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JAPANESE MAP RESULTS IN ANTARCTICA

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Abstract: As a major program of Japanese MAP, which was conducted in 1982–1985, the coordinated observations for the Antarctic middle atmosphere were carried out at and in the vicinity of Syowa Station. The observations were for the following six items: 1) Dynamics of the middle atmosphere, 2) Atmospheric constituents, 3) Stratospheric and tropospheric aerosols, 4) Wind, wave and tide in the stratosphere, 5) Atmospheric pollution, and 6) Particle precipitation and interaction of the middle atmosphere with the lower ionosphere. The results of some of these observations are reviewed in this report.

1. Introduction

The dynamics, structure, atmospheric composition and aerosol abundance of the middle atmosphere in Antarctica are different from those in middle and low latitude regions because of the differences in the geographic, geophysical and biochemical situations; namely, the importance of precipitating particles in the chemical and dynamical processes within the polar middlc atmosphere; the cooling of the atmosphere by the ice covering the Antarctic continent; an oblique or no incidence of the solar ultra-violet radiation; and the specific biochemical environment from which the minor constituents of the atmosphere originate.

As the biological and chemical activities in Antarctica are very low because of its severe natural environment, it is reasonable to consider that most of the minor constituents (of biological or chemical origin) in the Antarctic middle atmosphere have originated in middle and low latitude regions where these activities are very high. Based on the quantity of the stable minor constituents observed in Antarctica in relation to those in middle and low latitude regions, it is possible to discuss a large scale transport of the constituents in the middle atmosphere toward the polar region from lower latitudes. Furthermore, because Antarctica is the farthest from the middle and low latitude regions of the northern hemisphere with most dominant atmospheric pollution, the Antarctic region is the most suitable place for monitoring the global diffusion of the atmospheric pollution.

We therefore carried out intensive coordinated observations of the following items around Syowa Station (69°00′S, 39°35′E) in Antarctica:

(1) The mean patterns of temperature, pressure and density distribution and their seasonal evolution; and the influence of solar radiation and wind on them.

(2) Minor atmospheric constituents and excited species, and their vertical profiles and time variabilities.

(3) Role of the ozonosphere and quasi-recurrent features of sudden warming.

(4) Routine-based observations of the minor constituents in the middle atmosphere, such as CO_2, NO_x, CO, CH_4, O_3 and SO_2.

(5) Coordinated GBR (ground-based, balloon and rocket) observations to measure the distributions of O_3, NO_x, ion compositions and electron density, X-ray input and precipitating particle flux.

Successful operations at and in the vicinity of Syowa Station have brought significant information on the polar middle atmosphere. This report summarizes the experimental results of the coordinated studies.

2. Ozone Change over Syowa Station

The total amount of ozone was observed with Dobson spectrophotometer No. 122 (until January 1982) and No. 119 (in and after February 1982). Even during the polar night period the observation has been executed with the moonlight in recent years. The vertical distribution of ozone has been measured by a carbon iodine type ozonesonde. An intensified observation was carried out in 1982 by using 35 ozonesondes (CHUBACHI, 1984, 1985; CHUBACHI and KAJIWARA, 1986). Figure 1 shows the annual variation in total ozone over Syowa Station from February 1982 to January 1983. The annual variation shows two maxima in July and November. A sudden increase of the total ozone content occurred on October 28, 1982; it increased from 240 to 380 in units of 10^{-3} atm-cm within 34 hours. The data of ozonesonde soundings show that this event was associated with a stratospheric warming.

The year-to-year change of monthly mean values of the total ozone amount at

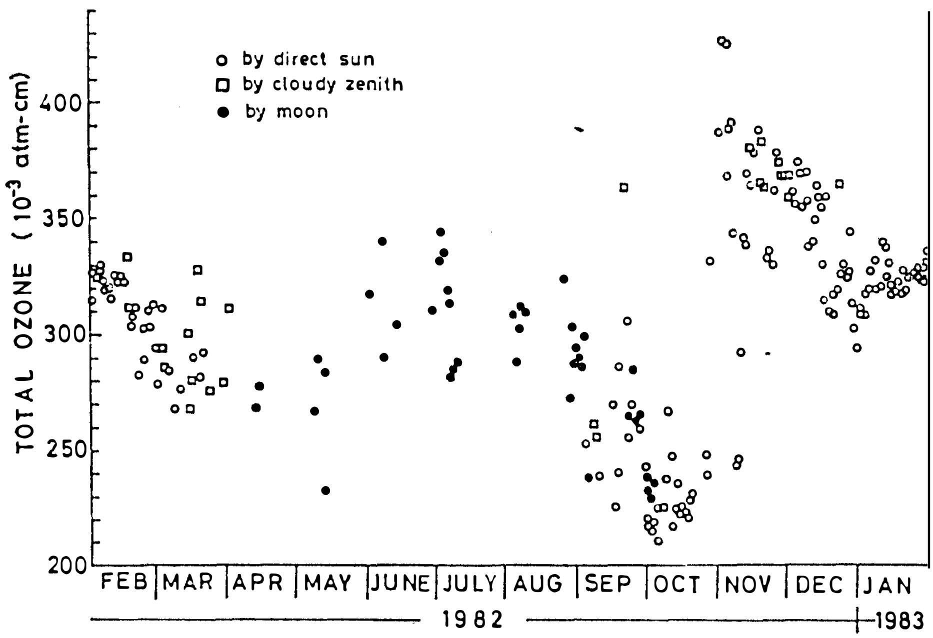

Fig. 1. Annual variation of the total ozone content over Syowa Station, Antarctica. Open circles: direct sun measurement, squares: cloudy zenith measurement, and full circles: moon measurement (after CHUBACHI, 1984).

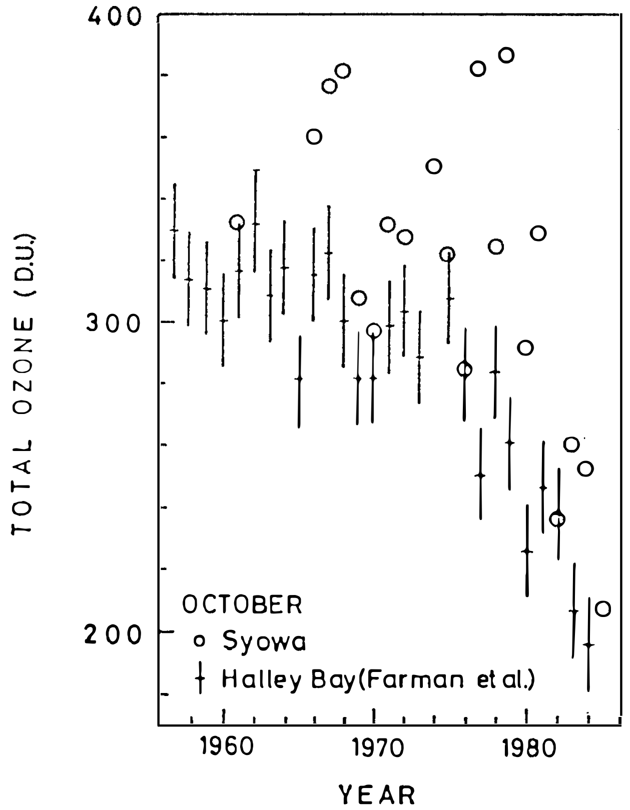

Fig. 2. Year-to-year change of the monthly total ozone content for October months, at Antarctic stations, Syowa and Halley Bay (after CHUBACHI and KAJIWARA, 1986).

Syowa exhibits a rapid decrease from 1982 to 1985, especially in spring months (October, November and December). In Fig. 2, monthly mean values of the total ozone amount are shown for October months during 1961–1985 together with the data from Halley Bay Station (FARMAN *et al.*, 1985). Although the total ozone amount at Syowa Station is, on the average, about 48 DU (10^{-3} atm-cm) higher than that at Halley Bay, the decrease in ozone amount with time is similar at both stations. A rapid decrease in ozone content began in 1977 at Halley Bay, while it began in 1982 at Syowa. This event is noticed as "ozone hole" phenomenon; the sudden depletion of the total ozone amount over the Antarctic. The rapid decrease in the total ozone amount in Antarctica was noticed at Syowa Station with ozonesonde and radiosonde data in the lower stratosphere (SEKIGUCHI, 1986). As is illustrated in Fig. 3, a very high correlation is found between monthly mean values of ozone content and those of stratospheric temperature for October and November. The correlation coefficients are 0.92 for October and 0.96 for November, respectively. This means that the rapid decrease of the Antarctic ozone content in recent years is caused by an extraordinary change in the stratospheric air circulation because a rapid decrease of the temperature in the lower stratosphere is observed simultaneously. IWASAKA and KONDOH (1987) reported that the active ozone loss region shows a good correspondency to the region where a noticeable drop in the stratospheric temperature is observed. They also showed that the temperature drops observed in the interannual trends activated

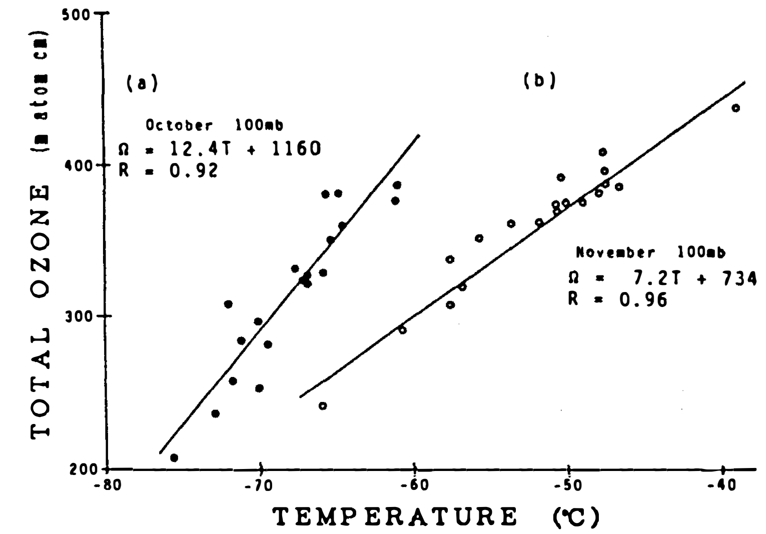

Fig. 3. Correlation between monthly mean values of total ozone content and 100-mb temperature over Syowa Station: (a) October and (b) November (after SEKIGUCHI, *1986).*

formation of ice particles and caused noticeable ozone loss in spring months through the reactions of heterogeneous ozone reduction.

Since February 1980, the data from TIROS-N/NOAA have been received at Syowa Station once a day. By using a simple statistical regression method, total ozone amount was obtained over the north-eastern part of the Antarctic for about 100 satellite orbits in 1981 and 1982 (SUZUKI *et al.*, 1985). The total ozone amount derived from the satellite data was compared with that from Dobson measurement. At Syowa Station the root mean-square (RMS) deviation from the regression is about 3 DU (10^{-3} atm-cm) in the season when the variation of ozone amount is small. For the data set at the South Pole, which is another Antarctic station where the total ozone observation was made on the ground, the RMS deviation is about 32 DU and the mean difference is about 5 DU (YAMANOUCHI *et al.*, 1984). Based on the assumption that the height of the peak of the ozone layer is proportional to the total ozone amount, the ozone amount is derived from the satellite data. A good agreement was found between the total ozone amount thus derived and that by Dobson measurement at Syowa Station during the period of a stratospheric sudden warming (RMS 12 DU). In the spatial dependence of the total ozone amount obtained from the satellite data, it was found that the region of abundant total ozone amount extends from the lower (60°S) to the higher (70°S) latitudes, sometimes to the inland of the Antarctic continent. A stratospheric sudden warming occurs at Syowa Station when the region of abundant total ozone reaches there. A good correlation was also detected between the ozone amount and the atmospheric temperature at 50–100 mb level (YAMANOUCHI *et al.*, 1984, 1985).

3. Stratospheric Aerosol

Lidar measurements for the aerosol content in the stratosphere were carried out at Syowa Station from 1983 to 1985 (IWASAKA *et al.*, 1985a, b, c; IWASAKA, 1986b;

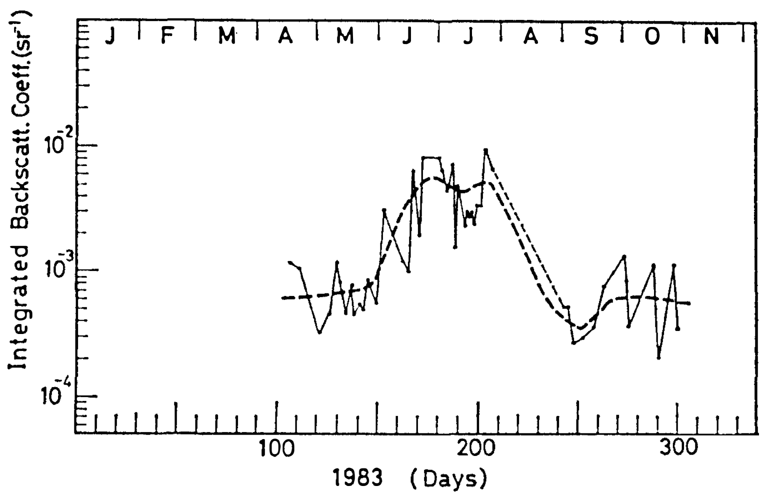

Fig. 4. Height-integrated backscattering coefficient of aerosols in the Antarctic stratosphere. There is no data during August 1983 (dotted line) (after IWASAKA et al., 1985b).

NOMURA *et al.*, 1985). The measurements revealed that a layer of extremely highly concentration of particles was formed in the winter stratosphere as illustrated in Fig. 4 (IWASAKA, 1985; IWASAKA *et al.*, 1985b) and that the depolarization ratio of lidar return from the layer was large (larger than 0.5) (IWASAKA, 1986a). Enhancement of antarctic stratospheric aerosol in winter, which is caused by an active growth of ice particles, is the most important feature of high-latitude stratosphere. A condensation growth of sulfuric acid droplets contributes to the enhancement of stratospheric aerosol in the early winter (IWASAKA, 1986c, d). Downward motion of the aerosol layer with the speed of 0.8 mm/s was found in winter (IWASAKA, 1986b). If the aerosol motion is substantial, this motion influences water vapor budget in the stratosphere (IWASAKA, 1986c).

Six aerosol sounding balloons were launched from Syowa Station during the years from 1983 to 1985 (MORITA *et al.*, 1985; ITO *et al.*, 1986). The concentration and size distribution of Mie particles (aerosol particles with diameter greater than 0.3 μm) were measured by using a light scattering aerosol particle counter. A layer of high aerosol concentration was found in the stratosphere during the flight on October 16, 1983. The numbers of aerosols in the high concentration layer were about 3 times larger than those during the period of low volcanic activity. The high-concentration aerosol layer could be attributed to the effect of the eruption of El Chichón in April 1982. Very high concentration layer of aerosols was also identified in the antarctic winter stratosphere on June 3, 1983. The aerosol concentration is about 10–15 times higher than that during the period of low volcanic activity. Though the effect of El Chichón's eruption is partly responsible for the enhancement of aerosols, this result gives direct evidence of "winter increase of the aerosol concentration in the antarctic stratosphere". Five Aitken particle sondes were flown from Syowa Station in 1983–1985 (ITO *et al.*, 1983, 1985a, b). The most important finding is that the high concentration layer of Aitken particles with nearly 1000/cc was observed in the lower stratosphere over Syowa Station in October 1983. In the stratosphere, it is hard to consider that SO_2 from El Chichón survived for more than fifteen months after the eruption. Therefore, it seems reasonable to attribute the high concentration Aitken particles in the stratosphere to the re-nucleation of sulphuric acid vapor. A drastic increase or decrease in the stratospheric temperature usually occurring in the antarctic spring must be playing an important role in such aerosol reactions.

In order to observe temporal variations of columnar amount and size spectrum of atmospheric aerosols, precise spectral measurements of the solar radiation were made at Syowa Station from January 1984 to January 1985 by a sunphotometer (SHIOBARA *et al.*, 1986a, b). The aerosol optical thicknesses obtained by the sunphotometry are greater in comparison with the values previously measured in the Antarctic. The aerosol optical thickness at $\lambda=500$ nm is about 0.08 on the average during January–April 1984, while it decreased to about 0.04 from September 1984 to January 1985. A wide-dynamic-range scanning radiometer (aureolemeter) was installed at Syowa Station to measure both direct-solar and diffuse-sky radiances automatically. The diffuse-to-direct radiation ratio in the solar almucantar, which is linearly related to the optical thickness determined by the sunphotometry, also decreased in the summer of 1985 to about one half of that observed in the summer of 1984. It is also found that the monomodal volume spectrum with a mode radius of about 0.4 μm is dominant throughout the year and that the loading of giant particles is enhanced in autumn and spring (SHIOBARA *et al.*, 1986a, b).

4. Minor Constituents in the Antarctic Atmosphere

The CO_2 measurements at Syowa Station were initiated using a flask sampling technique in January 1983 and by operating a continuous measurement system in February 1984 (TANAKA *et al.*, 1987). Since Syowa Station is isolated from vegetated lands and industrial regions, it is possible to detect precisely not only the mean rate of annual increase of the CO_2 concentration but also its small year-to-year fluctuations. Figure 5 illustrates that; (1) a regular diurnal variation is not observable; (2) irregular variations are sometimes observed with extremely small amplitude of 0.2 ppmv at most; (3) a seasonal variation shows the minimum concentration in mid-April and the maximum concentration in mid-October with the peak-to-peak amplitude of about 1.2 ppmv; and (4) annual mean values of the CO_2 concentration are 341.2 and 342.6 ppmv for 1983 and 1984, respectively.

For measuring the variation of the columnar density of atmospheric minor constituents, ground-based spectroscopic observations of the atmospheric infrared transmittance were carried out at Syowa Station from March 1983 to December 1986 (MURAMATSU *et al.*, 1983, 1984; MAKINO *et al.*, 1985). The columnar amount of N_2O deduced from the transmittance of solar radiation at 2576 cm^{-1} indicates a seasonal variation with two maxima in spring and autumn. By a least squares analysis of the solar spectra, it is shown that the deduced values of atmospheric methane from regions of 2600 cm^{-1} and 6000 cm^{-1} are well correlated each other, but the amount of the latter is 2.5–3.0 times greater than that of the former. The direct sunlight is measured in visible 430–450 nm range where the highly structured absorption bands of NO_2 exist. Seasonal variation of the total column density of stratospheric NO_2 shows the winter minimum of about 1×10^{15} cm^{-2} and the summer maximum of 7×10^{15} cm^{-2}. These

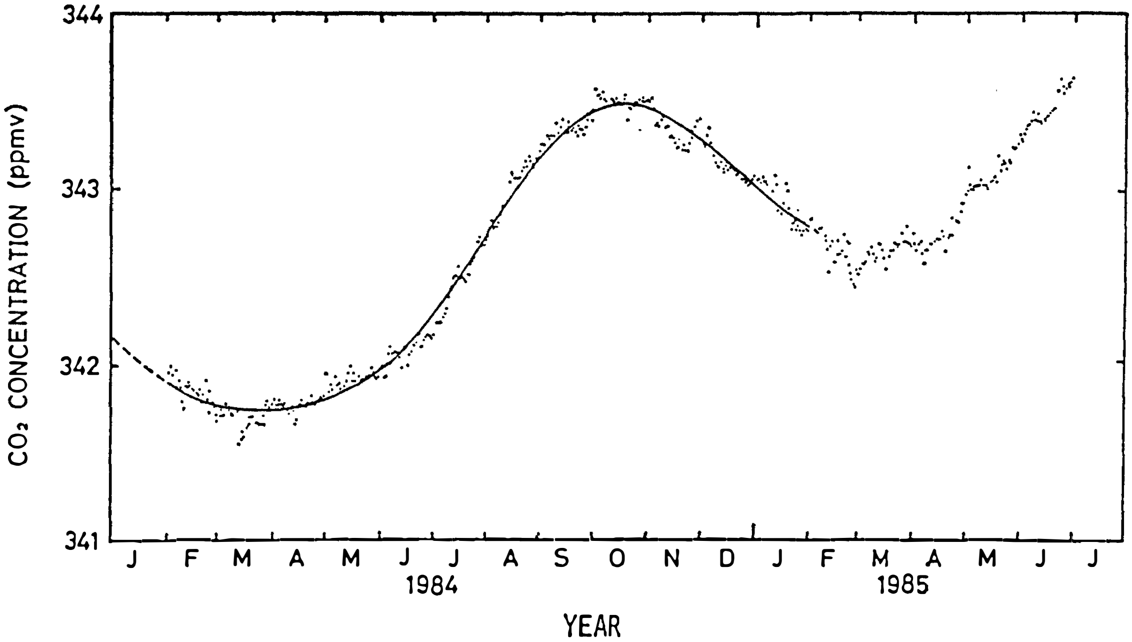

Fig. 5. Daily mean CO_2 concentrations at Syowa Station, obtained from hourly means with the standard deviations of less than 0.5 ppmv. Solid line shows a curve of best-fitting to the data. Values for the period February–June 1985 are plotted for reference (after TANAKA *et al., 1987).*

values are nearly equal to, but a little smaller than, those observed in northern high latitudes. A rapid increase in the column density of NO_2 occurred at the end of September before the minimum phase of total ozone amount in mid-October. This behavior suggests that the photochemical reactions in the stratosphere are related to the Antarctic ozone depletion (SHIBASAKI *et al.*, 1986).

The background atmospheric concentrations of halocarbons (CCl_2F_2, CCl_3F, CH_3CCl_3, etc.) and methane (CH_4) were measured and compared with those observed in the northern hemisphere in order to clarify transportations and lifetimes of these compounds in the atmosphere and to estimate their effects on the earth's environment. All samples collected in 1982–1985 at Syowa Station were analyzed by ECD gas chromatography (for halocarbons) and by FID gas chromatography (for methane) (MAKIDE *et al.*, 1983a). The concentrations of CCl_2F_2 in Antarctica in January–February 1982, 1983 and 1985 were 312, 331, and 359 pptv (pptv$=10^{-12}$ v/v), respectively, and those of CCl_3F were 169, 177, and 194 pptv. These concentration values are 8–10 % lower than those observed in mid-latitude Hokkaido Japan, 40–45°N (MAKIDE *et al.*, 1986). The concentration of CH_3CCl_3 is also about 30% lower in Antarctica (90 pptv in 1985) than those in Hokkaido in accordance with its relatively short atmospheric lifetime (6–7 years) due to the reaction with tropospheric OH radicals. The atmospheric concentrations of CCl_2F_2 and CC_3F in the both hemispheres increase steadily by 4–5% every year with their persistent world-wide releases (total 700 kt/year) and their extremely long lifetimes in the atmosphere exceeding 70 years (probably 80–150 years) (MAKIDE *et al.*, 1983b, 1985, 1986).

Another measurements of surface CF_2Cl_2, $CFCl_3$ and N_2O were carried out during the period from 1982 to 1985 in order to get the latitudinal variations from Japan to

Antarctica (Hirota *et al.*, 1984a, 1985) and the vertical distributions of the atmospheric minor constituents in Antarctica (Hirota *et al.*, 1984b). Along the route from Tokyo to Syowa Station, the volume mixing ratios of CF_2Cl_2 and $CFCl_3$ decreased toward the equator and were almost constant in the southern hemisphere. As for N_2O, no gradient in the mixing ratio was found between Tokyo and Syowa Station. Air samples were collected up to an altitude of 7.3 km by an aircraft over Syowa Station on January 24, April 5, October 18 and December 12, 1983. CF_2Cl_2, $CFCl_3$ and N_2O were vertically well mixed up to the altitude of 6 km in all flights. Above 6 km, CF_2Cl_2 and $CFCl_3$ seem to decrease slightly.

Balloon observations for stratospheric NO_2 profile were made on November 24, 1982 and November 12 and 20, 1983 at Syowa Station. Vertical profiles were determined from the variations of slant column densities with solar zenith angles. Above 25 km altitude, three profiles of NO_2 amount were basically identical to those observed at middle and high latitudes in the northern hemisphere. In the lower stratosphere below 25 km, variability in NO_2 density is large due to dynamical effects (Shibasaki *et al.*, 1986).

The balloon flights for the measurement of ion pair production were conducted on November 24, 1982, November 12 and 20, 1983. Three profiles of ion pair production rate were obtained up to about 29 km height. Since cosmic rays are the main source of ion pair production rate in the lower stratospheric layer, the rate depends on the geomagnetic latitude of the observing site and the solar activity. The obtained results show an inverse dependence of ion pair production rate on solar activity (Minami *et al.*, 1982, 1983).

5. Neutral Winds and Gravity Waves

The 50- and 112-MHz pulsed-doppler radars, which are fully controlled by a mini-computer, were operated at Syowa Station from 1982 to 1985. They have a nominal peak power of 15 kW, narrow antenna beams (about 4 degrees in the horizontal plane) in two directions (approximately geomagnetic south and geographic south) with a crossing angle of 33 degrees and three operation modes (specrtum, double-pulse and meteor mode) (Igarashi *et al.*, 1982). The two beams enabled us to determine the large-scale two-dimensional doppler velocities. Major objectives were to measure the echo intensities and doppler velocities of the auroral echoes and to detect the meteor echoes in the 80–100 km altitudes. Using the spectrum and double-plus modes, Igarashi *et al.* (1985, 1986) made case studies of the ionospheric electric fields during auroral substorms. The 50-MHz radar could also act as a meteor radar. Ogawa *et al.* (1985) investigated the altitudinal distribution and occurrence probability of the meteor echoes and the zonal and meridional components of neutral winds. It was confirmed that the mean meridional flow in the summer upper mesosphere was equatorwards with the velocity of the order of 10 m/s. They also found the evidence that the neutral wind motions derived from the observed doppler velocities of meteor trails were affected partly by the ionospheric electric fields appearing during the geomagnetically disturbed condition.

The measurements of gravity waves and tides were carried out by a combination of ground-based remote sensing (laser radar, meteor radar) and *in situ* measurements by rocketsondes. By the laser radar with a tunable dye laser, NOMURA *et al.* (1985) detected the atmospheric sodium layer in the 80–100 km region and the vertical profile of sodium concentration in the 30–80 km region. By using the meteor radar motions of atmospheric air in the 80–100 km region were measured. Meteorological rocket experiments were carried out at Syowa Station in 1985 for investigationing the behavior of internal gravity waves in the Antarctic middle atmosphere. Five rockets were launched successively every two hours on June 28 and four rockets on September 25, 1985. Disturbances identified as internal gravity waves were detected in the two trials of successive rocket launches. The following characteristics of the waves were found in the obtained data of the two rocket experiments; (1) the upward phase propagating in the stratosphere; (2) the vertical wavelength being about 10 km; (3) the period being about 10 hours; and (4) the wave amplitudes in the upper stratosphere being about 10–20 m/s for winds and about 5 K for temperature.

6. Concluding Remarks

In the polar regions, energy sources associated with particle precipitations could exert much influence on the energetics and dynamics of the middle atmosphere. Joule heating of auroral electrojet is one of the energy sources for the changes in the composition of minor constituents. The auroral particle precipitations were measured by a meridian-scanning photometer, a zenith photometer and riometer. The spatial distribution and motion of auroras were measured by all-sky camera and low-light-level TV camera with a fish-eye lense. Auroral electrojet currents were monitored by a magnetometer. Simultaneous measurements of auroral precipitating electrons, magnetic and electric field variations and electromagnetic waves were carried out by sounding rocket. Auroral X-rays and electric fields were observed by balloon.

Although both the Arctic and the Antarctic are located in the polar regions, their geographical and biochemical environments are very different from each other. It has been pointed out that the difference between the Arctic and the Antarctic regions is largest in winter insofar as the average structure, dynamics, constitution and aerosol content in the middle atmosphere are concerned. In order to compare the dynamics, structure and composition in the both hemispheres, the emphasis was placed on making coordinated GBR observations in the both hemispheres. The desirability is stressed on the southern-northern polar atmosphere comparisons, *e.g.* the coordination with other international and national MAP projects in the northern polar region such as Winter in Northern Europe Project, Global Observations and Studies of the Stratospheric Aerosols, Cold Arctic Mesopause Project and USSR Arctic MAP observation, etc.

The results of the investigation during MAP in Antarctica have supplied us with significant information about the Antarctic middle atmosphere. However, the investigation is still in progress and will be more and more fruitful. All experiments around Syowa Station were made as one of the special project of the Japanese Antarctic Research Expedition (JARE). We are very grateful to the members of JARE-23, -24,

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