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ON THE STRATOSPHERIC OZONE LOSS OVER EUREKA STATION IN THE CANADIAN ARCTIC

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Abstract: Ozone sonde data at Eureka (80°N, 86°W) since 1993 have been analyzed. Monthly average temperature at 50 hPa (T_{50}) and total ozone in winter have a positive correlation (slope is 3.5 m-atm cm/°C and correlation coefficient is 0.84). However, there is a trend in the correlation from 1993/94 to 1996/97. Both the slope and correlation coefficient decreased from 5.1 and 0.8 in 1993/94 to 2.3 and 0.3 in 1996/97, respectively. This is because the total ozone has been low irrespective of T_{50} in recent seasons.

In the lower stratosphere (475 K level), a positive correlation between potential vorticity (PV) and ozone mixing ratio is expected. This relation seems to have held well at Eureka in the first half of each observation period. Thereafter, however, ozone mixing ratio seems to decrease from that expected from the PV change.

These observations are consistent with the occurrence of chemical ozone loss. Especially in 1996/97, coexistence of PSCs and solar radiation after February would have depleted the ozone in large quantities.

1. Introduction

In relation to large ozone loss in the Arctic lower stratosphere, we have made lidar observations of polar stratospheric clouds (PSCs) in winter at Eureka (80°N, 86°W), one of the primary stations of the Network for the Detection of Stratospheric Change (NDSC), since 1993 (NAGAI *et al.*, 1997b). Ozone sonde observations have also been made there except in summer, usually once a week and whenever PSCs were observed. This paper reports the results of ozone sonde observations from September 1993 to April 1997.

2. Method

ECC type ozone sondes were used. Numbers of observations are shown in Table 1. In winter, 9 to 12 sondes/month on average were launched. Plastic balloons were used in order to lift the sonde to the altitude of 30 km. Column amount of ozone (total ozone) was calculated from the vertical ozone profile, when the ozone sonde reached an altitude higher than 17 hPa. Numbers of data are shown in parentheses in Table 1.

Table 1. Number of ozone sonde observations at Eureka from September 1993 to April 1997.

	1993	1994	1995	1996	1997	total
January		8 (7)	15 (15)	12 (11)	13 (6)	48 (39)
February		6 (6)	12 (9)	5 (3)	12 (11)	35 (29)
March		4 (4)	16 (16)	11 (9)	12 (9)	43 (38)
April			4 (4)		4 (3)	8 (7)
May						
June						
July						
August		5 (4)	5 (5)			10 (9)
September	5 (5)	4 (4)	4 (4)			13 (13)
October	4 (2)	4 (4)	4 (2)	5 (4)		17 (12)
November	3 (3)	5 (3)	5 (5)	4 (4)		17 (15)
December	11 (10)	10 (8)	15 (14)	11 (4)		47 (36)
Total	23 (20)	46 (40)	80 (74)	48 (35)		238 (198)

Numbers in parentheses are the numbers of total ozone data.

Temperature data were also obtained by ozone sonde observations.

3. Results and Discussion

3.1. Total ozone

Mean monthly average total ozone at Eureka is shown in Fig. 1, together with the corresponding values at Resolute (74.7°N, 95°W, about 600 km south of Eureka) since 1963 (NEWELL and SELKIRK, 1988; ATMOSPHERIC ENVIRONMENT SERVICE OF

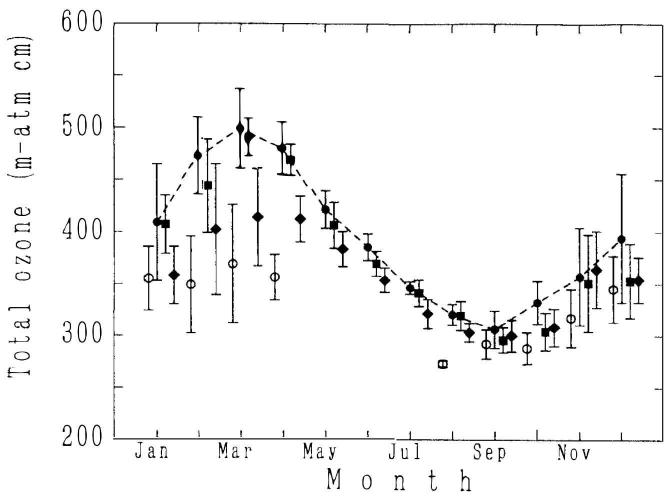

Fig. 1. Mean monthly average total ozone.
●: *Resolute, January 1963–December 1979.* ○: *Eureka, September 1993–April 1997.*
■: *Resolute, January 1980–December 1989.* I: *standard deviation.*
◆: *Resolute, January 1990–June 1997.*

CANADA, 1980–). Data at Resolute were obtained first with a Dobson and more recently with a Brewer spectrophotometer. Because the correction factor in ozone sonde observation was nearly equal to 1.0 (WMO, 1991), it is possible for the total ozone calculated from ozone sonde data to be compared with that at Resolute.

In the 1960s and 1970s, data at Resolute show a maximum in March and a minimum in September. In the 1980s, mean values in December and February decreased clearly, and in the 1990s, ozone loss between December and April has been remarkable. The data from Resolute suggest that the total ozone at Eureka in winter to early spring should have been higher in 1960–1990 than the values observed in the 1990s, and that the minimum value in summer has almost never changed.

Monthly averages of total ozone at Eureka since 1993/94 are shown in Fig. 2, together with monthly average temperatures at 50 hPa (T_{50}). In winter of 1993/94, both T_{50} and total ozone were low in February. In 1994/95, T_{50} increased from December to February and decreased to March. Total ozone also showed a similar variation. In 1995/96, both T_{50} and total ozone were low from December to February, and increased to March. In 1996/97, T_{50} was high in December and low from January to March. The values of T_{50} were -79.3°C in February and -78.0°C in March, respectively. Total ozone was generally low, especially in March. Average total ozone was 286 m-atm cm in March. All of the monthly avearge data of T_{50} and total ozone are shown in Fig. 3. Solid circles indicate values in winter (December to March (to April in 1995 and 1997)). Figures 2 and 3 indicate that both T_{50} and total ozone in winter decreased from 93/94 to 96/97 and that they have a positive correlation (slope is 3.50 m-atm cm/°C and correlation coefficient is 0.84). However, Fig. 3 shows only an average relation from 1993/94 to 1996/97. Table 2 shows the relation between daily total ozone

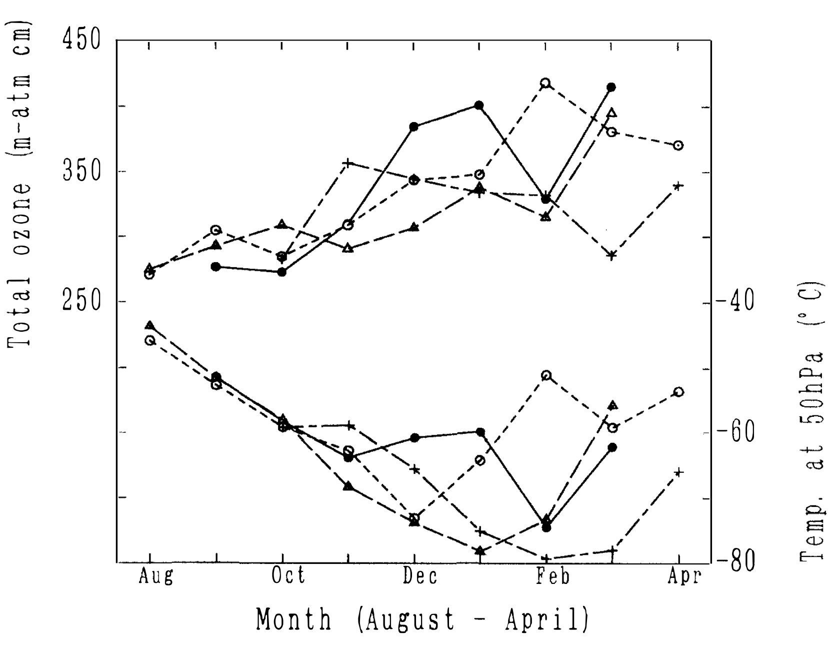

Fig. 2. Monthly average total ozone and temperature at 50 hPa at Eureka.
●: 1993/94, ○: 1994/95, △: 1995/96, +: 1996/97.

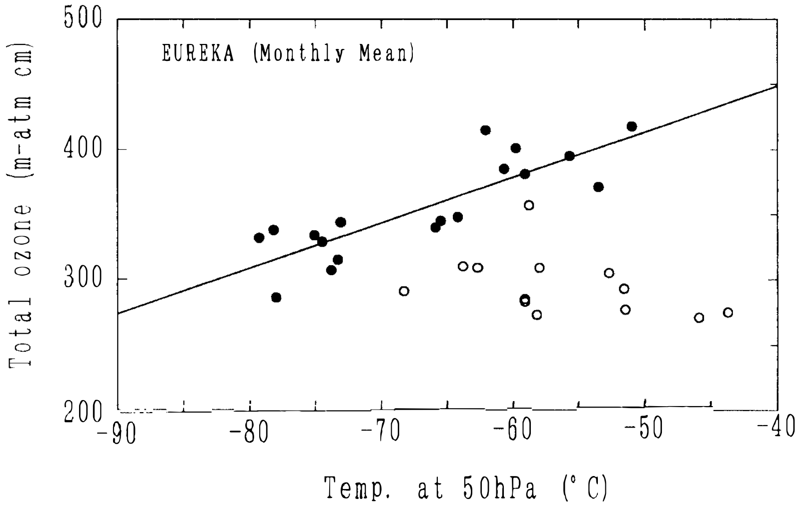

Fig. 3. Monthly average total ozone and temperature of 50 hPa at Eureka.
●: December-April. ○: August–November.
—: linear relation in winter (December to April)
slope; 3.50 m-atm cm/°C, correlation coefficient; 0.84.

Table 2. Relation between total ozone and temperature of 50 hPa and 100 hPa at Eureka.

	50 hPa	100 hPa
Monthly mean (December–April)	3.498 (0.840)	4.574 (0.763)
1993/94	5.149 (0.774)	5.996 (0.652)
1994/95	4.164 (0.813)	4.921 (0.755)
1995/96	3.623 (0.738)	4.492 (0.588)
1996/97	2.252 (0.329)	2.782 (0.418)

Slope (m-atm cm/°C) and correlation coefficient in parentheses.

and daily T_{50} in each winter, and indicates the trend from 1993/94 to 1996/97. It is evident that both slope and correlation coefficient decrease from 5.1 and 0.8 in 1993/94 to 2.3 and 0.3 in 1996/97, respectively. This is because the total ozone was low irrespective of T_{50} in recent seasons. This would be due to the continuous presence of PSCs in the vortex in recent seasons (see Section 3.2).

In Table 2, the relation between total ozone and temperature at 100 hPa is also shown. Their relation, however, is not so good as that between total ozone and T_{50}.

3.2. Ozone vertical profile

Mean monthly average ozone vertical profiles at Eureka in summer and autumn, and those in winter and spring, are shown in Figs. 4a and 4b, respectively. In summer, the ozone layer at Eureka was thin and high in altitude, and thick and low from

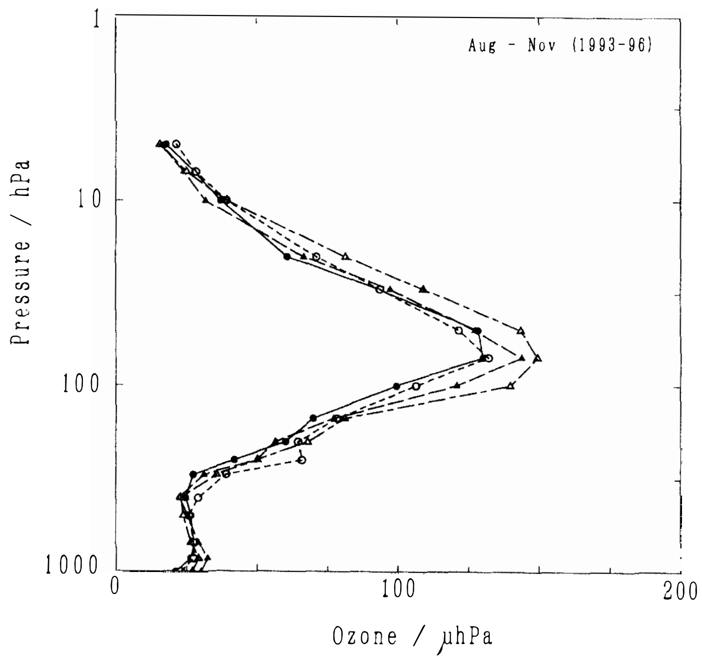

Fig. 4a. Monthly average ozone vertical profiles at Eureka. August–November (1993–1996).
●: August, ○: September, ▲: October, △: November.

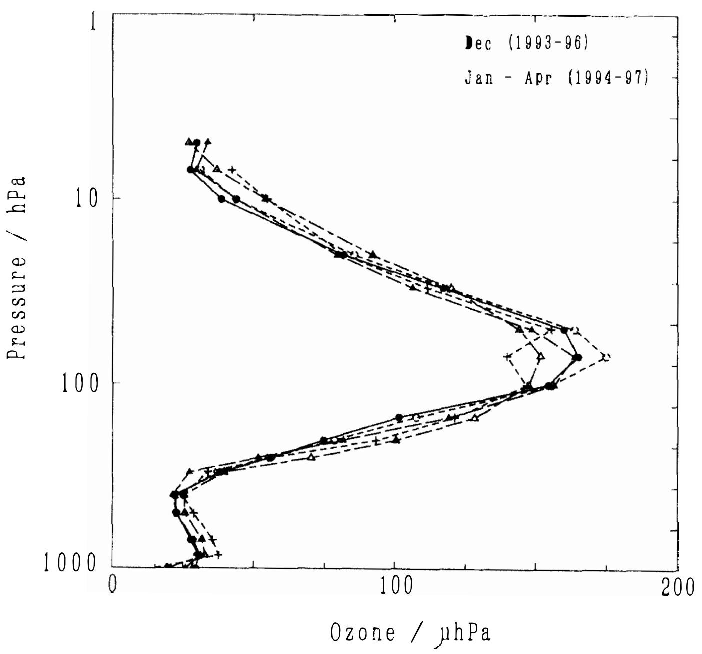

Fig. 4b. Monthly average ozone vertical profiles at Eureka. December (1993–1996) and January–April (1994–1997).
●: December, ○: January, ▲: February, △: March, +: April.

winter to early spring. These were similar to those observed at Resolute (FIOLETOV *et al.*, 1997).

The isentropic potential vorticity (PV) of the 475 K potential temperature level (18–20 km) in the lower stratosphere at Eureka is shown in Fig. 5. Judging from the PV maps of the Japan Meteorological Agency at 475 K potential temperature, Eureka with a PV value higher than 40×10^{-6} $Km^2s^{-1}kg^{-1}$ was within the polar vortex. In 1993/94, Eureka was inside the vortex in the middle of February and from the end of February to early March. In 1994/95, Eureka was inside the vortex in the middle of December, in the first half of January and from the middle of February to the middle of March. PSCs were first observed on 12 to 16 December (19–24 km), and then on 5 to 9 and 11 to 14 January (14–21 km) (NAGAI *et al.*, 1997b). In 1995/96, Eureka was inside the vortex from January to the middle of March. PSCs were observed on 15 to 20 December and 4 to 14 January (20–24 km) (NAGAI *et al.*, 1997a). In 1996/97, Eureka was inside the vortex from late January to early April. PSCs were observed on 10 to 21 and 25 to 27 February (14–23 km), when our observation was terminated. According to DONOVAN *et al.* (1997), PSCs were observed as late as 18 March. Figures 6a–6c show PV at 370 K (12–14 km), 475 K and 550 K (21–23 km) potential temperature levels together with ozone mixing ratios at the same levels in seasons when PSCs were observed. The periods when PSCs were observed are shown in Fig. 6b. At the 370 K level, PV is rather constant. At the 550 K level, the correlation

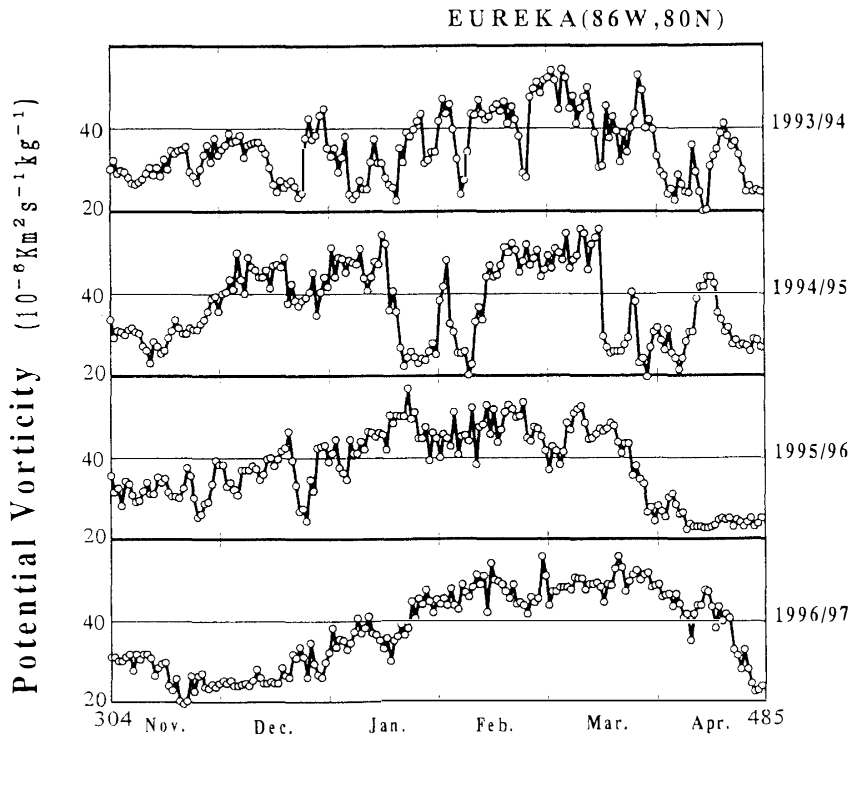

Fig. 5. Potential vorticity of the 475 K potential temperature level at Eureka. Potential vorticity: $\times10^{-6}$ $Km^2s^{-1}kg^{-1}$.

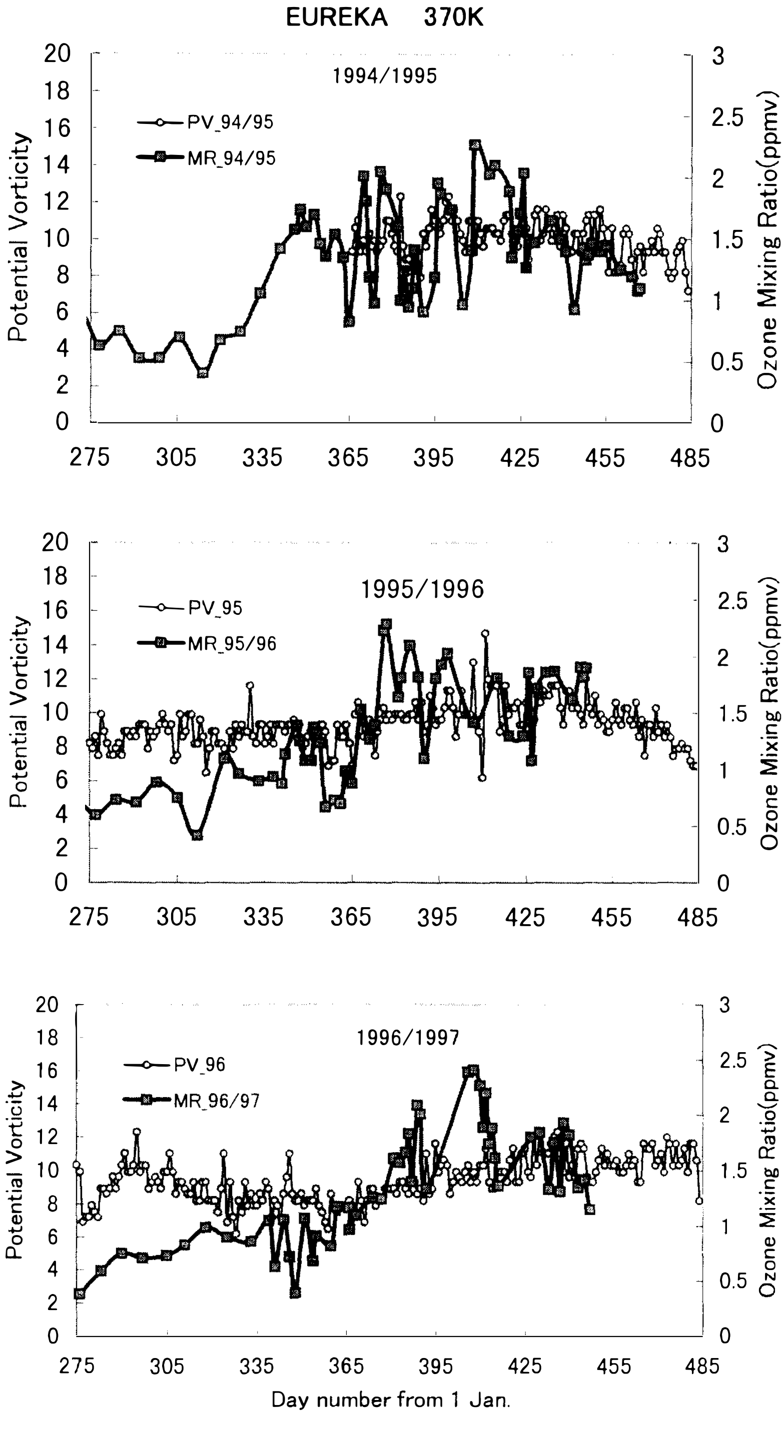

Fig. 6a. Potential vorticity and ozone mixing ratio at Eureka.
○: potential vorticity: $\times 10^{-6} Km^2 s^{-1} kg^{-1}$.
■: ozone mixing ratio: ppmv.
Potential temperature level of 370 K.

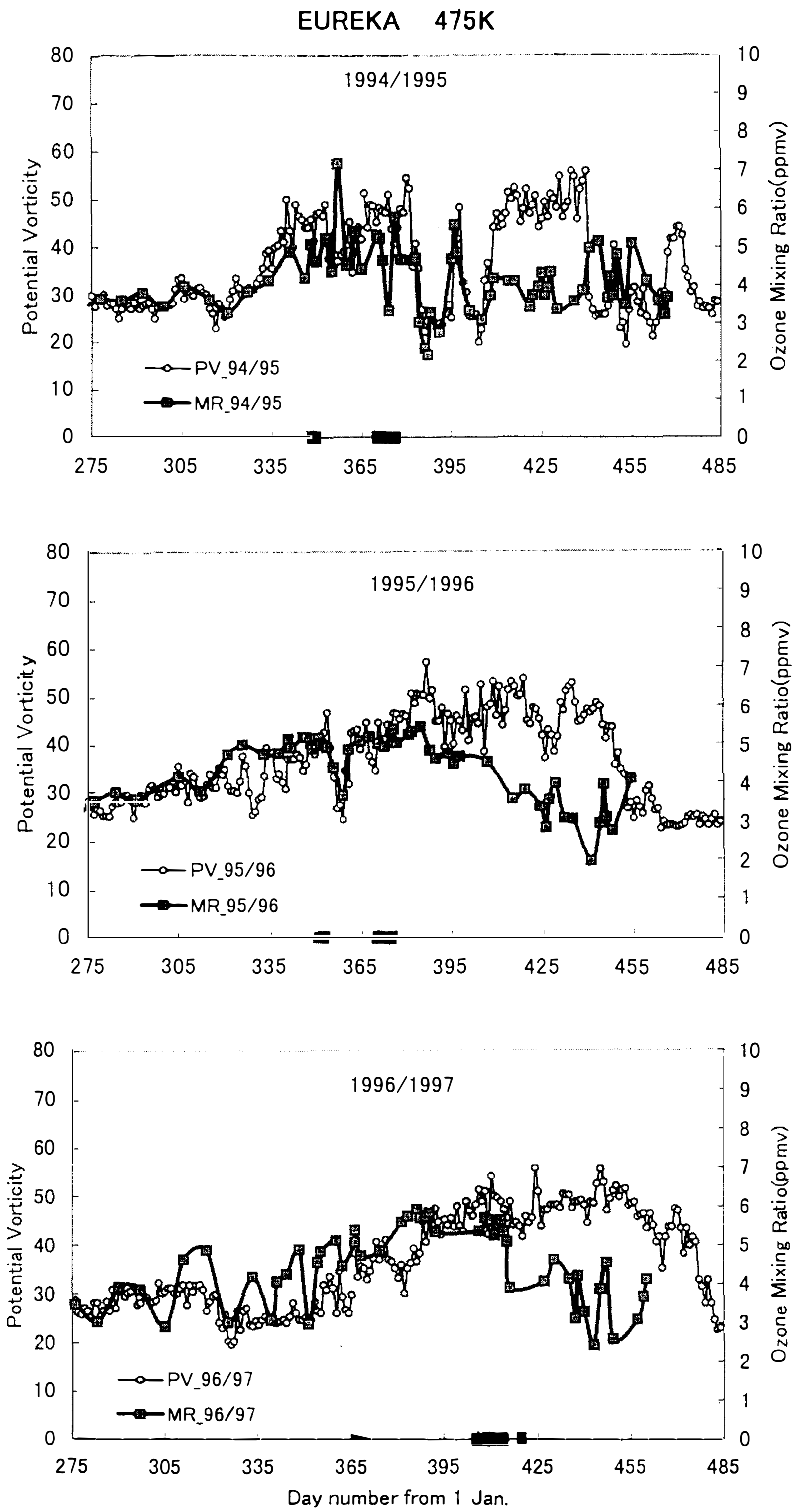

Fig. 6b. Continued.
Potential temperature level of 475 K. ■: PSCs were observed.

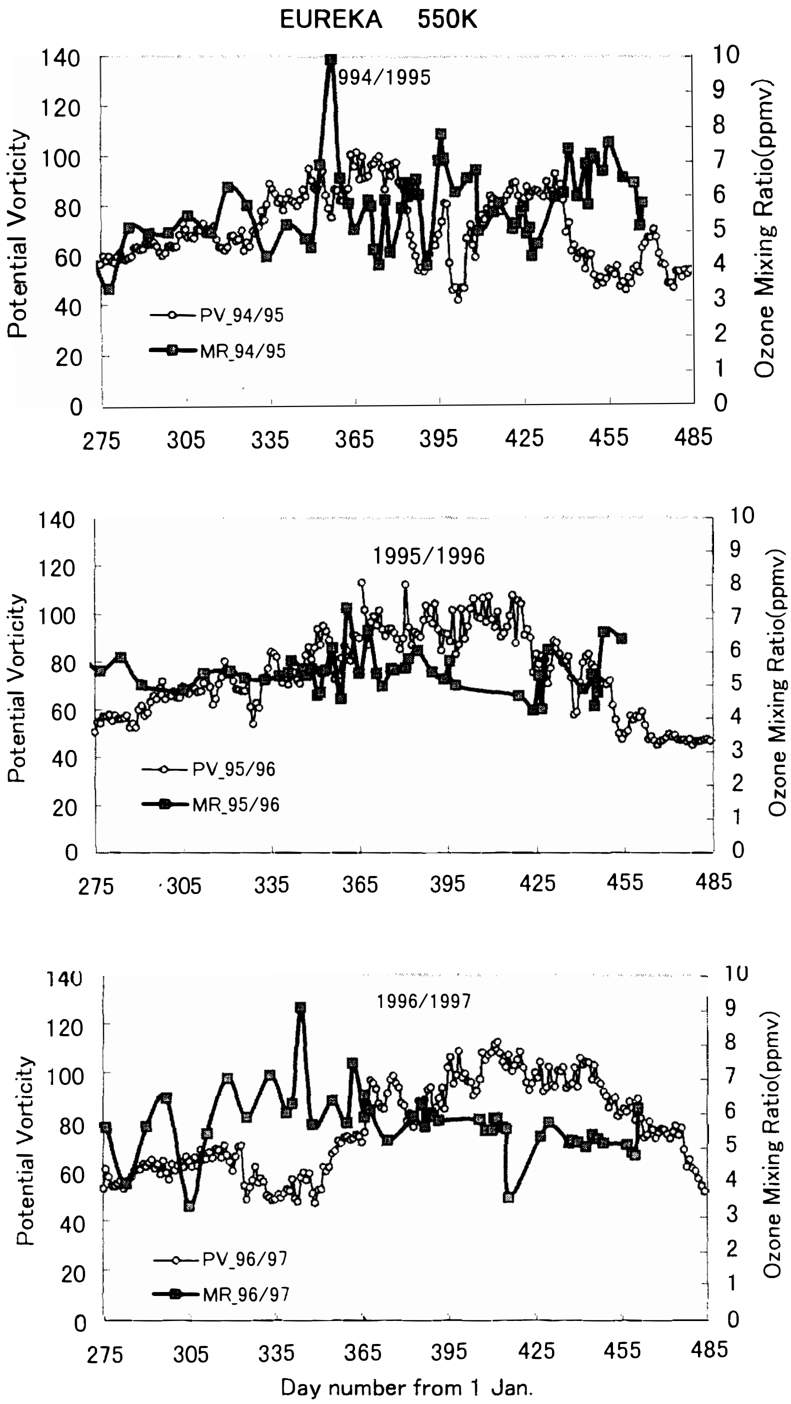

Fig. 6c. Continued.
Potential temperature level of 550 K.

between PV and ozone mixing ratio is not good, and seems to have been rather negative in 1996/97 (DONOVAN *et al.*, 1995). In the lower stratosphere (475 K level), a positive correlation between PV and ozone mixing ratio is expected (DANIELSEN, 1985; ALLAART *et al.*, 1993; DONOVAN *et al.*, 1995). This relation seems to hold well at Eureka in the first half of each observation period. Thereafter, however, the ozone mixing ratio seems to have decreased from that expected from the PV change. This would be due to the continuous presence of PSCs in the vortex. PSCs would have depleted the ozone in the vortex after the recovery of solar radiation. Especially in March 1997, the Arctic vortex was unusually cold (FIOLETOV *et al.*, 1997), and coexistence of PSCs and solar radiation after February would have depleted the ozone in large quantities. As the result of large ozone loss, elevated column amounts of ClO were measured at Eureka until late March (DONOVAN *et al.*, 1997).

Acknowledgments

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