Proc. NIPR Symp. Upper Atmos. Phys., **10**, 81–90, 1997

11-YEAR SOLAR CYCLE DEPENDENCE OF STRATOSPHERIC TEMPERATURE AND TOTAL OZONE CONTENT OVER SYOWA STATION, ANTARCTICA

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Abstract: A preliminary analysis of radiosonde observations over Syowa Station, Antarctica, was performed to see influences of the 11-year solar activity on the stratospheric environment in the high-latitude region of the terrestrial southern hemisphere. For Antarctic winter seasons of 1967–1993, relatively high temperatures were observed on the 30 hPa level during the solar maximum phase, for the westerly QBO. This tendency is generally in agreement with that shown by K. LABITZKE and H. VAN LOON (J. Atmos. Terr. Phys., **50**, 197, 1993) for the North-Pole stratosphere.

A positive correlation between the total ozone content over Syowa and the 11-year solar activity is found for early spring (October) during the easterly QBO years. High stratospheric temperatures at the 30 hPa level were associated with an increase in the ozone content. The global circulation of the stratospheric ozone in early spring is suggested to be enhanced in the easterly QBO phase, during the interval of a high solar activity.

1. Introduction

Two approaches may be conceived in the study of a connection between the solar activity and the meteorological changes. The first one is to focus on short-term (days) changes of the solar activity (*e.g.*, solar flares, cosmic-ray variations, geomagnetic activities, etc.) and the second one is to study long-term variations in the solar activity, covering several decades or more. A series of data analysis of radiosonde observations at Syowa Station, Antarctica, is in progress to find evidence of solar-activity related meteorological changes in the Antarctic region. For the short-term variations, a presence of correlation between the stratospheric/tropospheric temperatures and solar proton events was suggested by WATANABE (1996). The present work is the second step of the analysis to find a correlation between the 11-year solar cycle and the stratospheric condition over Syowa Station in the interval from 1967 to 1991.

A correlation between the North-Pole stratospheric temperature and the solar activity was examined extensively by LABITZKE (1987), and LABITZKE and VAN LOON (1988, 1993). Recently, LABITZKE and VAN LOON (1993; referred to here after as LvL) published an updated diagram showing a clear correlation between the North-Pole stratospheric temperature (at the 30 hPa level) in January + February (J+F) and the solar 10.7 cm radio flux, which is a measure of the solar activity

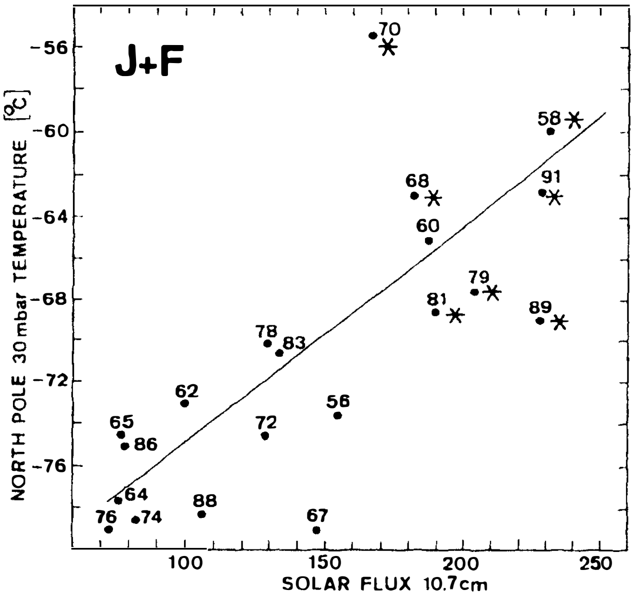

Fig. 1. The North Pole temperature on the 30 hPa level in January–February of westerly QBO years plotted against the solar 10.7 cm radio flux (LABITZKE and VAN LOON, 1993). The asterisks denote major midwinter warmings.

level, in the interval from 1958 to 1991 (Fig. 1). They concluded that high stratospheric temperatures on the 30 hPa level were observed in the years in the westerly QBO (quasi-biennial oscillation) of the zonal wind in the tropical stratosphere. The characteristic temperature difference between the maximum and the minimum phases of the solar activity is about 18 K. They showed also that a similar tendency was seen in the middle latitudes of the northern hemisphere of the Earth. On the other hand, LvL obtained an opposite correlation for the easterly QBO. Although the physical mechanism has not been known yet, a large-scale atmospheric circulation is suggested to have been changed by an external forcing which changes in accordance with the QBO phase and the 11-year solar activity cycle. In this paper, a provisional analysis of radiosonde observations over Syowa Station, Antarctica (69°S, 40°E), is performed to see the QBO/solar-cycle dependence of the stratospheric temperature in the Antarctic region. Solar-cycle dependence of the total ozone over Syowa will be examined also because the amount of the stratospheric ozone over Antarctica is known to be controlled by the global stratospheric circulation, in addition to the effect of man-made chlorofluorocarbons (CHCs).

2. Analysis of Radiosonde Observations at Syowa Station, Antarctica

The original data set of the radiosonde observations over Syowa Station, Antarctica, was provided by the Japan Meteorological Agency (*e.g.*, KANETO *et al.*, 1990). We use the data obtained in 1967–1993 because of the excellent data coverage. In this provisional analysis, we follow largely the course of the data analysis employed by LvL. First, we see the correlation between the stratospheric temperatures on the 30 hPa level and the 10.7 cm solar radio flux. Although the

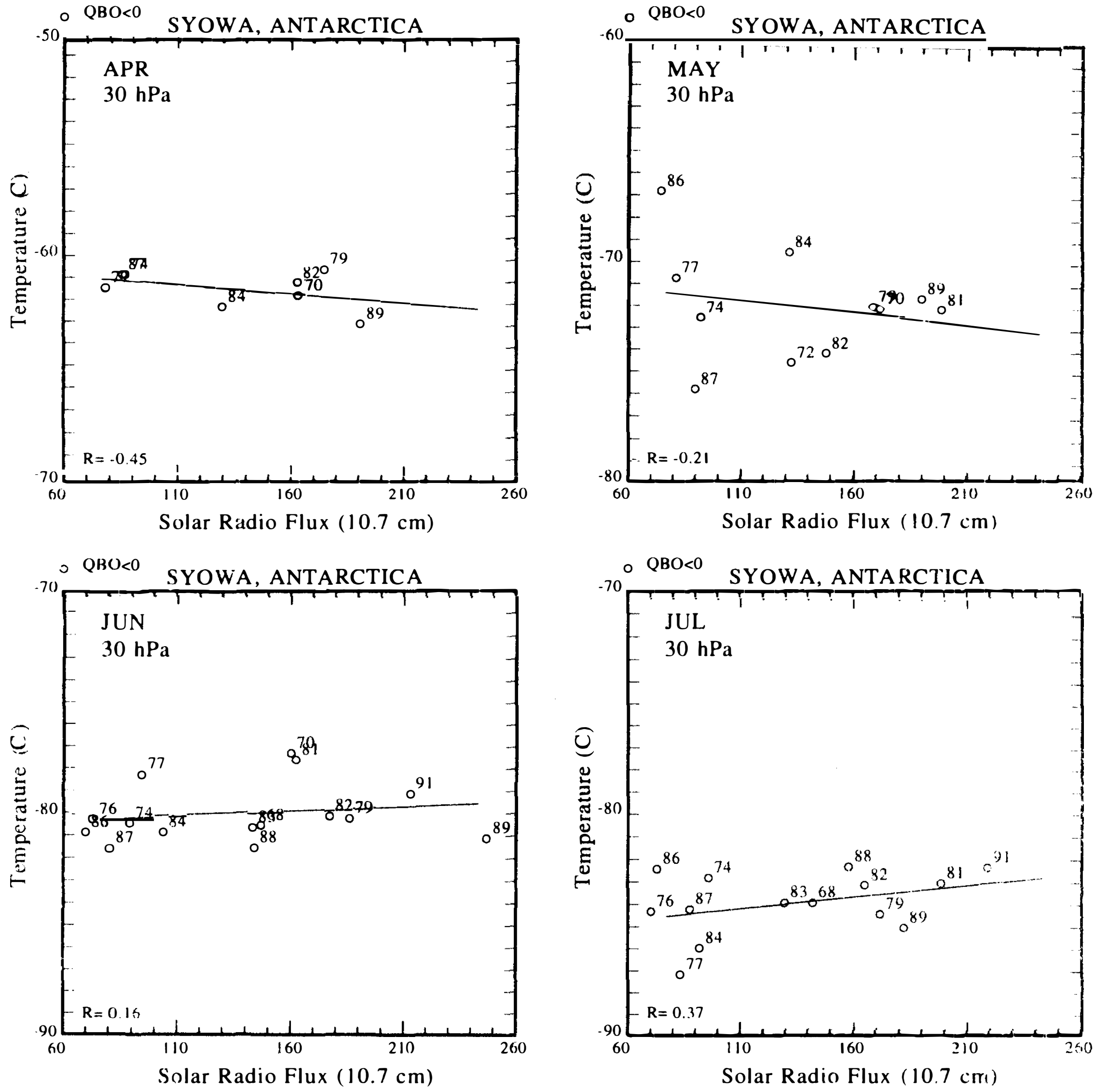

Fig. 2. Stratospheric temperature on the 30 hPa level over Syowa Station, Antarctica, in April–July plotted against the solar 10.7 cm radio flux, for the easterly (<0) QBO on the 30 hPa level. The correlation coefficient (R) is also shown.

averaged temperatures in January–February (J+F) were analyzed by LvL, we performed our provisional analysis on the basis of the monthly averages. The results of the correlation analysis between the temperatures at the 30 hPa level and the solar 10.7 cm radio flux in April–July are shown in Fig. 2 (easterly QBO) and in Fig. 3 (westerly QBO), with respect to the QBO phases at the 30 hPa level.

In the cases of the easterly QBO (Fig. 2), no clear dependence of the stratospheric temperatures on the solar-activity level (10.7 cm flux) is seen in April, June–July; almost similar temperatures were observed every year in these months. In May, on the other hand, there is a tendency that the lower temperatures were observed in the years around the maxima of the solar activity level. Although this tendency is consistent with that proposed by LvL for the North Pole winter, the correlation is not very significant.

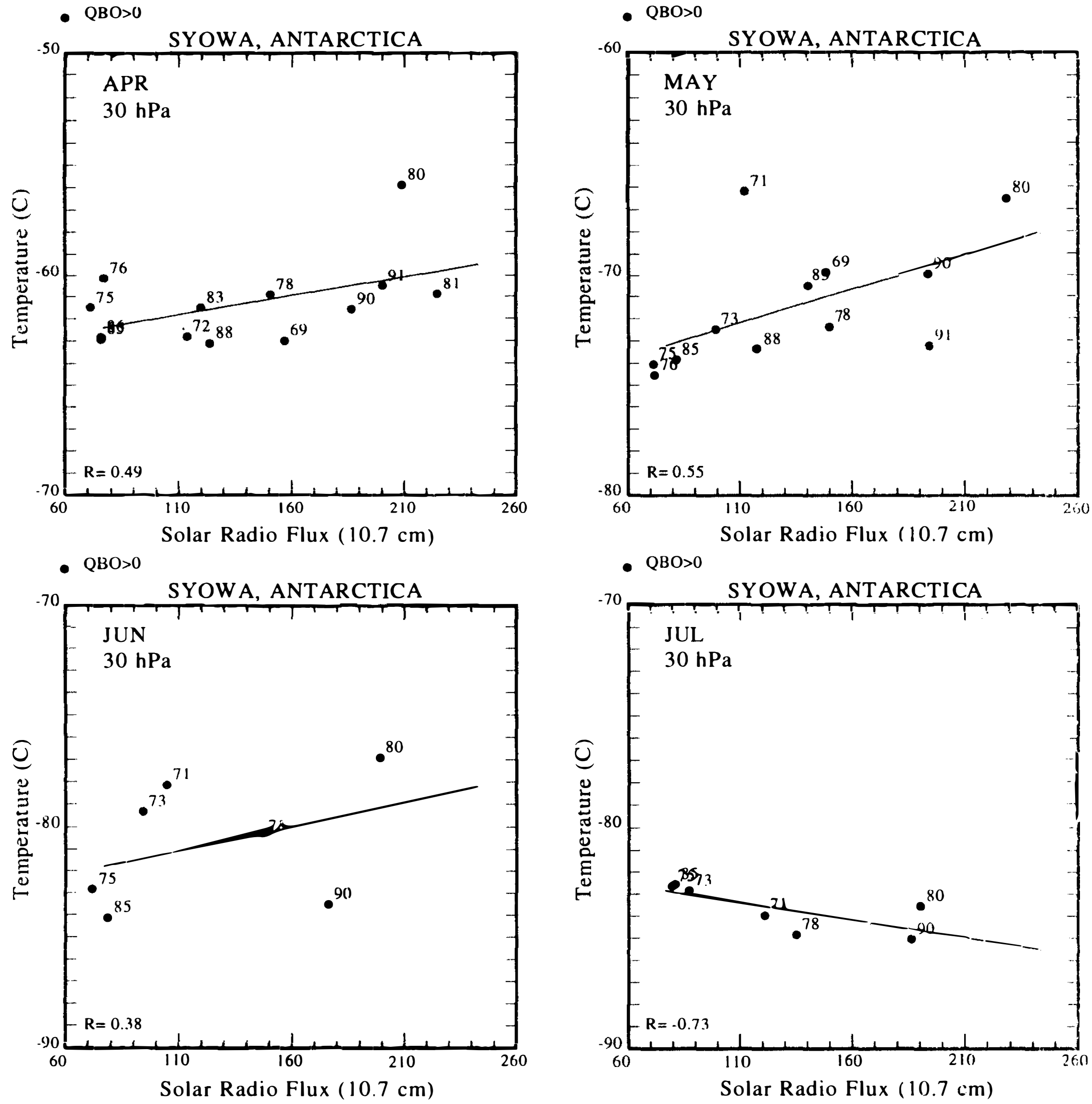

Fig. 3. Same as Fig. 2 but for the westerly (>0) QBO phase.

In the cases of the westerly QBO phase (Fig. 3), a relatively clear correlation (positive) is obtained in April–June, and the most strong correlation is seen in May (the correlation coefficient is about 0.55); the stratospheric temperatures in the Antarctic winter tend to be high in the westerly QBO phases, in the years around the maxima of the solar activity level. Although the correlations obtained by the present analysis are weaker than that obtained by LvL for the North Pole winter (Fig. 1), the general tendency of the solar-cycle dependence of the stratospheric temperatures over Syowa, Antarctica, is largely consistent with that proposed by LvL for mid-late winter (January–February), but a good correlation appeared in early winter (May) in our case.

3. Solar Cycle Dependence of the Total Ozone over Syowa Station, Antarctica

Figure 4 shows a plot of original monthly-averaged total ozone content over Syowa Station in 1967–1991. A general decreasing trend of the total ozone is obvious. Since our purpose is to find the relationship between the total ozone and the 11-year solar activity, it is necessary to remove the decreasing trend which has been proposed to be the effect of CFCs. Although the trend of long-term change in total ozone for each month will not be necessarily to be the same for all months, we estimate the regression line using all monthly data, then the deviation of each data from the line is calculated. The corrected data are plotted in Fig. 5. We perform

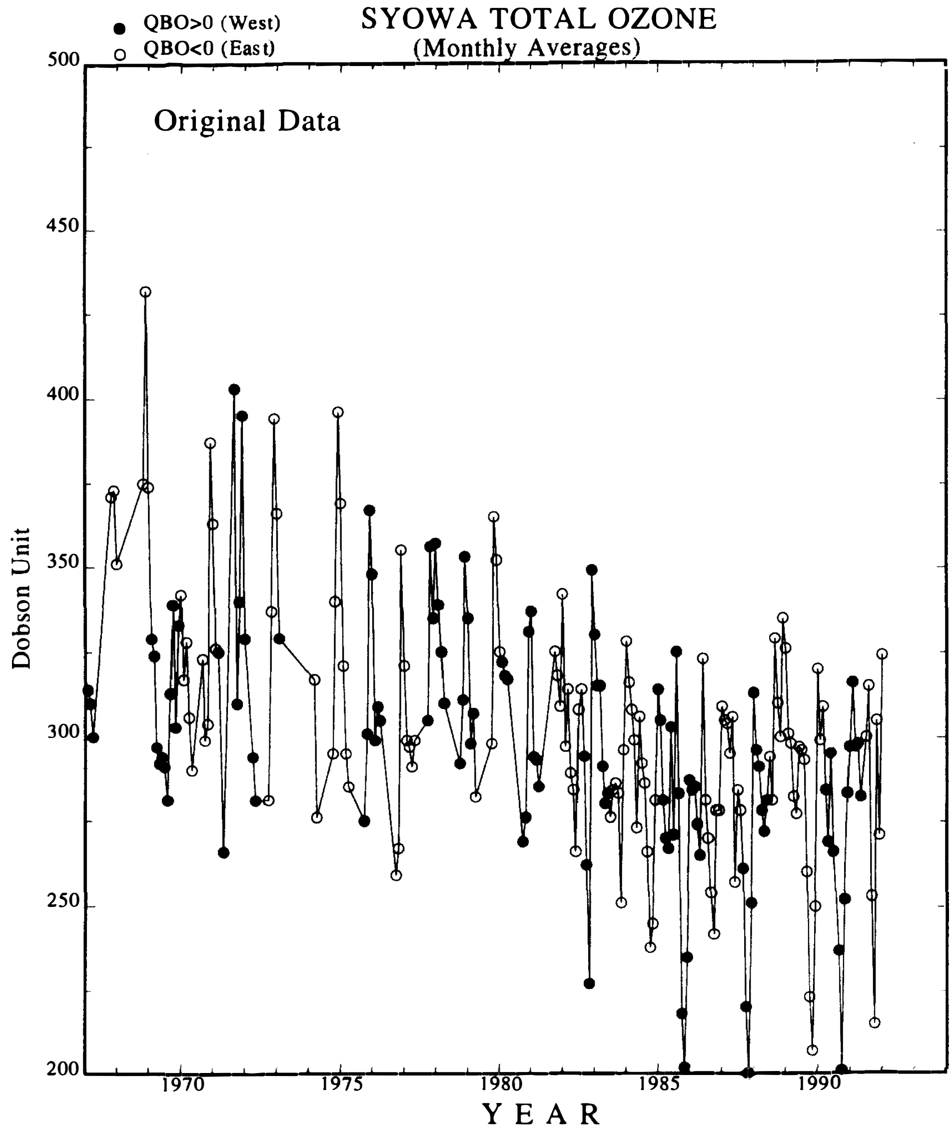

Fig. 4. Time series of monthly total ozone content (DU) over Syowa Station, Antarctica. The open circles and the filled circles denote respectively the easterly (<0) and the westerly (>0) wind phases of QBO on the 30 hPa level.

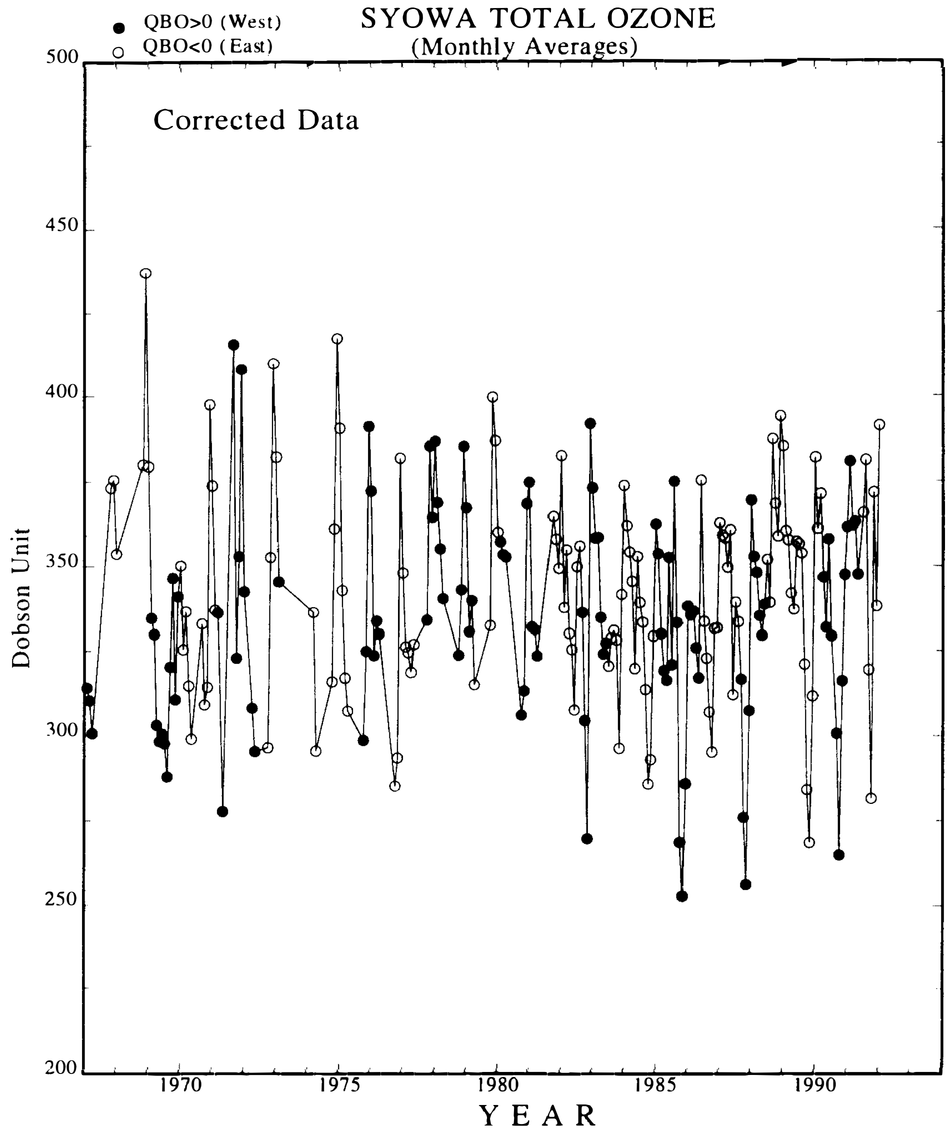

Fig. 5. Same as Fig. 4 but for monthly total ozone content (Dobson Unit, DU) over Syowa Station, Antarctica, corrected for long-term trend which is approximated by a line (see text).

a correlative analysis between the total ozone (corrected) and the solar 10.7 cm radio flux. The results for September–December are shown in Fig. 6 for the easterly QBO cases and in Fig. 7 for the westerly QBO. The most significant correlation is seen in October; the total ozone has a positive correlation with the solar activity (10.7 cm solar radio flux) in the easterly QBO.

Since the concentration of ozone in the Antarctic stratosphere is controlled by the stratospheric circulation which transfer a volume of ozone-rich warm air from the equatorial stratosphere, it is expected that higher temperature should tend to be observed in the easterly QBO phase. The correlation between the stratospheric temperature (30 hPa) and the 10.7 cm solar radio flux in October is shown in Fig. 8 for easterly and westerly QBO phases, respectively. A clear positive correlation

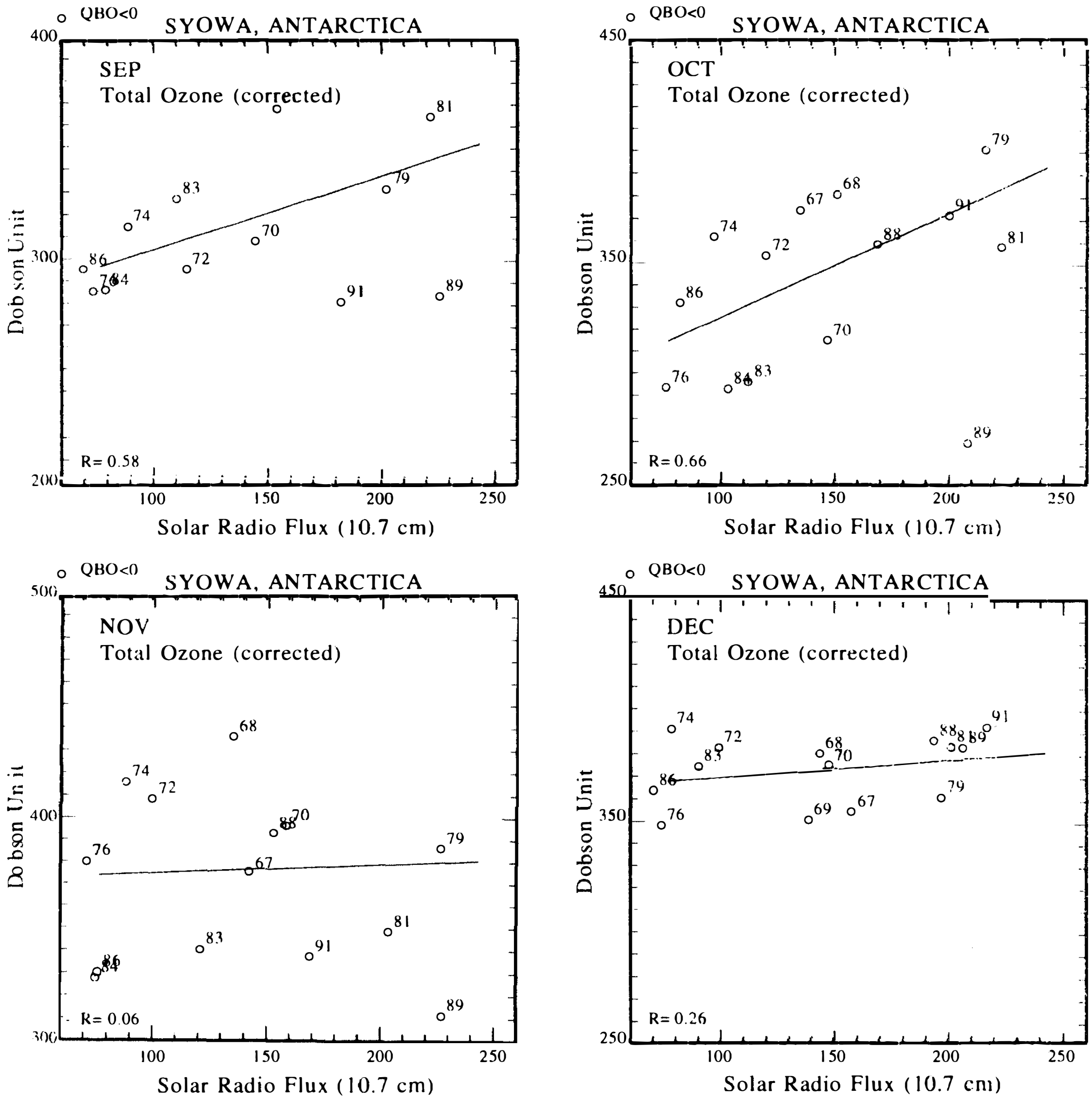

Fig. 6. Corrected total ozone content (Dobson Unit, DU) over Syowa Station, Antarctica, in September–December plotted against the solar 10.7 cm radio flux, for the easterly (<0) QBO phase.

(the correlation coefficient is about 0.7) is seen for the easterly QBO.

4. Concluding Remarks

Two principal results are obtained in the present preliminary analysis. The first one is a weak positive correlation between the stratospheric temperature over Syowa Station, Antarctica, in the early winter (particularly in May), during the westerly QBO phase. This tendency is largely consistent with the result given by LvL for the North-Pole winter (January–February), although the amount of the temperature variation observed over Syowa Station with respect to the solar cycle was much smaller than that at North Pole. Since the present analysis depends only on the radiosonde data obtained at Syowa Station (66° S), it is necessary to make a further

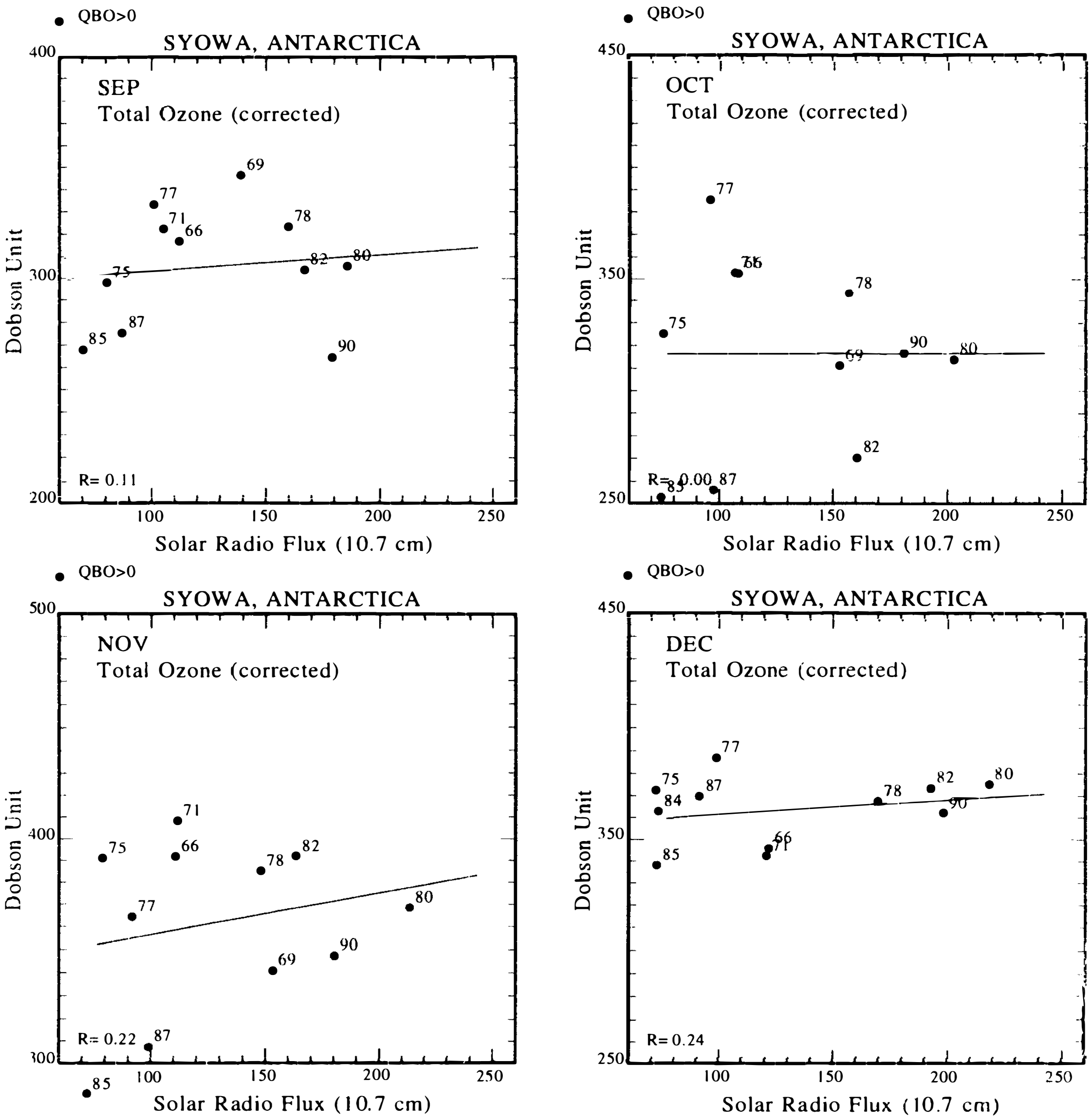

Fig. 7. Same as Fig. 6 but for the westerly (>0) QBO phase.

analysis including more comprehensive data sets obtained at other stations in Antarctica. KODERA (1991) proposed a mechanism to explain the QBO/solar cycle dependence of the stratospheric temperature at North Pole which was proposed by LvL. According to KODERA (1991), the solar activity and the equatorial QBO produce mean zonal wind anomalies in the middle and lower stratosphere during early northern winter and they modulate planetary wave propagations. Although physical connections between changes in the solar activity and the stratospheric conditions are unknown at this stage, the present study suggests that the similar correlation between the phases of the QBO/solar cycle and the stratospheric temperatures over North Pole is also seen over Antarctica. The second result obtained in the present data analysis is the positive correlation between the total ozone (and the stratospheric temperature) and the solar activity in early Antarctic spring (particularly in October), but in the easterly QBO phase. In other words, the

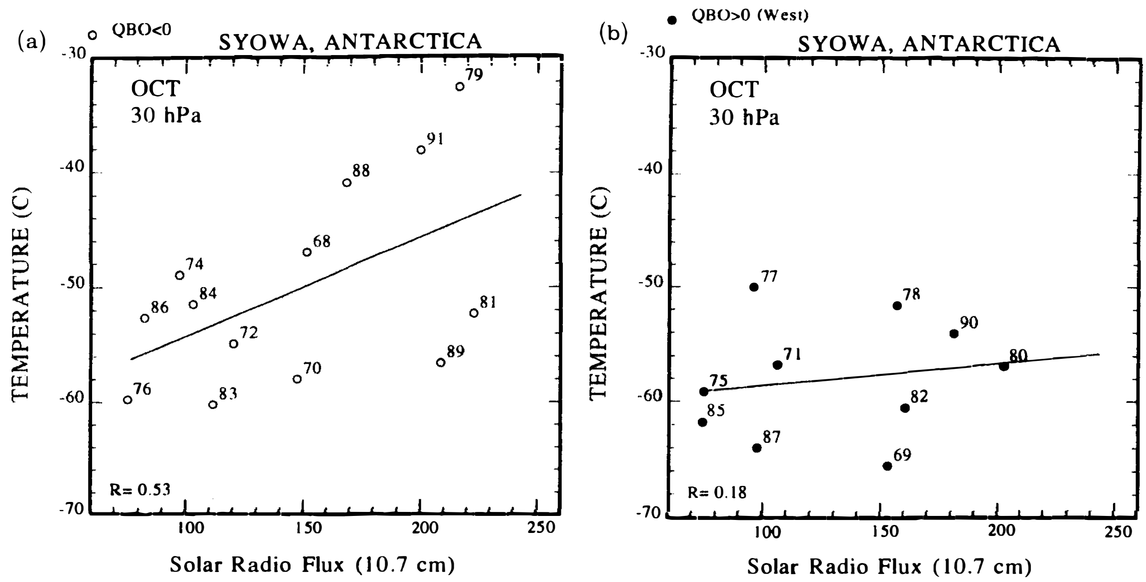

Fig. 8. The stratospheric temperature on the 30 hPa level over Syowa Station, Antarctica, in October plotted against the solar 10.7 cm radio flux, for (a) the easterly (<0) QBO, and for the westerly (>0) QBO (b) phases, respectively.

depth of the ozone hole in early spring is shallow during the interval of high solar activity and in the easterly QBO. This suggests that the global stratospheric atmosphere responds to the QBO/solar activity in a different way to that in early winter. KANZAWA and KAWAGUCHI (1990) found the large stratospheric warming and the shallow ozone hole over Syowa Station in late winter of 1988. They proposed that the strong activity of planetary waves in 1988 was due to an anomaly in the sea surface temperature in the equatorial Southern Pacific as discussed in KODERA and YAMAZAKI (1989). It is suggested that, from the present study, the tendency showing a shallower ozone hole in the easterly QBO phase in early spring can be enhanced by a higher solar activity. Further detailed studies and long-range observations are required to understand the complicated behavior of the Antarctic ozone hole.

Acknowledgments

The author would like to thank S. KANETO, the Japan Meteorological Agency, for his help in usage of radiosonde and ozone data obtained at Syowa Station. Thanks are also due to Dr. F. HASEBE, Ibaraki University, for his valuable suggestions on the present work.

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(Received May 29, 1996; Revised manuscript accepted August 23, 1996)