―研究ノート―
Scientific Note

Derivation of Total Ozone Amount in the Antarctic Atmosphere from TOVS of TIROS-N/NOAA Satellites

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TIROS-N/NOAA 衛星の TOVS による南極大気のオゾン全量の導出

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要旨: 南極昭和基地で受信された TIROS-N/NOAA 系気象衛星の TOVS データから，回帰法によって，オゾン全量の導出を試みた．HIRS/2 の中で，オゾン 9.6 μm 帯にあるチャンネル 9 のほか，チャンネル 1, 2, 3 と 8 を使った．回帰係数は，昭和基地のドブソン観測値を使って定めた．1981 年 2 月から 1982 年 1 月にかけて，NOAA-6, -7 の約 50 軌道のデータを解析した．こうして求めたオゾン量は，昭和基地ではドブソン値との平均 2 乗誤差が 3–13 DU (10^{-3}·atm·cm) であった．オゾン全量の水平分布も求め，南極点においても，衛星による値と地上でのドブソンによる値とがよい一致を示した．

***Abstract*:** A simple regression method is applied to derive the total ozone amount from the TOVS data of TIROS-N/NOAA meteorological satellites received at Syowa Station, Antarctica. Besides channel 9 located in the ozone 9.6 μm band, channels 1, 2, 3 and 8 of HIRS/2 are used. Regression coefficients are determined against Dobson measurements at Syowa Station. Data from 50 orbits of NOAA-6 and -7 are analyzed for 1981–1982. RMS errors of retrieved ozone amounts are 3 to 13 DU (10^{-3}·atm·cm) at Syowa Station. Horizontal distributions of the total ozone amount are also given and fairly good agreements are seen at the South Pole between the ozone amounts derived from satellites and ground Dobson measurements.

1. Introduction

The ozone measurement from satellites has become one of the most promising techniques of remote measurements of meteorological parameters. A global feature of the ozone distribution was given with seasonal variations by several authors (KRUEGER *et al.*, 1980). Several methods of satellite ozone measurements, the backscatter ultraviolet (B.U.V.), infrared limb or nadir radiance and solar occultation method, have been developed. Among them, the infrared nadir radiance method adopted for the

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TIROS-N/NOAA series meteorological satellites is not powerful enough to obtain a vertical distribution of ozone, but it has a capability to obtain information on the total ozone during day and night, especially in the polar night.

We are trying to derive total ozone amounts in the Antarctic atmosphere in a rather minute horizontal scale from infrared nadir scanning data of TIROS Operational Vertical Sounder (TOVS) of NOAA-6 and -7 received at Syowa Station (69°00′S, 39°35′E), Antarctica. As a first trial, we adopt a simple statistical regression procedure similar to that proposed by CROSBY *et al.* (1981), though there are still other methods proposed by MULLER and CAYLA (1983) and PRABHAKARA *et al.* (1976). In the present notes, an overview of the analytical method and typical results with an error estimate are given.

2. Analytical Procedures

The High-resolution Infrared Radiation Sounder (HIRS/2) of TOVS measures radiances emitted by 56 spots along a cross-track scanning line. The spot diameter is about 17 to 50 km according to the scanning angle. Systems and performances of satellite and radiometers have been reported elsewhere (SMITH *et al.*, 1979; WERBOWETZKI, 1981).

The upwelling infrared spectral radiance at wavenumber ν measured by radiometer of HIRS/2 is written as

$$I_\nu = B_\nu(T_s)\cdot\tau_\nu(p_s) - \int_0^{p_s} B_\nu[T(p)]\frac{\partial\tau_\nu(p)}{\partial p}\mathrm{d}p\,, \quad (1)$$

where B_ν, τ_ν, T and p are the Planck function, transmittance from any given level to the top of the atmosphere, temperature and pressure. The suffix s denotes the underlying surface. The channel 9 radiance in the ozone 9.6 μm band includes the information

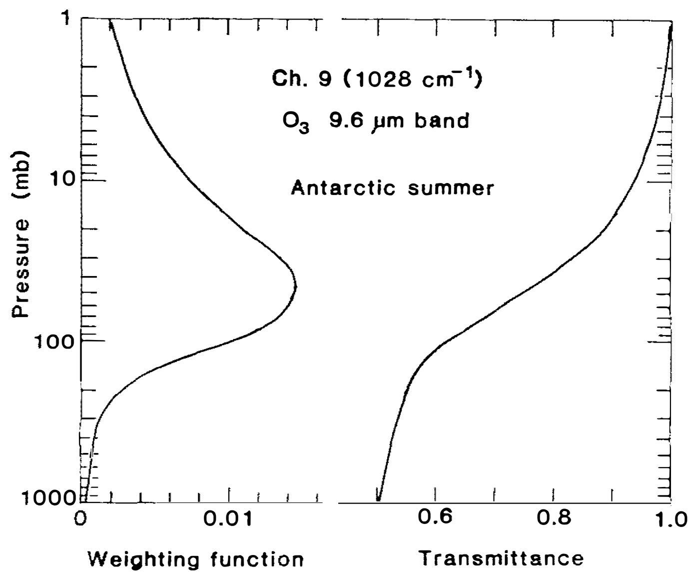

Fig. 1. Weighting function and transmittance of channel 9 of HIRS/2 in the ozone 9.6 μm band at the nadir angle. Calculation is made for the temperature and ozone profile for the Antarctic summer condition (derived from aerological data at Syowa Station).

on the ozone amount through transmittance τ_ν. However, the radiance is also affected by the vertical profile of ozone. The radiance also includes the effect of temperature distribution through $B_\nu(T)$. The transmittance τ_ν of channel 9, as shown in Fig. 1 based on the line-by-line calculation (ITO *et al.*, 1982), does not converge to 0, even for the path from the top of the atmosphere to the ground surface, and remains about 0.5 for the nadir angle. The contribution of the surface temperature—the first term of eq. (1)—still remains unnegligible. Then, the total ozone amount cannot be determined from the single measurement of channel 9. Since the ozone amount is said to correlate to the temperature of the ozone layer (CROSBY *et al.*, 1981; SAKAI, 1979), radiances of channels 1, 2, 3 which measure the temperature around the ozone layer, are taken into account. The radiance of channel 8, window channel, is also included to remove the effect of the surface.

Since the physical relationship between the total ozone amount and radiances of these channels is complicated, we used the simplest method, the linear regression method proposed by CROSBY *et al.* (1981), to obtain the total ozone amount. The total ozone amount U is expressed with brightness temperatures T_i in five channels as

$$U=\bar{U}+\sum_{i=1}^{5} C_i\cdot(T_i-\bar{T}_i), \tag{2}$$

where $\bar{U}$ is the average total ozone amount and C_i are the regression coefficients for five channels. Regression coefficients C_i and $\bar{U}$ are determined from the surface measurements by the Dobson spectrophotometer at Syowa Station, comparing with the satellite measurements of average brightness temperatures at the nearest four spots (within about 50 km). For other scanned spots, ozone amounts are calculated by eq. (2) using thus determined C_i and $\bar{U}$.

The foregoing data processing of each channel is performed by the method explained by TANAKA *et al.* (1982).

3. Results and Discussions

Among the data of 700 orbits received at Syowa Station by one of the authors (Y. SEO) during the 22nd Japanese Antarctic Research Expedition (JARE-22), about 50 orbital data from February 1981 to January 1982 are analyzed. Three different sets of regression coefficients are determined for three seasons, February to March, September to November and December to January, respectively. In the polar night, since we had no observation with the Dobson spectrophotometer that year, regression coefficients could not be generated.

Total ozone amounts obtained at Syowa Station from the NOAA-7 and Dobson spectrophotometer measurements (JAPAN METEOROLOGICAL AGENCY, 1986) are compared for an example in Fig. 2, also with brightness temperatures of five channels used in the regression. Though the results in Fig. 2 are in a season of large variation in ozone amount, day-to-day variations can be expressed by satellite measurements. Average amounts of total ozone, regression coefficients and the root mean-square (RMS) deviation of the satellite measurements from the Dobson measurements at Syowa Station are listed in Table 1. RMS deviations are small in the season when the variation of

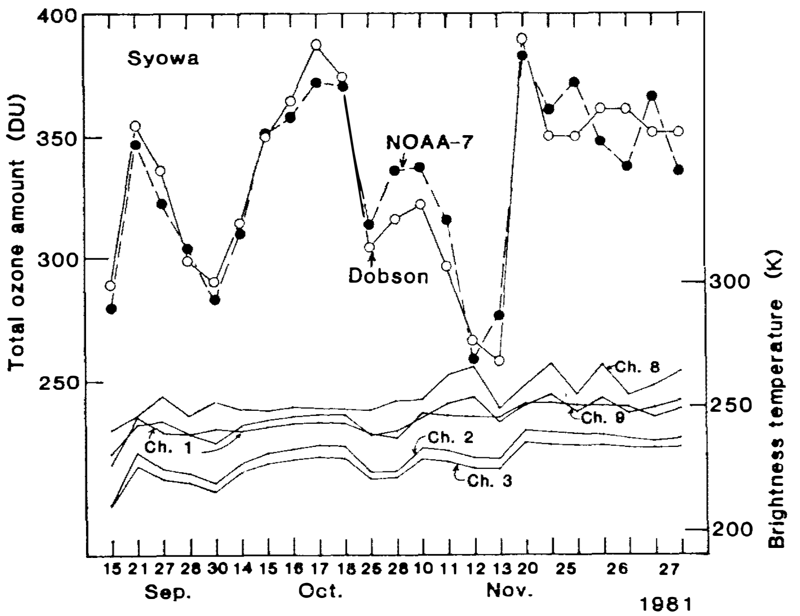

Fig. 2. Total ozone amounts at Syowa Station obtained from satellite (NOAA-7) and Dobson spectrophotometer measurements. Brightness temperatures of five channels used in regression are also compared.

Table 1. Average total ozone amounts, regression coefficients and RMS errors of satellite values at Syowa Station.

Seasons	(Numbers of data)	Average total ozone by Dobson (DU)	RMS errors of satellite values (DU)	Regression coefficients (DU/K)				
				C_1 (Ch. 1)	C_2 (Ch. 2)	C_3 (Ch. 3)	C_4 (Ch. 8)	C_5 (Ch. 9)
Feb.–Mar.	(12)	303.5	2.9	−2.405	5.755	1.105	1.7001	−4.7638
Sep.–Nov.	(23)	332.1	13.2	−19.849	41.270	−21.851	1.7202	−5.5044
Dec.–Jan.	(15)	313.9	2.3	−13.078	−7.9891	36.686	0.6816	−2.5079

ozone amount is small, and large in the season of large variation. These amounts are smaller than the standard error of 24.6 DU (10^{-3}·atm·cm) estimated by CROSBY *et al.* (1981) from about 600 data of TIROS-N. A scatter diagram of all results at Syowa Station is shown in Fig. 3. Since these results are only for those used in the regression, they do not have any bias.

Another comparison is made in Fig. 4 for the independent data set at the South Pole which is the only other station where the total-ozone observations are made on the ground in the Antarctic. Satellite values deviate larger than those in the case of dependent data set (Fig. 2); however, they still express the overall trend. RMS deviation of 27 data compared at the South Pole is 32 DU and the mean difference is 5 DU. These values compare with CROSBY *et al.*'s (1981) value, 34 and 11 DU, respectively.

Examples of horizontal distribution of the total ozone amount are shown in Fig. 5 from four orbits to present the seasonal variation. Fig. 5a of May 10 (derived using the regression coefficients obtained for February to March) shows a wintertime distribution with a moderate horizontal gradient of ozone amount. In Fig. 5b of October

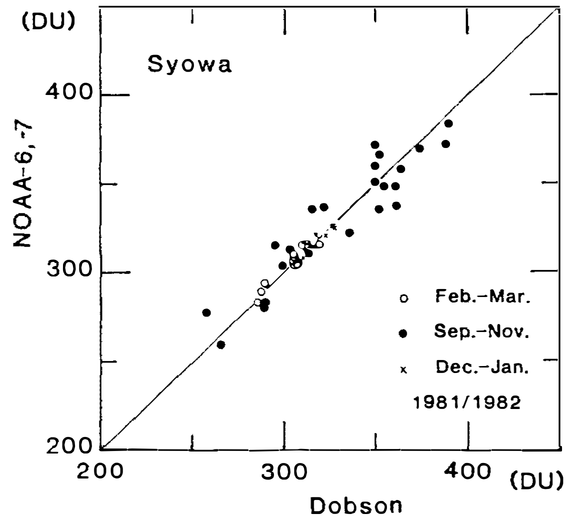

Fig. 3. Scatter diagram of total ozone amounts at Syowa Station obtained from satellites (NOAA-6 and -7) and Dobson spectrophotometer measurements.

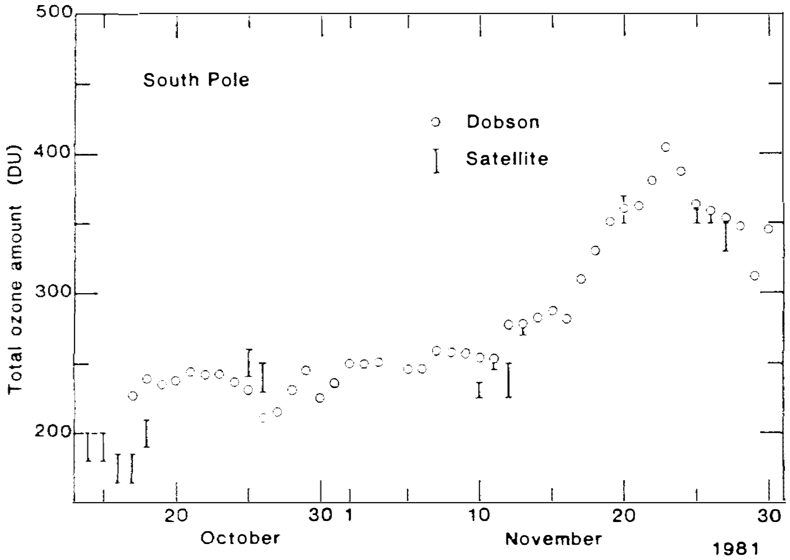

Fig. 4. Comparison of total ozone amounts at the South Pole obtained from satellite (NOAA-7) and Dobson spectrophotometer measurements. Satellite values are retrieved using coefficients determined at Syowa Station.

15, the maximum region of ozone in the lower latitude ($\approx 60°S$) is extending to the coast of the Antarctic Continent. This day corresponds to the time of rapid increase of the ozone amount at Syowa Station seen in Fig. 2. Fig. 5c of November 11 shows the time of transport of ozone maximum from the lower latitude to the higher latitude. The maximum region travels along the longitude of 90°E, in the east side of Syowa Station. In this time, the ozone shows a little minimum again (Fig. 2). Fig. 5d of December 22 shows a typical summertime distribution after a rapid increase of ozone amount (referred as the stratospheric sudden warming), again with a moderate gradient. The ozone maximum region exists at the higher latitude, in the inland of the Antarctic Continent. An overview of the seasonal variation of ozone amounts, thus presented, will

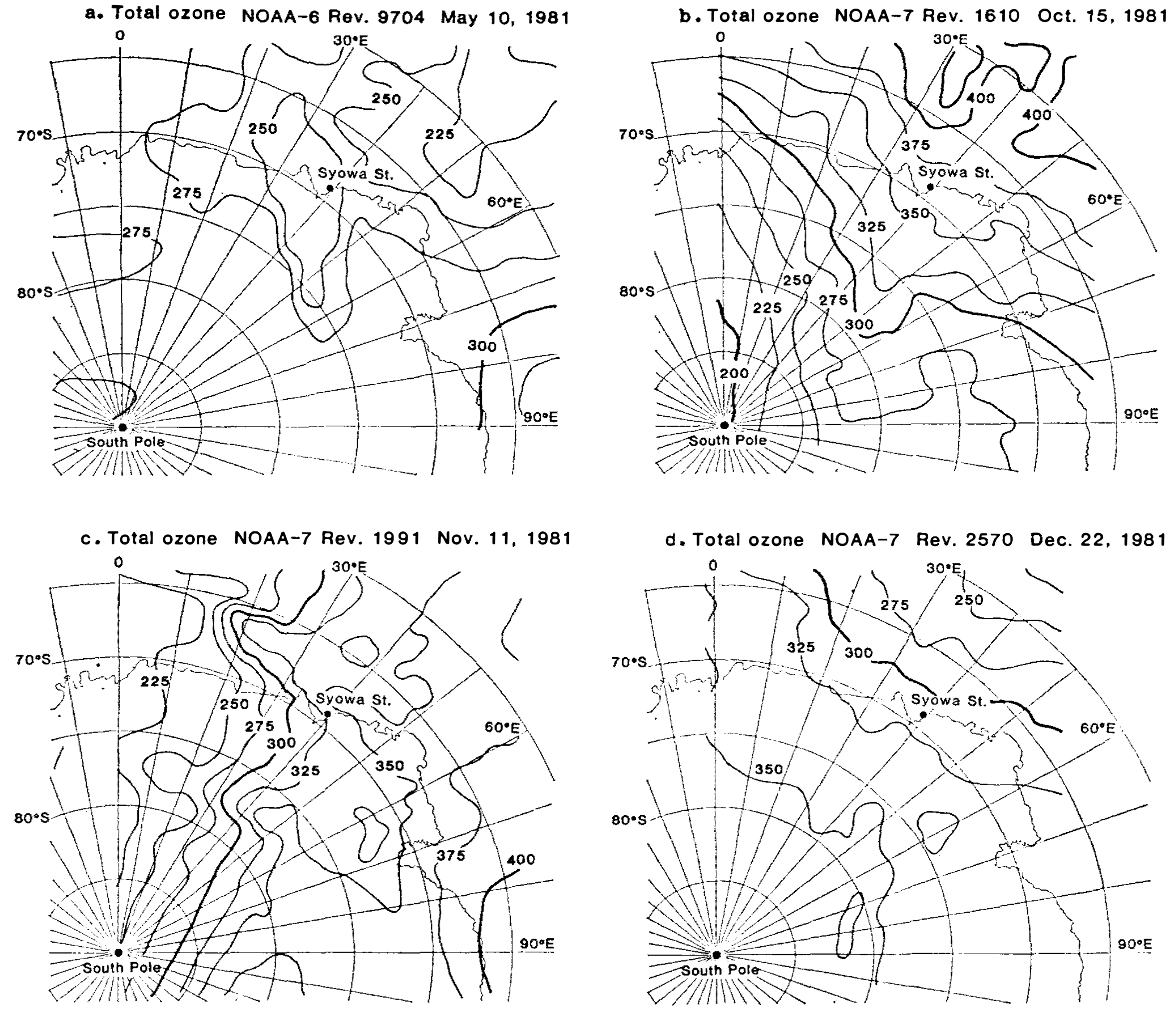

Fig. 5. Horizontal distributions of total ozone amount in the northeastern part of Antarctica obtained from satellites (NOAA-6 and -7). Numbers in DU (10^{-3}·atm·cm).

support the foregoing discussion just as supposed by SHIMIZU (1970). This seasonal variation is also consistent with the global behavior of ozone reported by PRABHAKARA *et al.* (1976) from the Nimbus-4 experiment.

Acknowledgments

The authors wish to express their sincere thanks to the members of the JARE-22, led by Prof. Y. YOSHIDA, National Institute of Polar Research, for their kind support to the satellite data receiving. Thanks are also due to Prof. T. YOSHINO of University of Electro-Communications and Prof. S. KAWAGUCHI of National Institute of Polar Research for their kind advice and encouragements throughout this work. Also the authors are indebted to Dr. J. DELUISI, NOAA-GMCC, and to the Antarctic Observation Office, Japan Meteorological Agency, for providing the Dobson data at the South Pole and Syowa Station, respectively.

The processing and analysis of the data were made by utilizing facilities of the Information Processing Center of National Institute of Polar Research including HITAC

M-160 II system. This work was supported financially in part by Grant-in-Aid for Scientific Research, No. 57740219, the Ministry of Education, Science and Culture.

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(Received December 27, 1983: Revised manuscript received January 14, 1984)