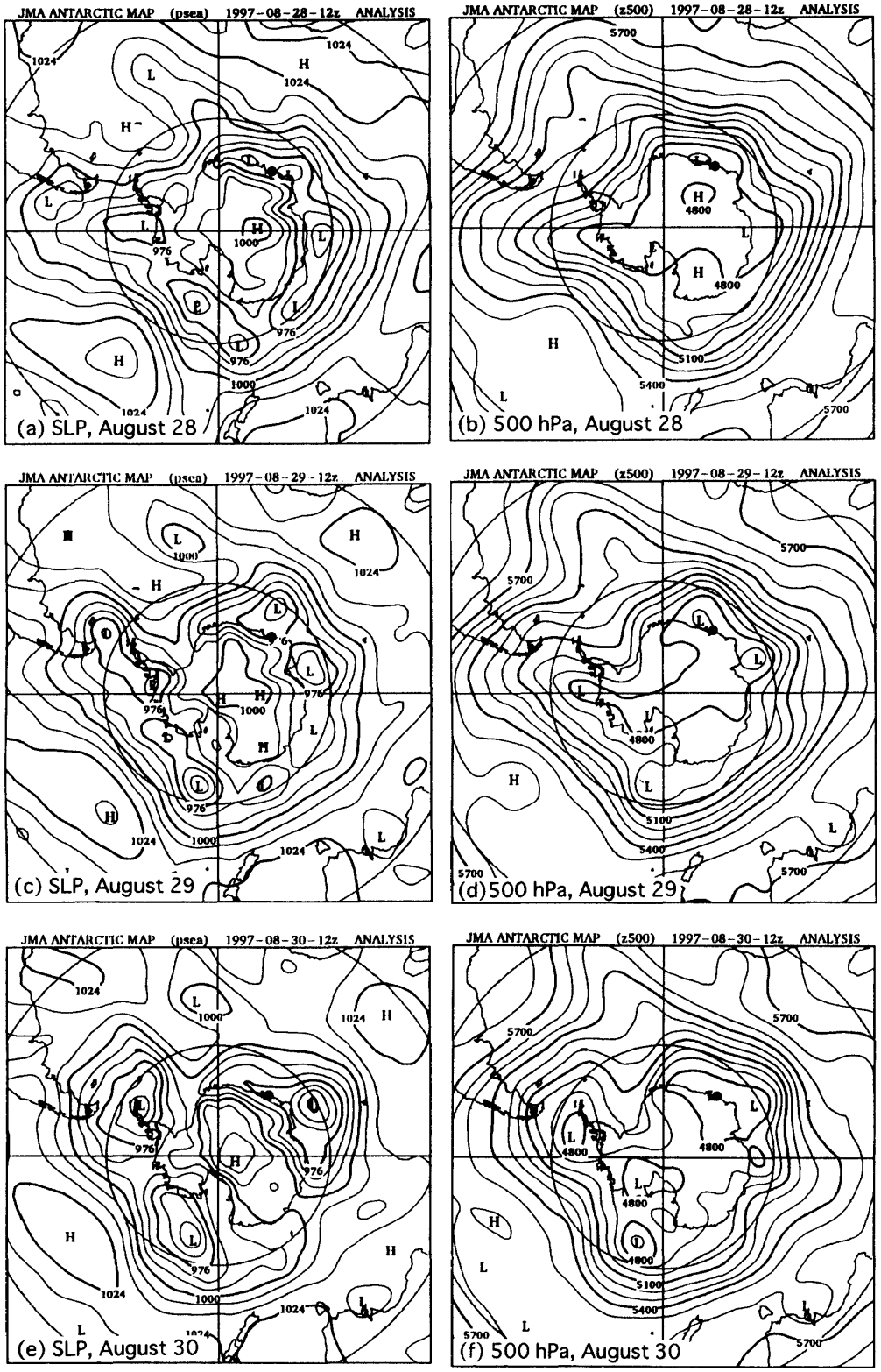

Fig. 11. Sea level pressure, (a), (c) and (e), and 500 hPa height, (b), (d) and (f), by JMA analysis at 12 GMT on August 28, 29 and 30, 1997, respectively. Solid circle shows the position of Syowa Station.

a sudden decrease of surface ozone to less than about 3 ppbv for about 23 hours was seen (ESAKI *et al.*, 1998). Esaki *et al.* also showed that the backward trajectory of an air parcel at an altitude of 500 m above sea level at Syowa Station originated from lower latitudes over the ocean during those days, while the trajectory was normally from over the continent. It seemed that this air mass with high aerosol loading ascended to the middle troposphere and intruded horizontally to about point H180 (about 120 km from the coast) at an altitude of 3800 m, and at least to Mizuho Station near the surface, at the time of the flight.

3.3. Seasonal variation from other flights

Distributions of water vapor and aerosols along the flight route were also observed on March 11, May 15, October 14, December 12 and on the afternoon of December 25. In order to save flight hours in the short day light season, the flight was made in the opposite direction on May 15. The flight on the afternoon of December 25 was made at a different height and the vertical profiles were obtained at several points, ascending flight around Syowa Station, at H280 and at S30, and descending flights at H120 and S 16. A level flight was made at an altitude of 2200 m from Syowa Station to H280.

Large variations of water vapor mixing ratio were seen on March 11, and May 15 near the coast, and sudden decreases of water vapor mixing ratio were seen near Mizuho Station on March 11 and December 2. Large variabilities of water vapor mixing ratio seen along the down slope flight were partly due to the difficulties in keeping constant flight altitude near the surface inversion layer (katabatic flow layer). Since the plane was equipped with no altimeter, altitude was maintained only manually, and it was very difficult to do over the slant snow surface. Rather stable but higher concentrations of particles with diameter larger than 0.3 μm were seen along the flight on October 14, similar to the values seen in the coastal area on the flight at an altitude of 3800 m on August 30. However, unfortunately, we had no data of smaller particles on October 14. On December 2 and on the afternoon of 25, simple vertical distributions of water vapor mixing ratio and aerosol concentration were seen. Along the 3800 m flight leg, gradual increases of water vapor mixing ratio were seen approaching Mizuho Station on March 11 and December 2, just as were seen on August 30 and December 25.

Vertical distributions of water vapor mixing ratio and aerosol particle concentrations from these flights are shown in Figs. 12a–j. The vertical profile of water vapor mixing ratio shows great differences according to the area and height. On March 11, higher mixing ratios in middle and lower layers are seen, and on May 15, a higher mixing ratio is seen in the upper layer above Syowa Station. On October 14, the mixing ratio was generally low, except in some lower layers along the slope. On December 2 and 25, mixing ratio gradually decreased with increase of height; it was generally higher on December 2 and lower on December 25. Comparing the same height, mixing ratio tends to be larger near the surface on December 2 and 25, except for the higher layer.

Vertical profiles of aerosol particle concentration with diameters larger than 0.3 μm shown in Figs. 12f–j, are rather similar compared to Fig. 4 on the morning of December 25. The vertical profile on March 11 shows some larger concentration layers at the lower level, and that on May 15 shows a simple increase with decrease of altitude; however, the general profiles resemble one another. On October 14, no special height

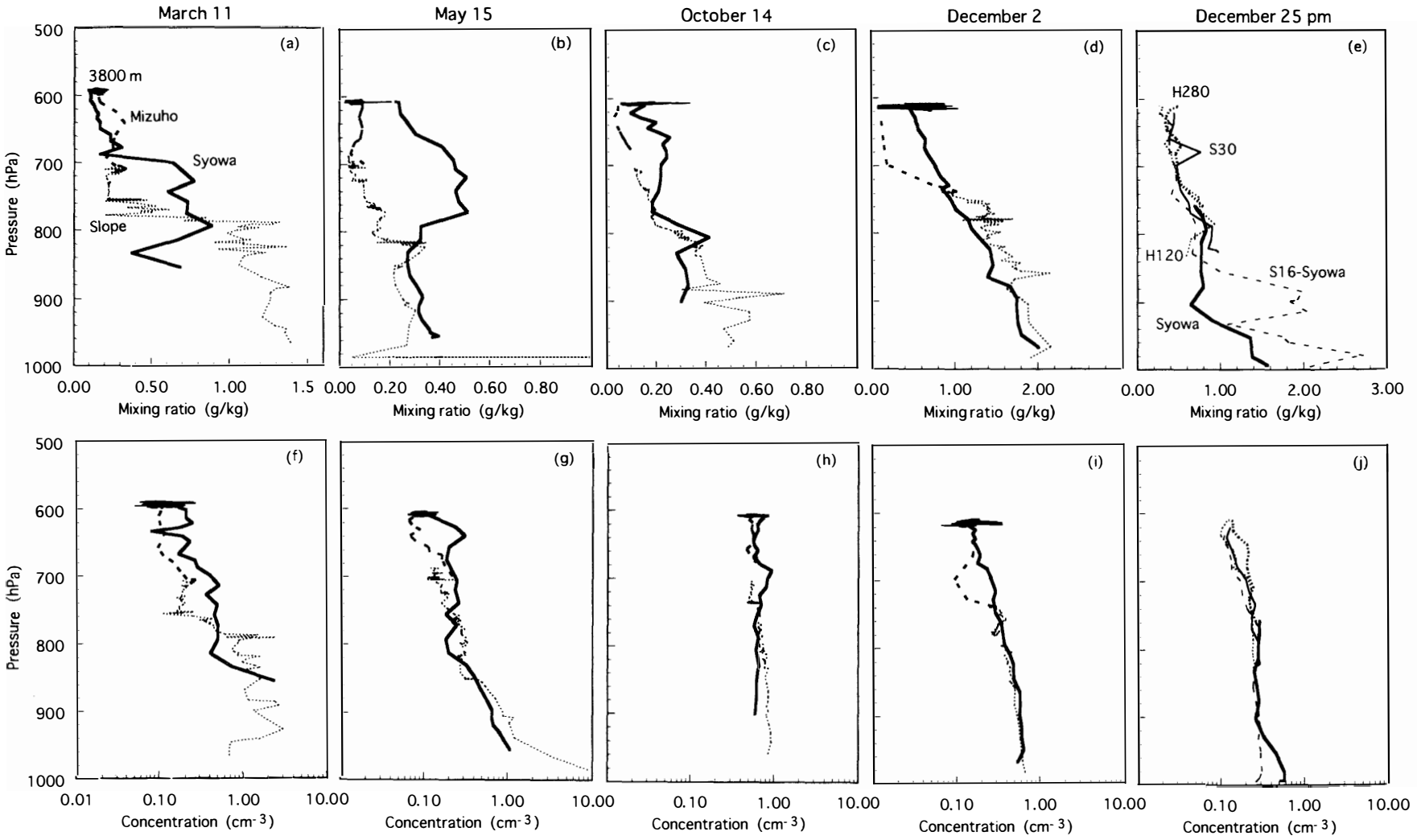

Fig. 12. Vertical profiles of water vapor mixing ratio, (a) to (e), and number concentrations of aerosol particles with diameters greater than 0.3 μm, (f) to (j), on March 11, May 15, October 14, December 2 and on the afternoon of December 25, 1997, respectively.

dependence is seen, just as on December 25 shown in Fig. 4 or Fig. 12j, but the amount is a little larger. The amount is similar to that of the lowest value seen at 670 to 600 hPa above Syowa Station or 600 to 700 hPa along the slope in the vertical profile on August 30. A slight dependence on height was seen on December 2; the concentration in the lower atmosphere is similar to that on October 14, and as low as on December 25 in the upper layer. Vertical distribution on the afternoon of December 25 again shows very slight dependence on the altitude. However, no meaningful difference is seen among the profiles in different regions and also no difference from the profile measured on that morning, except for some increases in the lowest layer. Extremely good mixing of aerosol particles was found in the middle and lower troposphere in October and December. Larger concentrations of aerosols in the lower layer in March and May suggest regular supply of sea-salt particles from open water close to Syowa Station; while no open water existed close to Syowa Station in October and December.

As noted in the previous paragraph, vertical profiles of aerosol number concentrations on March 11 and May 15 show some specific distributions. Particle size distribution was also examined, and number concentration of larger particles was rather large and size dependence was small on May 15, just as on August 30. On March 11 at all regions within the flight route, size dependence of particles smaller than 0.3 μm was large as found on December 25; however, that of particles larger than 0.3 μm was flatter. The number concentration of larger particles was rather large. The higher concentration of larger particles was characteristic on both days before winter.

4. Concluding Remarks

Vertical and horizontal distributions of water vapor and aerosol particles in the lower and middle troposphere were derived from airborne observations along the route between Syowa Station and Mizuho Station. Distribution of water vapor was variable, but larger mixing ratio usually appeared in the lower layer. In the horizontal distribution, larger water vapor mixing ratio was seen inland in four cases, and seems to be vaguely anti-correlated to the aerosol particle concentration. The relation between water vapor amount and aerosol concentration depended on the airmass; however, the cause is not certain.

Among seven flights made during the period from March to December 1997, concentrations of large aerosol particles with diameters larger than 0.3 μm decreased in the order August (even excluding the largest loading area), October, May, March and December. On the other hand, concentrations of smaller particles with diameters larger than 0.07 μm increased in the order August 30, May 15, December 2, December 25 and March 11. During spring and summer, vertical distribution of aerosols was very smooth and showed little difference between lower and upper layers. Generally, particle size distribution was steep in summer and flat in fall to winter, indicating an increase of larger particles and decrease of smaller particles in winter.

As seen in the results on August 30, high loading of aerosol particles together with moist air was transported into the inland middle troposphere on occasion of the passage of a low pressure system. A similar situation was also found at South Pole Station by HOGAN (1979) and HOGAN *et al.* (1982). It was assumed that large amounts of aerosol

particles and water vapor were transported into over the ice sheet by the intrusion of a maritime air mass with a low pressure system. This is similar to the transport of the heat, as explained by the sudden increase of surface air temperature at the inland Dome Fuji Station on the occasion of a blocking high (ENOMOTO *et al.*, 1998; HIRASAWA, 1999); however, the ratio of transport during this condition to the whole transport is not ascertained yet. From the present observation, such an intrusion of air with high aerosol concentration was only limited to one occasion, partly due to the smaller number of flights and also due to the restriction of flight operation to only clear calm weather. However, the effect on the total transport might be large, since the background aerosol concentration is very low in the Antarctic atmosphere.

In order to discuss the origin and transportation mechanism of aerosol particles, measurements of chemical components of aerosol particles are also indispensable. Also, much longer flights into the continent are to be made in the future. A long range flight inland is already planned to be made in 2000 by JARE-41.

Acknowledgments

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