# ENSO Signal in Total Ozone over Tibet①

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ABSTRACT

Based on the analysis of satellite ozone observation and atmospheric circulation data, this study discusses the ENSO signal in the inter–annual variation of Tibet total ozone, comparing with the tropics and non–mountain zone at the same latitudes of Tibet. It is shown that the Tibet ozone increases in El Niño events and decreases in La Niña events, with weakened amplitudes compared with the Southern Hemisphere. In addition this article discusses the mass transportation related to the ozone variations.

**Key words:** Ozone, ENSO, Tibet

## 1. Introduction

ENSO is one of the most important anomalies in the tropic ocean–atmosphere system (Walker and Bliss., 1932; Horel and Wallace, 1981; Karoly, 1989), and causes the global climate anomalies by the transportation of atmospheric waves (Simmons, 1982; Holton and Tan, 1980). During El Niño events, the tropical East Pacific SST increases, convection is strengthened, the tropopause is lifted, and therefore, the total ozone decreases, and vice verse in the La Niña events (Shiotani, 1992). Zou and Gao (1997) pointed out that the ENSO signal, with amplitude of about 50 DU, can be retrieved from the ozone variation at 60–70°S. Quiroz studied the ENSO transportation mechanism that due to the subtropical westerly jet acceleration in El Niño events, Rossby waves transfers the circulation anomalies in the tropics to middle and high latitudes, and the transferring is suppressed in the easterly wind phase in the subtropics. Zerofos et al. (1992) pointed out that a delayed correlation exists between SOI and the North American, Japan and European total ozone. Langford et al. (1996) proved that the correlation coefficient between SOI and the ozone anomaly in North American is 0.7, and ENSO makes 5% ozone change in the North American troposphere.

The thermal dynamic effects of the Tibetan Plateau influence the local and global circulation (Yeh and Gao, 1979), therefore the ozone variation over Tibet must contain the thermal dynamic features. Zou (1996) and Zou and Gao (1997) presented the relationship between the ozone loss and mass lifting caused by the thermal effects.

This article is attempting to present an analysis on the ENSO signal in Tibet ozone, compared with the tropics and the non–mountain zone at the same latitudes.

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## 2. Data and analysis method

Data used in this study are TOMS version 7 (CD–ROMs available from NASA / Goddard Space Flight Center, USA) in 1979–1992 for total ozone. An area–weighted (cos[latitude]) mean is applied in three regions: 25–40°N, 75–105°E for the Tibet; 25–40°N latitude belt without 75–105°E for the non–mountain region at the same latitudes of Tibet; and 5°S–5°N for the tropic region. The QBO index is from the standardized 30 hPa zonal wind over Singapore, the SOI index is the standardized sea surface pressure difference between Darwin and Tahiti, and the solar index is from the standardized 10.7 cm solar radio flux.

## 3. Analysis and discussion

### 3.1 *The seasonal variation in total ozone*

Figure 1 shows ozone seasonal cycles over the tropics, Tibet and non–mountain region averaged over 14–year observations. It is shown that the tropics seasonal ozone arrives a minimum of 250 DU in January and a maximum of 271 DU in September, with amplitude of 21 DU; the Tibetan ozone has a minimum of 269 DU in October and a maximum of 306 DU in March, with amplitude of 37 DU; and the non–mountain region ozone has a minimum of 273 DU in November and a maximum of 324 DU in April, with amplitude of 51 DU. The amplitude and phase have great difference between the tropical and mid–latitude ozone. Compared with the non–mountain zone at the same latitudes, the seasonal cycle phase in Tibetan ozone leads 1–2 months, and the amplitude is much smaller.

The seasonal productivity of ozone varies a little in the tropical stratosphere, the productivity is higher in summer than in winter at mid–latitudes, and the winter productivity can be ignored in winter at high latitudes. However, the seasonal ozone variation has no confirmed relation to the productivity at all latitudes and seasons (Wang, 1985). The pattern of total

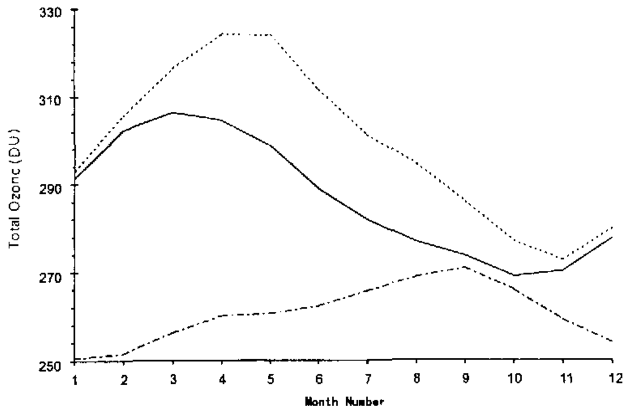


Fig. 1. Seasonal variation of total ozone. Solid line is for Tibet, Dashed for the non–mount zone at same latitudes as Tibet, and dash–dotted for the topics.

ozone distribution is mostly based on the eddy and mean meridional circulation (MMC) transportation (Dukorton and Baldwin, 1991; Holton, 1992). Because of the stronger outward transportation in winter than in summer, the tropical ozone accumulates in summer. Therefore, the seasonal ozone peak appears in autumn in the tropics. On the same transportation scheme, ozone at mid–latitudes accumulates in winter, and therefore arrives maximum in spring. The maximum in seasonal cycle of Tibetan ozone is suppressed due to the maximum heating and ozone loss in spring (Zou, 1996; Zou and Gao, 1997a, 1997b), therefore the amplitude of the seasonal cycle is smaller than the non–mountain region at the same latitudes.

### 3.2 *Inter–annual ozone variation*

For studying the inter–annual ozone variation, the above seasonal ozone cycles are removed from monthly ozone over the above three regions, and a 7–month smoothing treatment is applied to the anomaly time series. The purpose of 7–month smoothing is to filter out the perturbation with periods of less than half a year and keeps the main components of inter–annual variations. Figure 2 exhibits the inter–annual variation of the anomalies over the tropics, Tibet and non–mountain zone at the same latitudes. From Fig. 2, one can notice that the ozone anomaly stands high in 1979–1983, decreases after 1983 until the lowest level in 1985–1987, and thereafter, increases until a level lower than it was before. This long–term tendency coincides with the varying solar radiation and the declining ozone trend. The process is that the solar activity makes radiation change in upper atmosphere (about 80 km), and the ozone concentration varies related to the photochemical reaction; meanwhile, the absorption of solar radiation by ozone in the stratosphere changes the atmospheric thermal and dynamic status, and therefore the mass transportation by eddies and circulation that can cause ozone distribution change.

Bowman (1989) pointed out that the QBO signal exists in the extratropical ozone variation. In Fig. 2, a clear QBO signal is shown in inter–annual variation of total ozone over Tibet. Compared with the QBO in the tropical wind (Fig. 4), the ozone QBO varies with wind

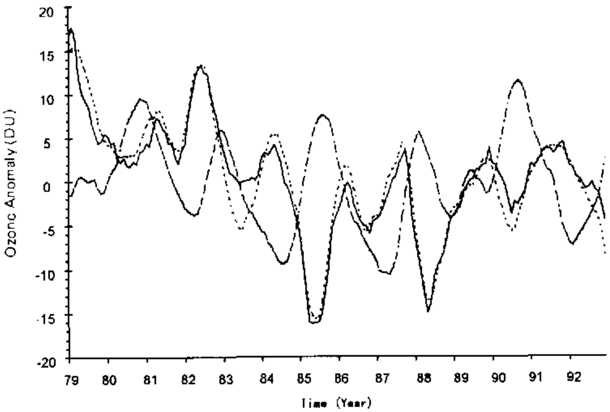


Fig. 2, Ozone anomaly. Solid line is for Tibet, Dahsed for the non–mount zone at same latitudes as Tibet and dash–dotted for the topics.

QBO in the same phase in the tropics. The ozone QBO over Tibet and the non–mountain zone varies in phase against the ozone and wind QBO in the tropics, i.e., when the tropical stratospheric wind is in the easterly phase, total ozone over Tibet and the non–mountain zone at the same latitude zone increases, and vice verse in the westerly phase.

### 3.3 *ENSO signal in total ozone*

To isolate the impact of ENSO on total ozone, the impact from solar activities, trends caused by chemical depletion and QBO must be removed from the inter–annual variation of total ozone (7–month smoothing is applied to the 3 variables). A regression equation is applied to the ozone anomalies discussed in the last section. $A(O_3) = a_1 I_{solar} + a_2 I_{trend} + a_3 S_{QBO} + R$, where $A(O_3)$ is the ozone anomaly in last section, $I_{solar}$ is the solar index, $I_{trend}$ is the ozone trend retrieved from a linear regression, $S_{QBO}$ is the standardized zonal wind at 30 hPa over Singapore, $R$ is the residuals including the ENSO signal, and $a_1$, $a_2$ and $a_3$ are the regression constants. Multi–correlation coefficients are 0.75, 0.74 and 0.76 for the regression equations over Tibet, the non–mount zone and the tropics, respectively. $F$ values are 72.13, 67.18 and 72.98 for the above three regions, respectively, therefore the regressions are meaningful. Figure 3 shows the ENSO signals retrieved from the regression for Tibet, the non–mount zone and the tropics.

From Fig. 3, a 3–5–year oscillation can be found in the ozone inter–annual variation over Tibet, the non–mount zone and the tropics. The maximum of inter–annual anomalies is 9 DU (May, 1982), 10 DU (May, 1982) and 8 DU (August, 1983), and the minimum −11 DU (July, 1985), −10 DU (July, 1985) and 5 DU (June, 1990), for Tibetan, non–mount zone and the tropics, respectively. Total ozone over Tibet increases during large El Niño events, e.g. 1982–1983, 1986–1987 and 1991, and decreases during large La Niña events, e.g. 1988. However, small Tibetan ozone anomaly can appear in normal years, e.g. the ozone anomalies were −6 DU and −11 DU in normal years 1980–1981 and 1985–1986.

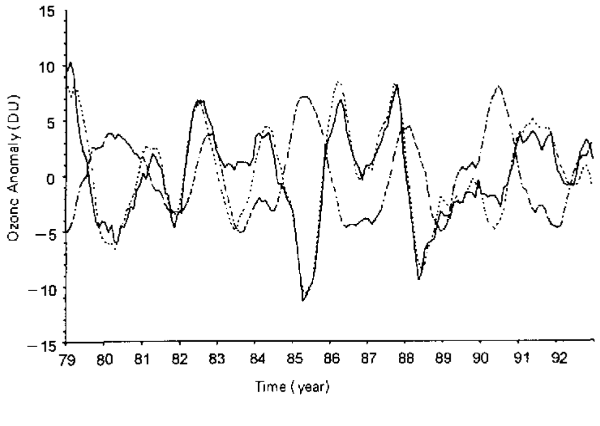


Fig. 3. Ozone anomaly after removal of the solar activity, trends and QBO. Solid line is for Tibet, Dashed for the non–mount zone at same latitudes as Tibet, and dash–dotted for the topics.

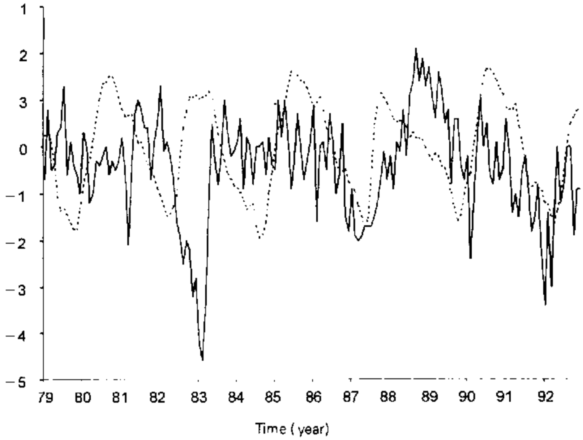


Fig. 4. Southern oscillation index (SOI, solid line) and QBO index (dashed line).

Figure 5 shows the zonal ozone anomaly in 5°N−5°S. Compared with Fig. 4, the ENSO signal in the tropical ozone is very clear, i.e., an obvious seesaw oscillation can be found between the West and East Pacific. The tropical ozone ENSO is in antiphase with the ENSO index. Figure 6 shows the 25−40°N ozone zonal anomaly. There is no obvious seesaw pattern between the east and west Pacific sections in the ozone variation over this zone, which is different from the middle and high latitudes in the Southern Hemisphere. The difference of ozone anomaly between the East and West Pacific is c.a. 9 DU that is within the error range of TOMS observation, 3%.

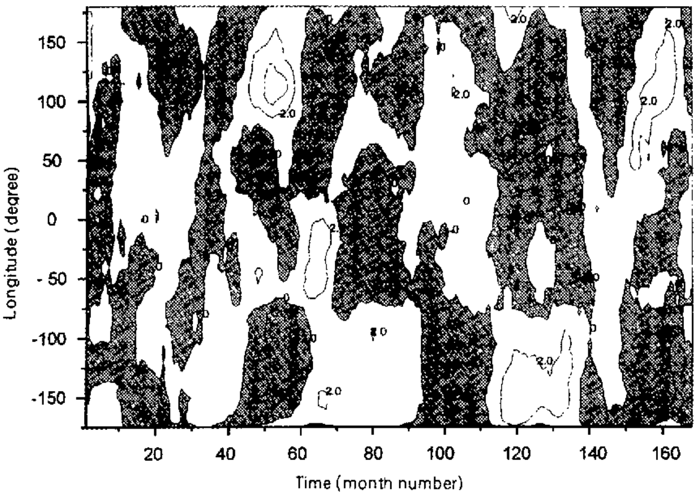


Fig. 5. Zonal ozone anomaly over the tropics. The curve interval is 2 DU, and the negative area is shadowed.

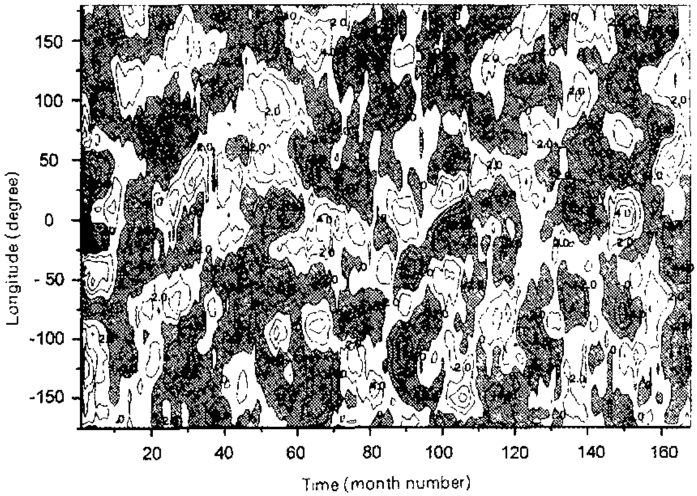


Fig. 6. Zonal ozone anomaly over 25–40°N, the curve interval is 2 DU, and the negative area is shadowed.

Therefore compared with the middle and high latitudes in the Southern Hemisphere, there is no obvious seesaw pattern of ozone variation in the East and West Pacific section of middle latitudes as the Tibet Plateau (Fig.6), but ozone in the whole latitude zone varies in phase against the ENSO index (Fig. 3). The explanation for the above described phenomenon can be the analysis done by Quiroz et. al. (1983): Under the conditions of the strengthened westerly jet in El Niño events, vertically and horizontally transferred Rossby waves carry the tropical circulation anomalies to higher latitudes, and when easterly is increased in non–El–Niño years, depressed transportation of Rossby waves stops the transportation of circulation anomalies from the tropics to higher latitudes. In addition, the amplitude of ozone ENSO signal at middle and high latitudes of the Southern Hemisphere is about 50 DU (Fig. 5, Zou, 1996; Zou and Gao, 1997), but the amplitude in Tibetan ozone ENSO is much smaller, about 20 DU. This indicates a easy transportation of the tropical circulation anomalies. Therefore, the study on the transportation manner and path of atmospheric circulation from the tropics to middle and high latitudes during El Niño events and its impact on ozone variation is needed.

## 4. Conclusion remarks

Based on the study, the following conclusions can be made:

1) The seasonal variation of Tibetan ozone is influenced by the meridional transportation of atmospheric mass;

2) The inter–annual variation of Tibetan ozone contains impacts from the solar activity, chemical depletion trends and QBO;

3) The inter–annual variation of Tibetan ozone contains a 3–5 year oscillation after the impacts from solar activity, trends and QBO, with amplitude of about 20 DU and antiphase against SOI during strong El Niño and La Niña events; and

4) There is no clear seesaw pattern in Tibetan ozone between the East and West Pacific section during strong El Niño and La Niña events, which is different from the middle and high latitudes in the Southern Hemisphere.

The cause of ENSO signal of Tibetan ozone is from northward transportation of the tropical atmospheric anomalies. Therefore, the mechanism in the transportation must be further studied.

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## REFERENCES

Bowman, K. P., 1989: Global pattern of the quasi-biennial oscillation in total ozone. *J. Atmos. Sci.*, **46**, 3328–3343.

Dukerton, T. J., and M. P. Baldwin, 1991: Quasi-biennial modulation of Planetary-wave fluxes in the Northern Hemispheric winter. *J. Atmos. Sci.*, **48**, 1043–1061.

Holton, J. R., and H. -C. Tan, 1980: The influence of the equatorial quasi-biennial cycle of the tropical stratosphere. *J. Atmos. Sci.*, **37**, 2200–2208.

Holton, J. R., 1992: *An Introduction to Dynamic Meteorology*. 403–432 (Academy Press, San Diego, California, USA, ed. 3, 1992)

Horel, J. D., and J. M. Wallace, 1981: Planetary-scale atmosphere phenomena associated with the Southern Oscillation. *Mon. Wea. Rev.*, **109**, 813–829.

Karoly, D. J., 1989: Southern Hemisphere circulation features associated with El Niño / Southern Oscillation event. *J. Climate*, **2**, 1239–1252.

Langford, A. O., M. H. Proffitt, T. E. VaZandt, and J. -F. Lamarque, 1996: Modulation of tropospheric ozone by a propagating gravity wave. *J. Geophys. Res.*, **101(D21)**, 26605–26613.

Shiotani, M., 1992: Annual, quasi-biennial, and El Niño-Southern Oscillation (ENSO) time-scale variations in equatorial ozone. *J. Geophys. Res.*, **97**, 7625–7633.

Simmons, A. J., 1982: The forcing of stationary wave motion by tropical diabatic heating. *Quart. J. Roy. Meteor. Soc.*, **108**, 503–534.

Walker, G . T., and E. W. Bliss, 1932: World weather V. *Mem. R. Meteorol.. Soc.*, **4**, 53–84.

Wang G-Q, 1985: *Study on Atmospheric Ozone*. Science Press, Beijng, 494pp.

WMO, 1985: Atmosphere ozone 1985, Assessment of our understanding of process controlling its distribution and change. *Global ozone research and monitoring project*, Rep. 16, Geneva, pp 331–343.

Yeh T., and Y. Gao, 1979: *Meteorology of Tibet*, Science Press, Beijing, 278pp.

Zerefos, C. S., F. B. Alkviadis, and I. S. Zosmas, 1992: On the relative importance of Quasi-biennial and El-Niñ o / Southern Oscillation in the revised total ozone records. *J. Geophys. Res.*, **97**, 10135–10144.

Zou, H., 1996: Seasonal variation and trends of TOMS ozone over Tibet. *Geophys. Res. Lett.*, **23**, 1029–1032.

Zou Han, and Gao Yongqi, 1997a: Long-term variation in TOMS ozone over 60–70°S. *Geophys. Res. Lett.*, **24**, 2295–2298.

Zou., H., and Y. Gao, 1997b: Vertical ozone profile over Tibet using Sage I and II data. *Advances in Atmospheric Sciences*, **14**, 505–512.

# 青藏高原臭氧的 ENSO

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**摘 要**

通过对臭氧卫星观测资料及大气环流资料的分析，研究了青藏高原上空臭氧年际变化中的 ENSO 信号，并与同纬度无山区及赤道地区进行比较。研究指出：在 El Niño 年(SOI 指数为负)青藏高原臭氧总量增加，在 La Niña 年(SOI 指数为正)青藏高原臭氧总量减小。本文同时讨论了与 ENSO 事件有关的大气环流物质输送。

**关键词**: 臭氧, ENSO, 青藏高原