Study on Atmospheric Ozone in East Asia with Satellite Observation①

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ABSTRACT

The atmospheric ozone in East Asia has been studied with satellite remote sensing. The relationship between atmospheric ozone and tropopause height is analyzed and its response to weather processes has been discussed. The mean deviation between the total atmospheric ozone content derived from TOVS data and that got from ground-based Dobson spectrophotometer observation is 3.67%. The total atmospheric ozone content increases with the latitude increasing in East Asia. The correlation coefficient between total ozone content and tropopause height is negative. The average is 74%. The total atmospheric ozone content is closely related to weather processes. Ozone content increases while arctic air mass invading and decreases while tropic air mass coming.

Key words: Atmospheric ozone, Tropopause height, TOVS data, Ozone and weather

I. INTRODUCTION

We try to use satellite data of TIROS−N TOVS to derive the distribution and variation of total ozone content in East Asia, and to analyze the change of atmospheric ozone in response to weather processes.

II. RETRIEVAL METHOD

The physical-retrieval method of atmospheric ozone (Ma X.L. et al., 1984, 1986) is adopted here. The radiative transfer equation is

$$I(v,\theta)=B(v,T_s)\tau(v,\theta,p)-\int_0^{p_s}B(v,T)\frac{\partial\tau(v,\theta,p)}{\partial p}dp, \quad (1)$$

where $I(v,\theta)$ is the radiance received by satellite, $B(v,T)$ the Planck function, $\tau(v,\theta,p)$ the transmittance, v the frequency, θ the zenith angle, T and T_s are the temperature and surface temperature respectively, p and p_s are pressure and surface pressure, respectively.

The iterative retrieval (Smith, 1970, 1983) is used to derive atmospheric ozone. Using a first order Taylor expansion of Planck function $B(v,\theta,T)$ in terms of temperature and integrating Eq. (1) by parts, then Eq. (1) can be expressed as

$$T_B(v,\theta)-T_B^{(n)}(v,\theta)=\int_0^{p_s}[\tau(v,\theta,p)-\tau^{(n)}(v,\theta,p)]Q(v,\theta,p)\frac{dp}{p}, \quad (2)$$

where

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$$Q(v, \theta, p) = \frac{\partial B(v, \theta, T) / \partial T}{\partial B(v, \theta, T_B) / \partial T}\left(\frac{\partial T}{\partial \ln p}\right).$$

$T_B(v, \theta)$ is the measured brightness temperature, $T_B^{(n)}(v, \theta)$ is the brightness temperature calculated for the nth estimate of ozone profile and transmittance $\tau_B^{(n)}(v, \theta, p)$. The brightness temperature measured by HIRS-9 ozone channel is used to derive atmospheric ozone content with iterative method,

$$T_B(v, \theta) - T_B^{(n)}(v, \theta) = \int_0^{p_s} \ln\frac{u(p)}{u^{(n)}(p)} W^{(n)}(v, \theta, p)\frac{dp}{p}, \tag{3}$$

where

$$W^{(n)}(v, \theta, p) = \left(\frac{\partial B(v, \theta, T) / \partial T}{\partial B(v, \theta, T_B) / \partial T}\right)\left(\frac{\partial T}{\partial \ln p}\right)\left(\frac{\partial \tau(v, \theta, p)}{\partial \ln u^{(n)}(p)}\right),$$

$u(p)$ is the ozone concentration, the superscript n denotes an nth estimate value. An estimate of the true ozone concentration profile is obtained by using

$$u^{(n+1)}(p_j) = u^{(n)}(p_j) r^{(n)}(v), \quad j = 1, 2, \cdots 40,$$

where j is the layer number, and the atmosphere is divided into 40 layers vertically.

According Eq. (2), we derive the true ozone profile $u(p)$ as follows:

$$r^{(n)}(v) = \frac{u(p)}{u^{(n)}(p)} = \exp\left\{\frac{[T_B(v) - T_B^{(n)}(v)]}{\int_0^{p_s} W^{(n)}(v, p)\frac{dp}{p}}\right\}. \tag{4}$$

Radiances of HIRS-1, HIRS-2, HIRS-3, HIRS-4 and HIRS-9 are used to determine the first guess of ozone profile. Radiances of HIRS-5, HIRS-6, HIRS-7 are used to eliminate the cloud influence in order to derive the equivalent clear radiance. The atmospheric temperature and humidity are derived from TOVS data. The ozone content can be derived by means of iteration method, iterated until $r^{(n)} = 1$ and $u(p) = u^{(n)}(p)$, i.e., $|T_B(v, \theta) - T_B^{(n)}(v, \theta)| \leq \delta$, where δ is slightly larger than instrumental noise 0.2K. The flow chart of ozone content retrieval is shown in Fig. 1.

III. TEST OF ATMOSPHERIC OZONE CONTENT RETRIEVAL

First, we test the sensitivity of atmospheric ozone content to the brightness temperature of HIRS-9. The sensitivity factor K is

$$K = \Delta T_{B9} / \Delta X, \tag{5}$$

where T_{B9} is the brightness temperature of HIRS-9, X is the atmospheric ozone content, K is the brightness temperature of HIRS-9 in response to the change of atmospheric ozone content. As to the 4711 samples in July of 1989, we have $K = -0.225$ K / Dobson Unit. It reveals that the response of ozone content change to the brightness temperature of HIRS-9 is sensitive.

We have derived atmospheric ozone content in East Asia in July, August, September and October of 1989 with TOVS retrieval. The results in Beijing area have been compared with those observed at Xianghe near Beijing with Dobson spectrophotometer in the same time. The comparison results are shown in Fig.2. The regression formula is

$$\begin{aligned} &Y = 136.314 + 0.550X, \\ &R = 0.65, \quad N = 34, \quad s = 3.67\%, \end{aligned} \tag{6}$$

where Y is the ozone content of ground-based observation with Dobson spectrophotometer at Xianghe near Beijing, X is the ozone content retrieved with TOVS data in Beijing area, R is the correlation coefficient, N is the comparison sample, s is the variance. (The ozone data at Xianghe are provided by the Institute of Atmospheric Physics, Chinese Academy of Sciences).

IV. ATMOSPHERIC OZONE DISTRIBUTION IN EAST ASIA

The monthly mean atmospheric ozone distributions in July and October 1989 are shown in Fig. 3 and Fig. 4, respectively. Bowman (1984) analyzed 4-year data (from October 1979 to September 1982) of Nimbus 7 TOMS and obtained the global ozone distribution. As the value and change tendency are considered, the results in Fig. 3 and Fig. 4 are in agreement with those of Bowman. Ozone content increases with latitude increasing. There is a high value center in East Siberia. Near the equator about 20°N, the ozone content derived from TOVS is smaller than that from TOMS. The possible reason is that cirrus causes the TOVS ozone value on the low side. (Ohring, 1991).

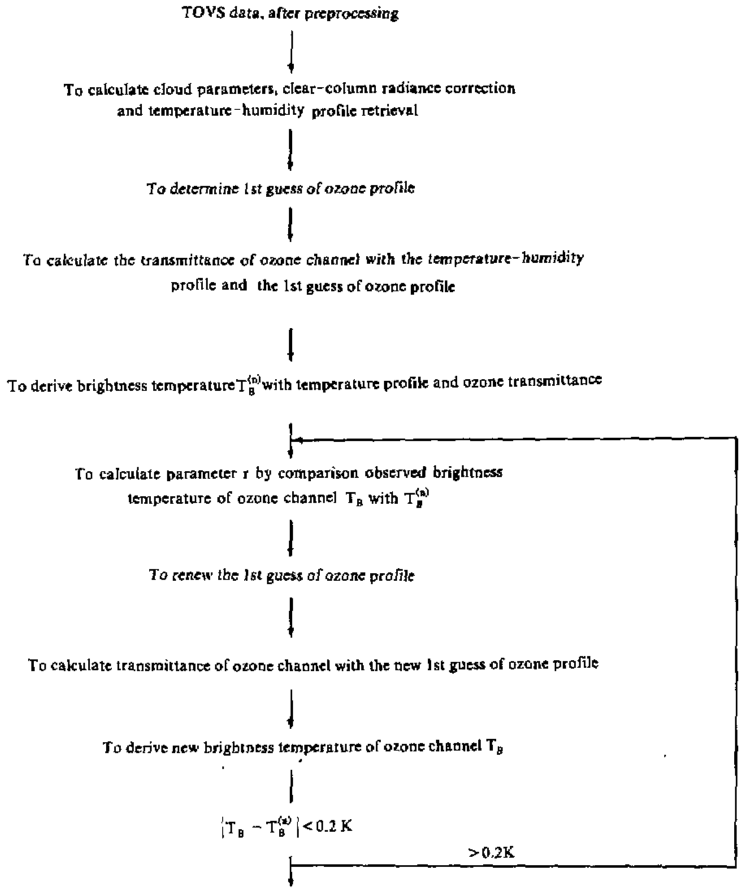


Fig. 1. Flow chart of the total ozone content retrieval.

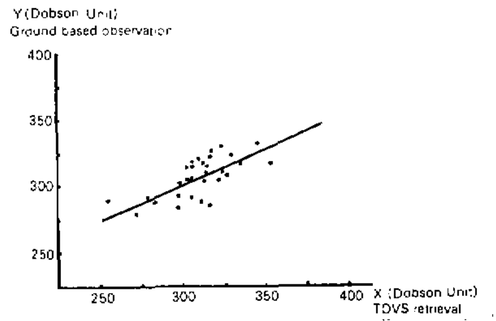


Fig. 2. Atmospheric total ozone content value, derived from TOVS retrieval against that of ground-based Dobson-spectrophotometer observation in Beijing, June–October, 1989.

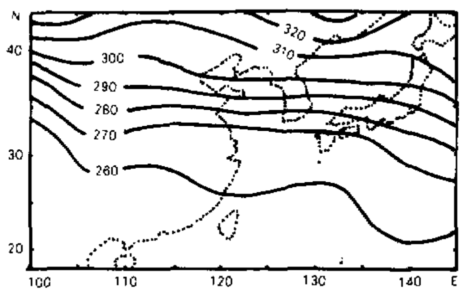


Fig. 3. TOVS retrieved monthly mean distribution of atmospheric ozone content in East Asia in July 1989. Unit: Dobson unit.

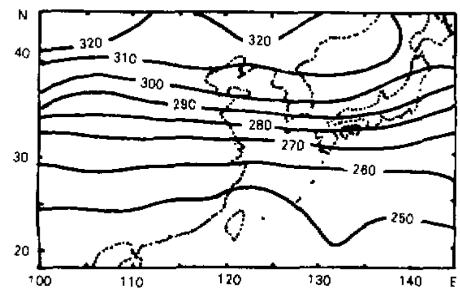


Fig. 4. TOVS retrieved monthly mean distribution of atmospheric ozone content in East Asia in October 1989.

V. ATMOSPHERIC OZONE AND TROPOPAUSE HEIGHT

(1) To Derive Tropopause Height from TOVS Data

We choose the sensitive channel of HIRS–2 and MSU. Let the sensitivity factor of tropopause height K' be

$$K' = \Delta T_B / \Delta H_{Tp}, \tag{7}$$

where T_B is the brightness temperature (K), H_{TP} the tropopause height (km). We change the tropopause height to find the variance of brightness temperature by means of radiative transfer equation. Then we find the retrieval channels of tropopause height HIRS–3, HIRS–4, HIRS–9, HIRS–12, HIRS–16 and MSU–3 and construct the retrieval formula of tropopause height H_{TP} as

$$H_{Tp} = A_0 + \sum_{k=1}^{6} A_k T_{Bk}, \quad k = 1,2,3,4,5,6, \tag{8}$$

where H_{TP} is the tropopause height (km), T_{BK} the brightness temperature (K) of HIRS–3, HIRS 4, HIRS 9, HIRS–12, HIRS–16 and MSU–3, $A_i (i = 1,2,3,4,5,)$ the regression coefficients (Zhao Bolin et al., 1991).

(2) Relationship between Atmospheric Ozone and Tropopause Height

From TOVS data, we have retrieved the tropopause height in East Asia. As an example, Fig. 5 shows the monthly mean tropopause height distribution in July 1989. The distribution of tropopause height is inversely proportional to that of ozone content. The tropopause height decreases as latitude increasing. Between the atmospheric ozone and tropopause height, there exists an negative correlation. On the matching time and place, the regression formula of atmospheric ozone against the tropopause height in July 1989 is

$$H_{Tp} = 20.902 - 0.0188X, \quad (9)$$
$$R = -0.74, \quad N = 15735, \quad s = 0.47 \text{ km},$$

where X is the atmospheric ozone content (Dobson Unit), R the correlation coefficient, N the sample number, s the variance. As an example, the relationship between atmospheric ozone and tropopause height on one satellite orbit is shown in Fig. 6.

VI. ATMOSPHERIC OZONE AND WEATHER

There exists a certain relationship between atmospheric ozone and weather. Two kinds of weather systems are analyzed in the following.

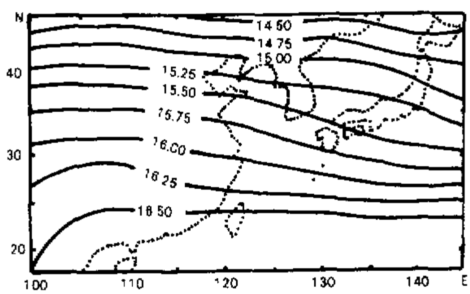


Fig. 5. Monthly mean distribution of tropopause height of TOVS retrieval in East Asia in July 1989.

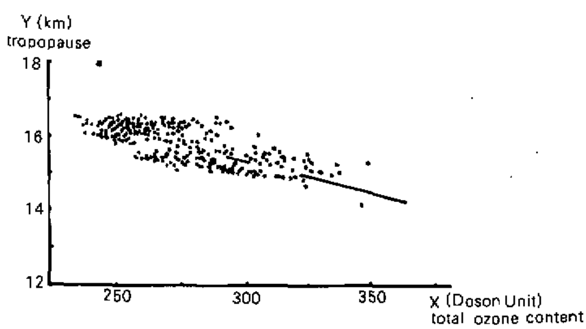


Fig. 6. Relationship between tropopause height and total ozone content at 10:40 on July 27, 1989.

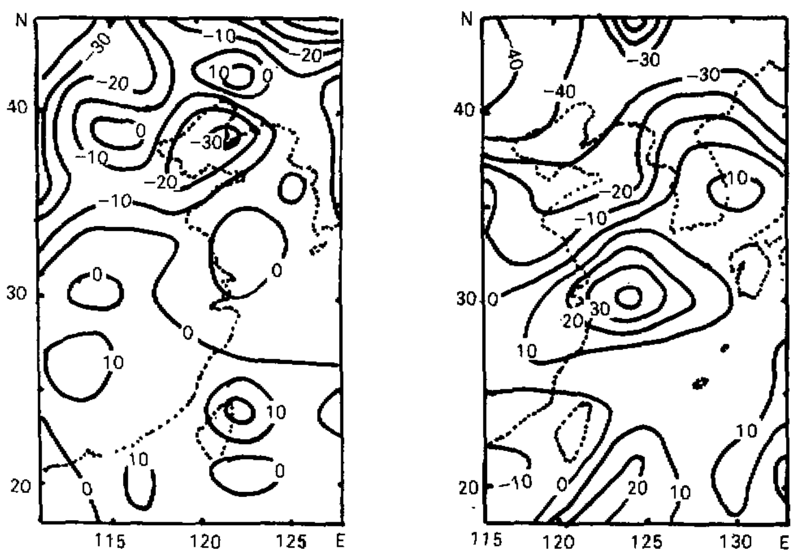
(1) Rainstorm weather on July, 21–22, 1989

On July, 21–22, 1989, there was strong convective precipitation in North China. It was caused by warm–humid air mass coming to North China. On mid–latitude front, there was a small stream of cold air, which moved eastward and was affected by orography, resulting in the rainstorm in North China. The anomalous distributions of ozone content and tropopause height are shown in Fig. 7 and Fig. 8, respectively. From Fig. 7 and Fig. 8, on July, 21–22 in North China there exist tropopause height development and positive deviation from the monthly mean, revealing strong convective lifting and orographic depression weather situation. Negative deviation of atmospheric ozone content exists during that period and its absolute value is rather large. On July 22, Northeast China has positive deviation of tropopause height and negative deviation of ozone content, rainstorm exists in Northeast China correspondingly. In summary, these reflect the relationship between tropopause height, ozone content and strong convective weather situation, i.e., the tropopause height lifting and ozone content decreasing in response to surface low pressure weather system, and vice versa.

(2) Cold Air Action on October 4–8, 1989

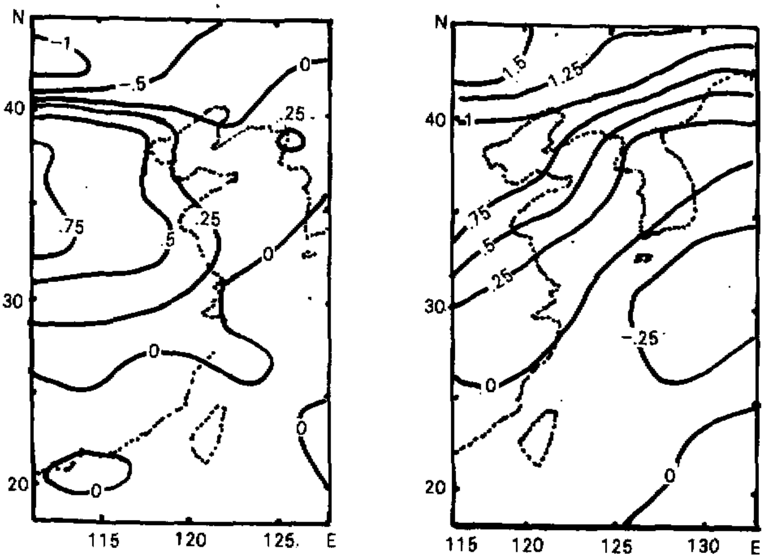
In the first dekad of October, cold air was active in China. A drop in the temperature was 8–12°C in Northeast China and 5–10°C in North China. The frost line was moved to North China plain. The characteristics of surface chart on October 4–8, 1989 are as follows:

(a) In Siberia and Mongolia, a cold high was moving southward and its cold front invaded China. Eventually, the high pressure controlled the whole Chinese main land.



(a) July 21 1989 11:13 (b) July 22 1989 10:51

Fig. 7. Distribution of monthly mean ozone content deviation of TOVS retrieval in rainstorm weather in North China on July, 21–22, 1989.



(a) July 21 1989 11:13   11:13 (b) July 22 1989 10:51

Fig. 8. Distribution of monthly mean tropopause height deviation of TOVS retrieval in rainstorm weather in North China on July, 21–22, 1989.

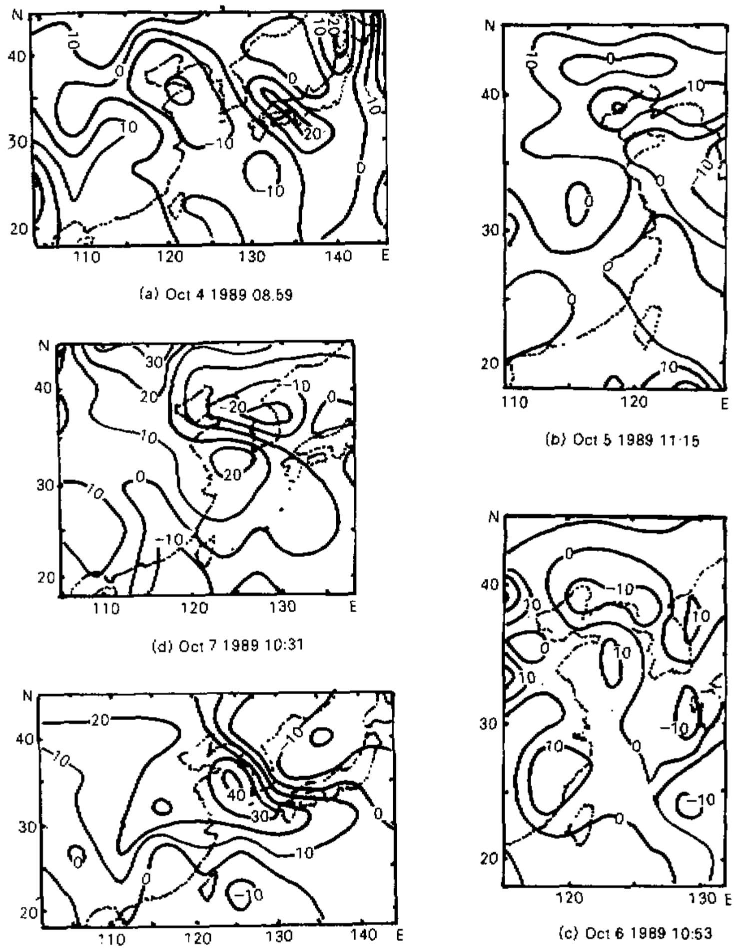
(b) In Southeast Japan and the northwestern Pacific, there were two typhoons, one moving toward to Northwest Japan and the other toward to the South China Sea. On October 4, from the deviation of ozone content we can see that there was a high ozone content district in North China and Mongolia, while a low center in East Taiwan. On 5 October, the cold front moved southward to Hunan province, ozone increased in this area obviously. On 6 October, cold air invaded Fujian province and a high center of ozone appeared. On 7–8 October, cold air mass controlled the whole China, the deviation of ozone content was positive. There were two ozone low centers in response to two typhoons, one near Japan and the other at Taiwan (Fig. 9).

VII. CONCLUSION

1. The atmospheric ozone can be retrieved from TOVS data. The sensitivity K is −0.225K / Dobson Unit. It is sensitive to derive atmospheric ozone content by means of TOVS data.

2. In East Asia, the atmospheric ozone increases with the latitude increasing. There is a ozone trough in (45°N, 130°E) area, and the trough is stronger in autumn than that in summer.

3. There exists negative relationship between ozone content and tropopause height. From the analysis of July 1989 data, the variation of correlation coefficient is from 0.42 to 0.87. To 75% of the whole sample, the correlation coefficient is larger than 0.7 while the average is 0.74 for the 15735 samples. The correlation of atmospheric ozone and tropopause height and its variation are related to the local air mass change in a certain degree. In low pressure, there



(a) Oct 4 1989 08.59

(b) Oct 5 1989 11:15

(c) Oct 6 1989 10:53

(d) Oct 7 1989 10:31

(e) Oct 8 1989 10:09

Fig. 9. Distribution of monthly mean ozone content deviation of TOVS retrieval in cold air action weather on October 4–6, 1989.

exists low ozone center and vice versa. Ozone content increases while arctic air mass invading and it decreases while tropic air mass coming. (Zhao Jiuzhang et al., 1965).

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