OBSERVATIONS OF TOTAL OZONE AMOUNTS AND LOWER STRATOSPHERIC TEMPERATURES DURING A STRATOSPHERIC SUDDEN WARMING IN THE ANTARCTIC BY TOVS OF NOAA-7

Kazuya SUZUKI[1], Takashi YAMANOUCHI[2], Takeo YOSHINO[1] and Sadao KAWAGUCHI[2]

[1]*University of Electro-Communications, 5-1, Chofugaoka 1-chome, Chofu-shi, Tokyo 182*
[2]*National Institute of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

Abstract: A comparison of total ozone amounts and lower stratospheric temperature during the 1982 stratospheric sudden warming in the Antarctic is made by the TIROS Operational Vertical Sounder (TOVS) data of NOAA-7 received at Syowa Station. A method assuming a vertical ozone profile is applied to obtain total ozone amounts. The total ozone can be determined independently of the surface measurements. A good agreement between the total ozone amounts derived from satellite data and those of Dobson measurements is seen at Syowa Station. RMS error is 12 DU (10^{-3}·atm·cm). A good correlation between the total ozone and the lower stratospheric temperature is observed in the Antarctic. Patterns similar to the wave number 5 structure of the total ozone during the Southern Hemisphere summer are seen during the 1982 sudden warming.

1. Introduction

The increase in a total ozone amount during a stratospheric sudden warming in the Antarctic is already known from the observations of the total ozone and stratospheric temperature at Syowa Station (69°00′S, 39°35′E), Antarctica, as shown in Fig. 1. The stratospheric temperatures were obtained from radiosonde measurements (JAPAN METEOROLOGICAL AGENCY, 1984). The total ozone amounts were obtained from Dobson measurements. But the knowledge of the relation between the total ozone and the stratospheric temperature during the sudden warming is not sufficient.

The satellite observation is useful for the study of the total ozone and stratospheric temperature. A comparison of the total ozone and the stratospheric temperature using satellite data was made by several authors. A strong correlation between the planetary waves in the temperature field and the total ozone was reported by PRABHAKARA *et al.* (1976). During the sudden warming in the Northern Hemisphere, a positive correlation between the total ozone and the mean temperature of a stratospheric layer 100–5 mb was reported by GHAZI (1974). During the Southern Hemisphere summer, distinct medium-scale disturbances of the total ozone were reported by SCHOEBERL and KRUEGER (1983). However, for the sudden warming in the Southern Hemisphere, there is no study of a comparison of the total ozone and the stratospheric temperature using satellite data.

In the present study, we derived total ozone amounts and lower stratospheric

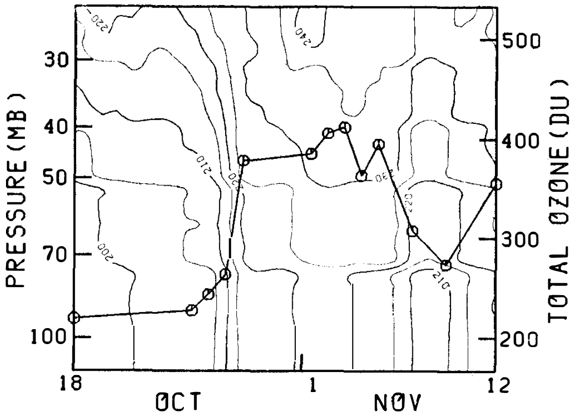


Fig. 1. The vertical temperature distribution and total ozone amounts during the 1982 stratospheric sudden warming at Syowa Station, Antarctica (○ : total ozone amount, numbers in K).

temperatures from the NOAA-7 TIROS Operational Vertical Sounder (TOVS) data during the 1982 stratospheric sudden warming in the northeastern part of the Antarctic. Total ozone amounts were derived from the High Resolution Infrared Radiation Sounder (HIRS/2) data by the method assuming a vertical ozone profile proposed by PRABHAKARA *et al.* (1976). This method is based on the assumption that the height of the ozone layer is proportional to the total ozone, and the total ozone can be determined independently of the surface measurements. Therefore, this method is useful where a few surface measurements exist, like the Antarctic. Besides channel 9 located in the ozone 9.6 μm band, channels 1, 2, 3 and 8 of HIRS/2 are used. Derivation of the total ozone in the Antarctic from the TOVS data of TIROS-N/NOAA satellites has been already attempted by a simple statistical regression method proposed by CROSBY *et al.* (1981) (YAMANOUCHI *et al.*, 1984).

The High Resolution Picture Transmission (HRPT) data of TIROS-N/NOAA series environmental satellites have been received at Syowa Station, once or twice a day since February 1980 by the members of the Japanese Antarctic Research Expedition. The HIRS/2 data of TOVS were extracted from the HRPT data after they were converted into a computer compatible tape at the National Institute of Polar Research.

2. Derivation of Total Ozone Amount

A method assuming a vertical ozone profile is applied to derive the total ozone from the HIRS/2 data. The channel 9 radiance in the ozone 9.6 μm band includes the information of the total ozone through the transmittance. The radiative transfer equation for channel 9 is written as

$$I=B[T_s]\cdot\tau(p_s)+\int_{p_s}^{0}B[T(p)]\frac{\partial\tau(p)}{\partial p}\mathrm{d}p$$
$$=B[T_s]\cdot\tau(p_s)+B[T_e]\cdot\{1-\tau(p_s)\}\,, \qquad (1)$$

$$(B[T_e]=\int_{p_s}^{0}B[T(p)]\frac{\partial\tau(p)}{\partial p}\mathrm{d}p/\int_{p_s}^{0}\frac{\partial\tau(p)}{\partial p}\mathrm{d}p)\,, \qquad (2)$$

where B, T, p and τ are the Planck function, temperature, pressure and transmittance. The subscript s denotes the surface.

The absorptance $A(p)$ is approximately written by the quadratic equation with the ozone amount $U(p)$ (atm·cm) above the pressure level of p; *i.e.*,

$$A(p)=1-\tau(p)=K1\cdot U(p)+K2\cdot U(p)^2. \tag{3}$$

Therefore,

$$B[T_{\mathrm{e}}]=\int_{p_{\mathrm{s}}}^{0} B[T(p)]\cdot[-\{K1+2\cdot K2\cdot U(p)\}]\frac{\partial U(p)}{\partial p}\mathrm{d}p \Big/ \int_{p_{\mathrm{s}}}^{0}[-\{K1+2\cdot K2\cdot U(p)\}]\frac{\partial U(p)}{\partial p}\mathrm{d}p, \tag{4}$$

$K1$ and $K2$ are determined from the transmittance based on the line-by-line calculation for channel 9 (Ito *et al.*, 1982). Values of $K1=2.40$ and $K2=-2.32\times10^{-3}$ were chosen.

Additional information of ozone is now introduced by assuming a relation between the total ozone amount $U(p_{\mathrm{s}})$ and the mean pressure of the ozone layer $\bar{p}$ of the form

$$U(p_{\mathrm{s}})=U_{\mathrm{m}}(p_{\mathrm{s}})+C\cdot(\bar{p}-\bar{p}_{\mathrm{m}}), \tag{5}$$

where $U_{\mathrm{m}}(p_{\mathrm{s}})$ and $\bar{p}_{\mathrm{m}}$ are mean values of $U(p_{\mathrm{s}})$ and $\bar{p}$ (Miller, 1960). Values of $U_{\mathrm{m}}(p_{\mathrm{s}})$, C and $\bar{p}_{\mathrm{m}}$ are described in the following section.

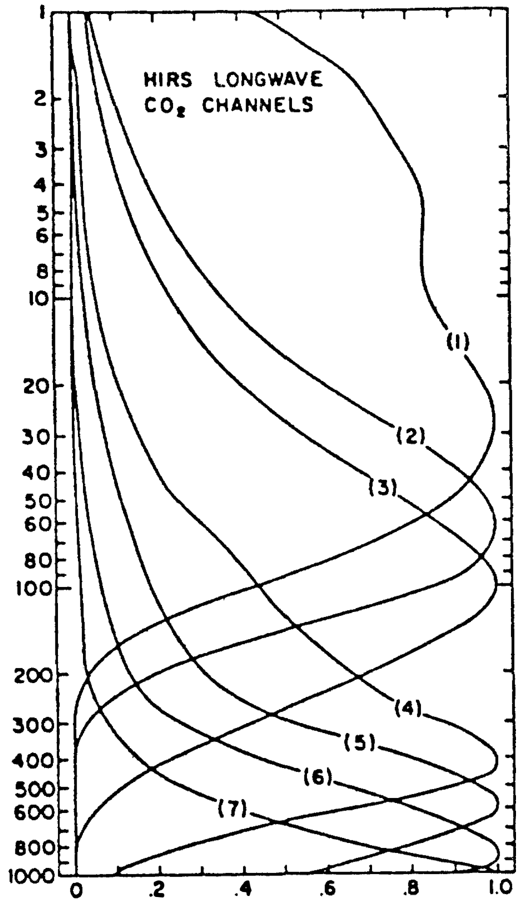


Fig. 2. HIRS/2 channels 1–7 weighting functions (normalized) (Werbowetzki, 1981).

If eqs. (3) and (5) are used along with the additional approximation

$$T_e = T(\bar{p}), \tag{6}$$

eq. (1) can be written as

$$I - B[T_s] = \{B[T(\bar{p})] - B[T_s]\}\,[K1 + K2\cdot\{U_m(p_s) + C\cdot(\bar{p} - \bar{p}_m)\}]\cdot\{U_m(p_s) + C\cdot(\bar{p} - \bar{p}_m)\}\,. \tag{7}$$

Equation (7) is solved approximately with the surface temperature T_s from channel 8, and the temperature around the ozone layer $T(p)$ derived from channels 1, 2 and 3. Weighting functions of channels 1, 2 and 3 have peaks at the 30, 60 and 100 mb levels, respectively. These weighting functions are shown in Fig. 2. $T(p)$ is derived by a simple statistical regression method (TANAKA *et al.*, 1982). Regression coefficients of $T(p)$ are determined from radiosonde measurements of the temperature at Syowa Station.

In this method, the total ozone can be determined independently of the surface measurements.

3. Assumption of a Vertical Ozone Profile

Assumption of a vertical ozone profile is examined. The relation of $U(p_s)$ and $\bar{p}$ from February 1982 to January 1983 is shown in Fig. 3. $\bar{p}$ were derived by eqs. (4) and (6). $\partial U(p)/\partial p$, $U(p)$ and $T(p)$ were obtained from ozonesonde measurements. At the height where the ozonesonde did not reach, $\partial U(p)/\partial p$ and $U(p)$ were assumed from the U.S. Standard Atmosphere for subarctic winter proposed by MCCLATCHEY *et al.* (1972) and $T(p)$ were assumed from the rocket measurements at Molodezhnaya Station in the Antarctic. The ozone amount at the height where the ozonesonde did not reach is about 20% of the total ozone. The distance from Syowa Station to Molodezhnaya Station is about 300 km. $U(p_s)$ were obtained from Dobson measurements at Syowa Station. In Fig. 3, numbers are months of measurement. The

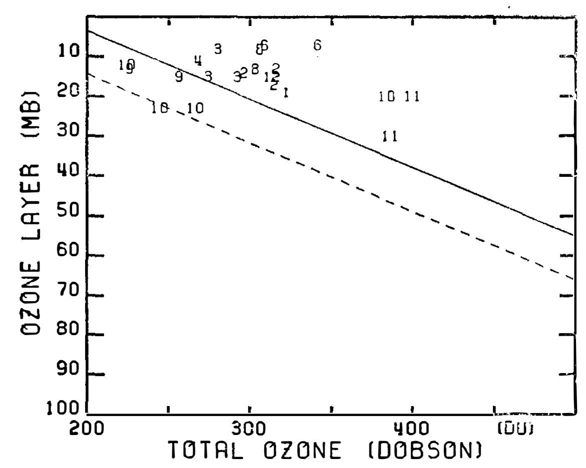


Fig. 3. The relation of total ozone amount and mean pressure of ozone layer derived from ozonesonde and rocket measurements (numbers are months of measurement).

broken line is the relation of $U(p_s)$ and $\bar{p}$ reported by HERING and BORDEN (1967). Values of $\bar{p}_m$=40 mb, $U_m(p_s)$=348 DU (10^{-3}·atm·cm) and C=5.8 DU/mb were chosen. This line does not agree with the results, because $\bar{p}$ is obtained by approximation that the absorptance is linearly dependent on the total ozone. Therefore, we chose the value of $\bar{p}_m$ which minimizes the RMS deviation of the total ozone amounts derived by satellites from those by Dobson measurement. A value of $\bar{p}_m = 29$ mb is chosen. The solid line is the relation of eq. (5) with this $\bar{p}_m$.

4. Result of the Derivation of Total Ozone Amounts at Syowa Station

Total ozone amounts derived from satellite measurements by the method assuming a vertical ozone profile during the stratospheric sudden warming (which occurred on 27th–28th of October 1982 at Syowa Station) at Syowa Station and those at the South Pole (Amundsen-Scott Station) are shown in Fig. 4. These are compared

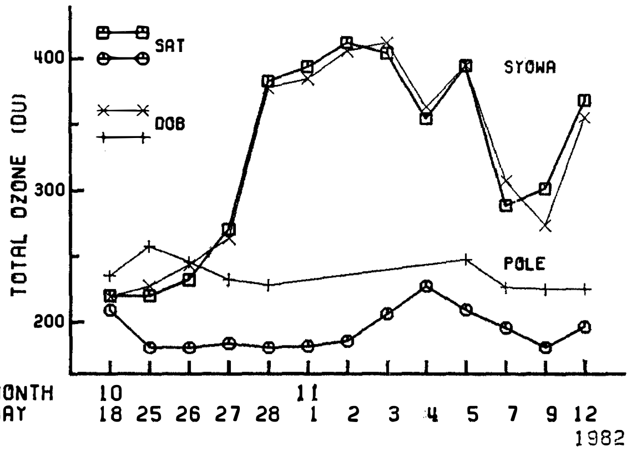


Fig. 4. Total ozone amounts derived from satellite measurements and those of Dobson measurements during the 1982 stratospheric sudden warming.

with total ozone amounts obtained from Dobson measurements at these stations in Fig. 4. At Syowa Station, a good agreement between the total ozone amounts derived by satellites and those by Dobson measurement is seen. The RMS error in the satellite-derived total ozone amounts from those of Dobson measurements is 12 DU ($10^{-3}\cdot$atm$\cdot$cm). This result suggests that the assumption of the vertical ozone profile holds during the sudden warming. At the South Pole, the total ozone amounts derived by satellite are smaller than those of Dobson measurements, and the RMS error is 48 DU. The large RMS error at the South Pole is probably caused by the error in deriving the stratospheric temperature using the regression coefficients determined at Syowa Station. Because the shape of vertical temperature distribution derived by satellite at the South Pole was different from those of radiosonde measurements in the same season of other years.

The satellite-derived total ozone amounts at Syowa Station from February 1982 to January 1983 are shown in Fig. 5. This duration was divided into four periods (February–April, March–August, September–October, November–January), and the regression coefficients for derivation of the stratospheric temperature were determined for each period. The annual variation of the total ozone shows two maxima, one

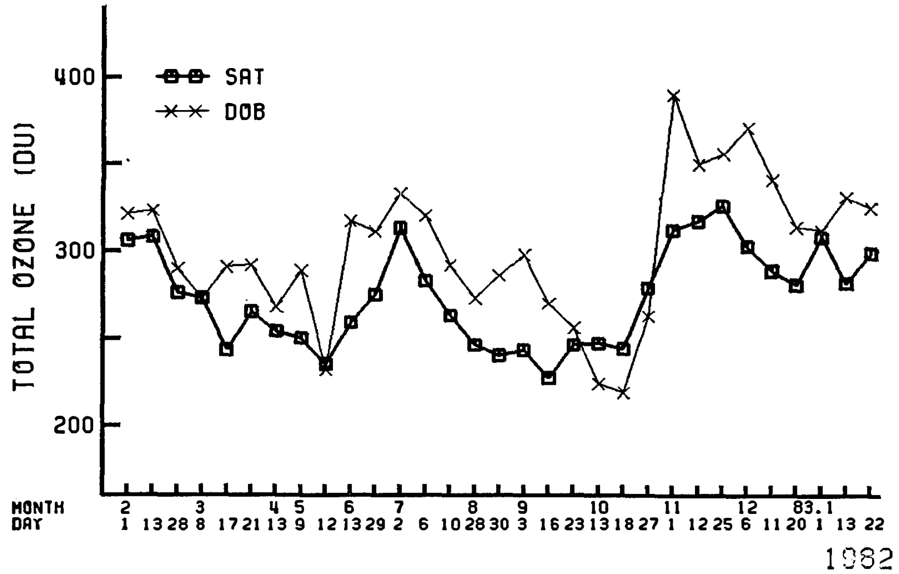


Fig. 5. Annual variation of total ozone amounts derived from satellite measurements and those by Dobson measurements from February 1982 to January 1983 at Syowa Station.

in July and another in November. The general tendency of the total ozone derived by the satellite agrees with that by Dobson measurement. The RMS error is 37 DU. Difference in the satellite-derived total ozone amounts during the sudden warming shown in Figs. 4 and 5 is caused by the difference of regression coefficients for the temperature. The satellite-derived temperatures by the regression coefficients determined from the data of only during the sudden warming are more accurate than those from the data of a longer period of September–October or November–January. Therefore, if the satellite-derived stratospheric temperature is accurate, the total ozone will be derived more accurately by this method.

5. Comparison of the Total Ozone Amount and the Stratospheric Temperature

A comparison of the total ozone and the lower stratospheric temperature is made. The brightness temperature of channels 1, 2 and 3 is used as the temperature at the 30, 60 and 100 mb levels, respectively, because it can be regarded as the mean temperatures in the layer around the peak of the weighting function for each channel.

Horizontal distributions of the total ozone derived from the satellite data and those of the brightness temperature of channels 1, 2 and 3 are shown in Fig. 6. Before the sudden warming occurred at Syowa Station (see Fig. 6.1), a good correlation is seen among the horizontal distributions of the brightness temperature of channels 1, 2 and 3, but they do not agree with that of the total ozone. After that (see Figs. 6.2–6.4), a good correlation is seen among the horizontal distributions of the total ozone and those of the brightness temperature of channels 2 and 3. However, the horizontal distribution of brightness temperature of channel 1 is different from others. The maximum region of the total ozone corresponds to the maximum temperature region of channels 2 and 3. On October 27, the brightness temperature of channel 1 (Fig. 6.2b), in the high latitude was higher than that in the lower latitude. This fact suggests that the sudden warming already occurred above 30 mb level.

Comparisons of the vertical distribution of the lowei stratospheric temperature obtained from channels 1, 2 and 3 brighness temperature and total ozone are shown in Figs. 7 and 8. Figure 7 is the latitudinal cross sections along 40°E, and Fig. 8 is the longitudinal cross sections along 70°S. These cross sections pass through the neighborhood of Syowa Station. In Figs. 7 and 8, the sudden waiming is seen at 40–100 mb level. A good correlation between the total ozone and the temperature, especially at 100 mb level, is apparent. In Fig. 7a, the high temperature region at 100 mb level is located around 55°S, and the total ozone in this region is larger than that in higher latitudes. In Fig. 7b, the increase of the total ozone occurs in the region of increasing 100 mb temperature. The center of this region is located at 60°S. In the same region, both the total ozone and the 100 mb temperature decrease, in Fig. 7c, and increase again, in Fig. 7d. In Fig. 8, a good agreement is also seen between the increase region of the total ozone and that of the temperature. Therefore, the

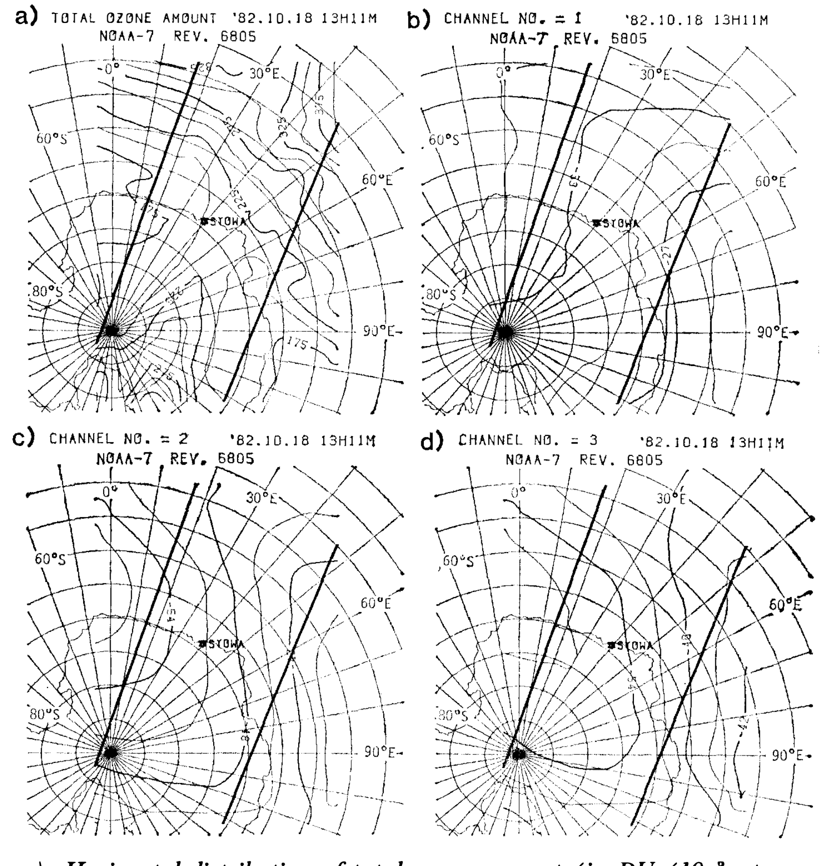
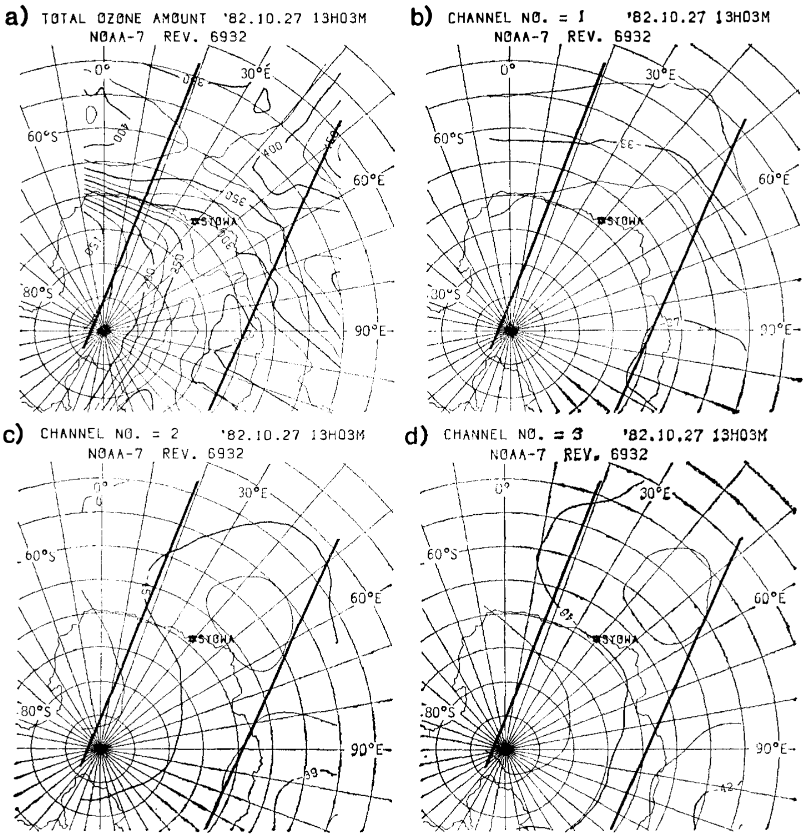


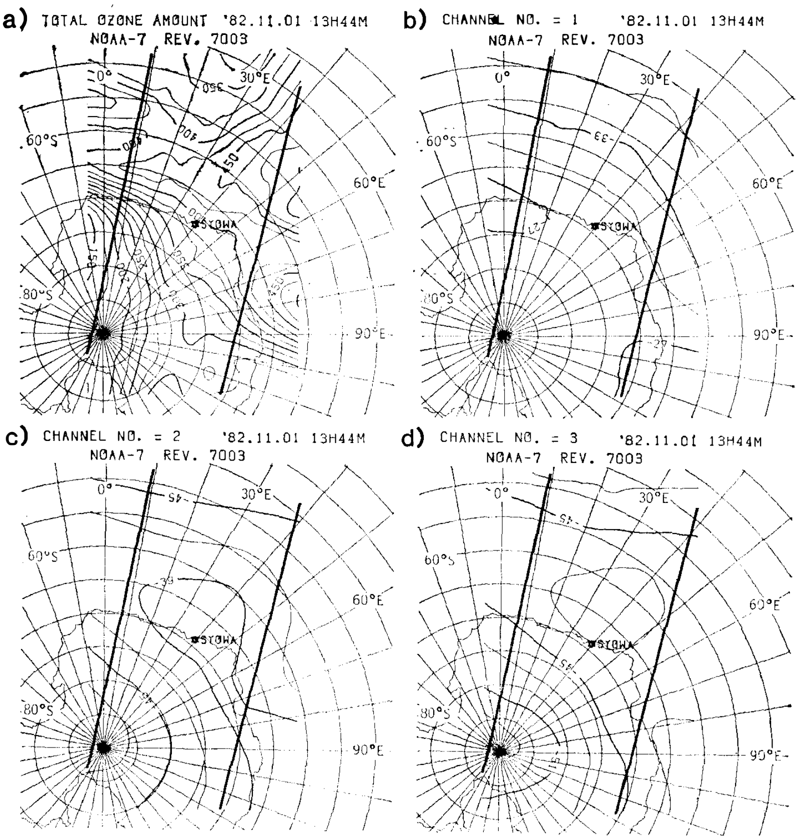
Fig. 6.1.

Fig. 6.1–6.4. *a) Horizontal distribution of total ozone amount (in DU (10^{-3}·atm·cm)), and b)–d) those of brightness temperature (in °C) of channels 1, 2 and 3 of HIRS/2 in the northeastern part of the Antarctic obtained from NOAA-7. The area between two solid lines is satellite-scanned area, and the outside of this area does not show an actual distribution.*



a) TOTAL OZONE AMOUNT '82.10.27 13H03M
NOAA-7 REV. 6932
b) CHANNEL NO. = 1 '82.10.27 13H03M
NOAA-7 REV. 6932
c) CHANNEL NO. = 2 '82.10.27 13H03M
NOAA-7 REV. 6932
d) CHANNEL NO. = 3 '82.10.27 13H03M
NOAA-7 REV. 6932
0°
30°E
60°S
60°E
SYOWA
80°S
90°E

Fig. 6.2.



a) TOTAL OZONE AMOUNT '82.11.01 13H44M
NOAA-7 REV. 7003
b) CHANNEL NO. = 1 '82.11.01 13H44M
NOAA-7 REV. 7003
c) CHANNEL NO. = 2 '82.11.01 13H44M
NOAA-7 REV. 7003
d) CHANNEL NO. = 3 '82.11.01 13H44M
NOAA-7 REV. 7003
0°
30°E
60°S
60°E
SYOWA
80°S
90°E

Fig. 6.3.

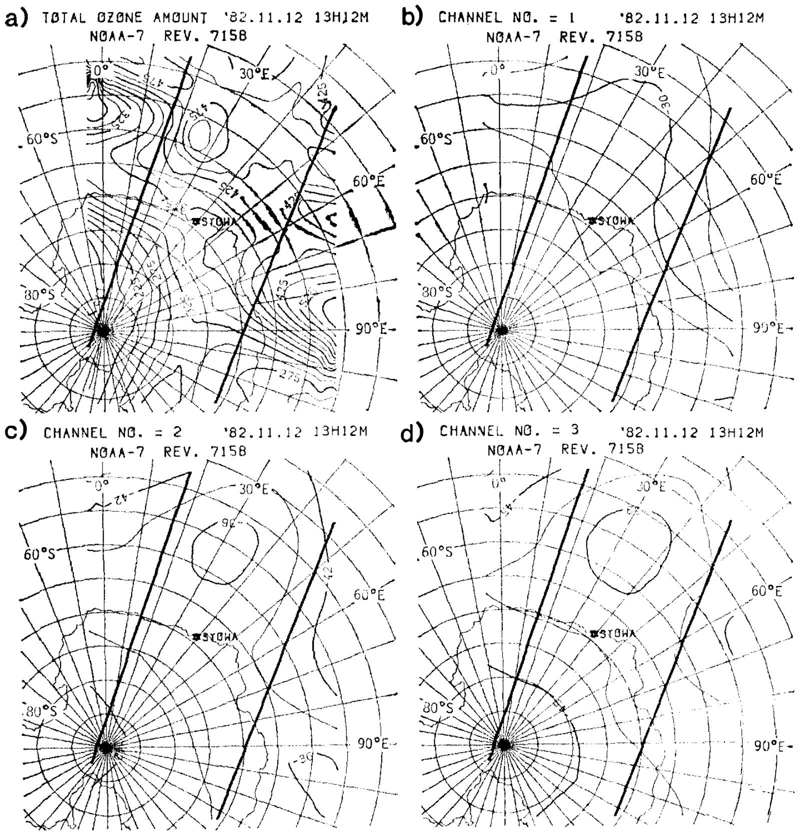


Fig. 6.4.

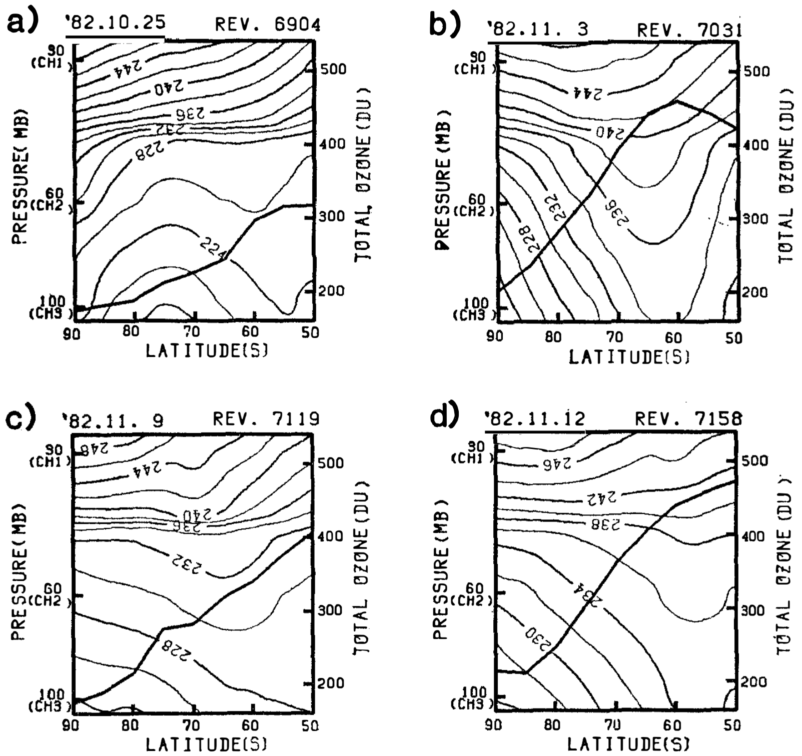


Fig. 7. Latitudinal variations of vertical temperature distribution (brightness temperature) and total ozone amount (thick line is total ozone amount, numbers in K).

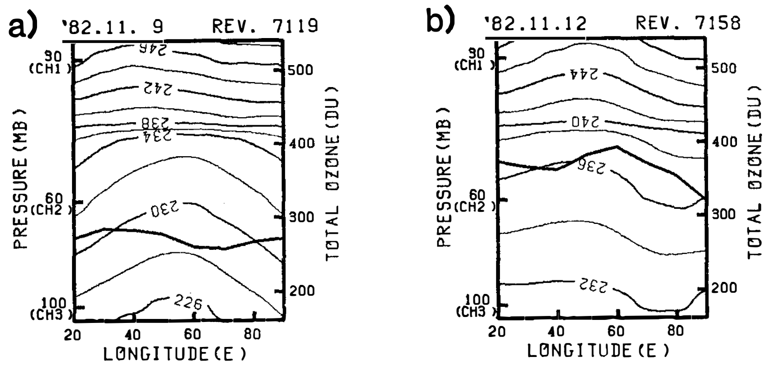


Fig. 8. Longitudinal variations of vertical temperature distribution (brightness temperature) and total ozone amount (thick line is total ozone amount, numbers in K).

increase of the total ozone occurs in the region where the sudden warming is occurring at 40–100 mb level.

A good correlation between the ozone amount and the temperature at 30–100 mb level during the stratospheric sudden warming at Syowa Station was reported by CHUBACHI (1984). The difference of top boundaries is caused by the broad peak above 30 mb level of channel 1 weighting function. A good agreement between the maximum region of the total ozone and that of the lower stratospheric temperature during the sudden warming in the Northern Hemisphere was reported by GHAZI (1974). The result in this study corresponds to these results.

In Fig. 6, patterns similar to the wave number 5 structure of the total ozone reported by SCHOEBERL and KRUEGER (1983) during the Southern Hemisphere summer are seen. But this pattern was not seen in total ozone distributions during the 1981 sudden warming described by YAMANOUCHI *et al.* (1984). This result suggests that the zonal harmonic wave 5 which centered near the tropopause contributed to the 1982 spring maximum of the total ozone in the Southern Hemisphere. However, this phenomenon does not always occur during the sudden warming.

5. Summary

Total ozone can be derived from satellite measurements by the method assuming a vertical ozone profile, independently of the surface measurements. A good agreement is seen between the total ozone amounts derived by satellite and those by Dobson measurement, especially during the sudden warming, at Syowa Station. Therefore, this method is useful for the analysis of the total ozone in the Antarctic, especially during the sudden warming.

A comparison of the total ozone amount and the lower stratospheric temperature during the 1982 sudden warming in the Antarctic is made. A good correlation between the increase of the total ozone and the increase of lower stratospheric temperature is observed not only at Syowa Station but also in the wide area in the Antarctic. Distributions of the total ozone during the 1982 sudden warming are similar to the wave number 5 structure of the total ozone during the Southern Hemisphere summer.

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