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QBO Signal in Total Ozone over Tibet①

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ABSTRACT

From data analysis of ozone satellite observation and general circulation, this article discusses the seasonal and interannual variations of total ozone over Tibet. Analysis has been done on Quasi–Biennial Oscillation (QBO) in interannual ozone variation over Tibet, in comparison with QBO over the tropics and non–mountain region at the same latitudes of Tibet. The fact is shown that Tibet ozone QBO has an averaged period of 29 months, with an averaged amplitude of 8 DU. The Tibet ozone QBO is antiphase to the stratospheric wind QBO over the tropics, i.e., when the tropics 30 hPa–wind is easterly, ozone has a surplus, and vice verse. This article also discusses the impact of atmospheric transfer on ozone QBO over Tibet.

Key words: Ozone, QBO, Tibet

1. Introduction

Ozone is one of the trace gases in the atmosphere distributed in 10–50 km altitude with the maximum in 20–28 km. Ozone is significant in the following three aspects impacting the climate and environment: 1) Ozone absorbs harmful solar ultra–violet radiation for protecting the ecological system on the Earth; 2) ozone heats the stratosphere and forces the circulation systems in this layer; 3) ozone variation in the stratosphere can change the incoming radiation at the surface level and therefore the surface temperature. This process is the negative feedback for the greenhouse effect. The destruction of atmospheric ozone is due to the photochemical and catalytic processes. Atmospheric circulation and eddy transportation are significant in global ozone distribution (WMO, 1985). Since the first report on the Antarctic ozone hole, the ozone losses have drawn the public attention, and a large amount of researches have been done on the ozone hole and global ozone variation (WMO,1985; WMO,1991; Farman et al., 1985). The studies showed decreasing trends in total ozone over the globe (Zou, 1990; Stolarski et al., 1992; Bojkov et al., 1990).

Dynamics studies show a QBO in the stratospheric zonal wind and temperature in the tropics region (Ebdon, et al., 1961; Reed, et al., 1961; Lindzen, et al., 1968). Thereafter, QBO is discovered from the atmosphere outside of the tropical region (Holton, et al., 1972; Dunkerton, 1985). For the mechanism in atmospheric QBO, Reed (1964), Lindzen and Holton (1968), Lindzen (1987) discussed, and Andrews et al. (1987) came to a conclusion that the kinetic source of the downward transferring QBO is the absorption of vertically upwards transferring waves by the Kelvin wave and mixed Rossby–gravity wave in the stratosphere. The ozone QBO is caused by the following processes: As the tropical stratospheric

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wind is easterly, the temperature increases northwards, the tropopause height increases, and therefore the total ozone reduces; as the tropical stratospheric wind is westerly, the temperature decreases northwards, the tropopause height decreases, and therefore the total ozone increases. When the tropical stratospheric wind shifts from easterly to westerly in a biennial period, a QBO can be found in total ozone. Therefore, the tropical ozone QBO has the same phase as the wind QBO (Reed, 1964; Reid et al., 1985). QBO was also discovered from the extratropics (Holton, et al., 1980). Bowman (1989) and O'Sullivan et al. (1990) discussed that the extratropical QBO in total ozone was consistent with a quasi–biennial forcing of the mean meridional circulation (MMC) by planetary waves and the resulting modulation of the vertical advection of ozone.

Zou (1996) and Zou et al. (1997) showed that the ozone loss over Tibet is closely related to the upwards mass lifting due to the surface heating, the ozone loss is caused by the thermal dynamic processes. The thermal dynamics in the Tibetan atmosphere has great impacts on the local and global circulation (Ye et al., 1979), so the features in ozone variation, such as QBO and ENSO, over this region must imply this thermal dynamic impact. The purpose of this study is to retrieve the ozone QBO over Tibet, and analyze its characteristics by comparison with ozone QBO over the tropics and the non–mountain regions at the same latitudes of Tibet.

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 tropical region. The QBO index is from the standardized 30 hPa zonal wind over Singapore, and the solar index is from the standardized 10.7 cm solar radio flux.

3. Analysis and discussion

3.1 *Seasonal ozone cycle*

Figure 1 shows ozone seasonal cycles over the tropics, Tibet and non–mountain region averaged from 14–year observation. It is shown that the tropics seasonal ozone reaches minimum 250 DU in January and maximum 271 DU in September, with amplitude 21 DU; the Tibetan ozone has minimum 269 DU in October and maximum 306 DU in March, with amplitude 37 DU; and the non–mountain region ozone has minimum 273 DU in November and maximum 324 DU in April, with amplitude 51 DU. The amplitude and phase are of great difference between the tropical and mid–latitude ozone. Compared with the non–mountain zone at the same latitudes, the seasonal cycle phase in Tibet 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 middle latitudes, and the 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 ozone distribution is mostly based on the eddy and MMC transportation (Dunkerton et al., 1991; Holton, 1992). Because of the stronger outward transportation in winter than in summer, the

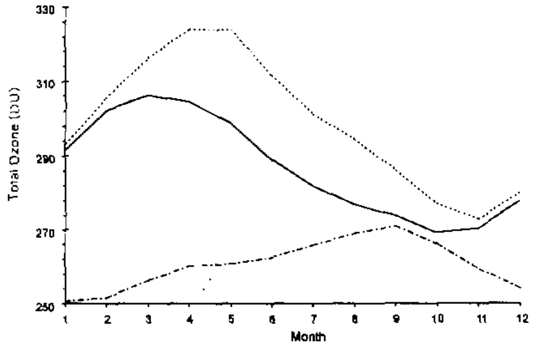

Fig. 1. Seasonal ozone variation over Tibet (solid line), the non–mountain zone (dashed line) and the tropics (dot–dashed line).

tropical ozone accumulates in summer. Therefore, the seasonal ozone peak appears in autumn in the tropics. On the same transportation scheme, ozone at middle latitudes accumulates in winter, and therefore reaches maximum in spring. The maximum in seasonal cycle of Tibet ozone is suppressed due to the maximum heating and ozone loss in spring (Zou, 1996; Zou et al., 1997), therefore the amplitude of the seasonal ozone cycle in Tibet is smaller than that in the non–mountain region at the same latitudes.

3.2 *Interannual ozone variation*

For studying the interannual 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 reason for the 7–month smoothing is that 7 months cover about 1 / 4 period of QBO, and normally QBO takes a 26–30 months period, therefore 7–month smoothing filters out the smaller perturbation and keeps the main components of QBO. Figure 2 exhibits the interannual variation of the ozone 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: The solar activity makes radiation change in the upper atmosphere (about 80 km), and the ozone concentration varies related to photochemical reaction; meanwhile, the absorption of solar radiation by ozone in the stratosphere changes the atmospheric thermal and dynamic status, and therefore changes the mass transportation by eddies and circulation which can cause ozone distribution changing.

3.3 *Ozone QBO signal*

To retrieve the QBO signal from the Tibet ozone, the impacts from solar activity and chemical depletion trends should be removed. A regression equation is applied to the ozone anomalies discussed in the last section. $AO_3 = a_1 + a_2 \times I_t + a_3 \times I_s + R$, where AO_3 is the ozone anomaly in last section, I_t is the ozone trend retrieved from a linear regression, I_s is the solar index, R is the residuals including QBO signal, and a_1, a_2 and a_3 are the regression

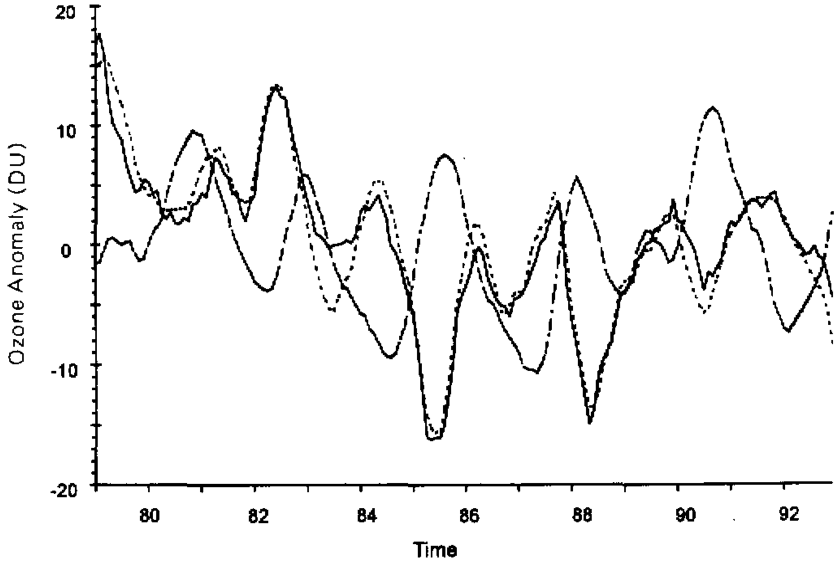

Fig. 2. Time series of deseasonalized ozone anomalies over Tibet (solid line), the non-mountain zone (dashed line) and the tropics (dot-dashed line).

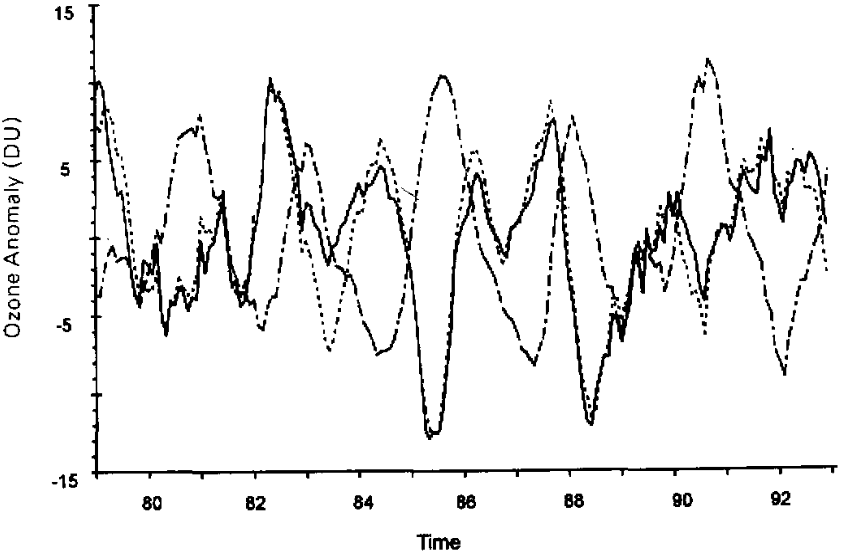

Fig. 3. The ozone anomalies without solar cycle and chemical trends over Tibet (solid line), the non-mountain zone (dashed line) and the tropics (dot-dashed line).

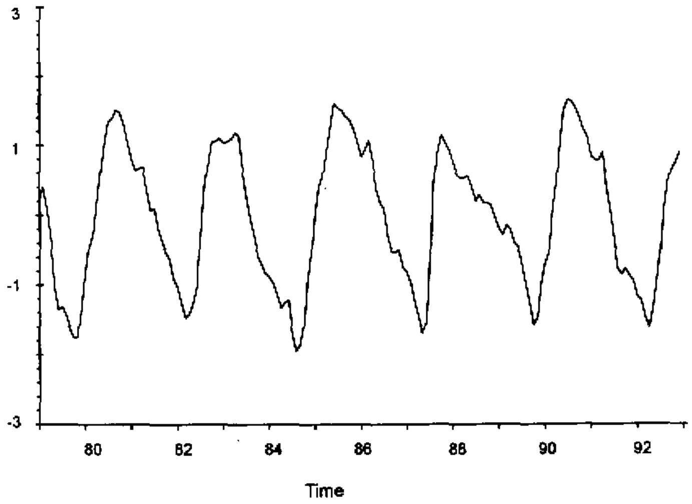

Fig. 4. Standardized 30 hPa zonal wind over Singapore (QBO index).

constants. Multi–correlation coeffcients are 0.36, 0.65 and 0.66 for regression equations over the tropics, Tibet and non–mount zone, respectively. The F–test shows: $F_1 = 11.95$, $F_2 = 61.21$ and $F_3 = 62.82$ for the tropics, Tibet and non–mountain zone, respectively, therefore, in the statistics, the correlation coefficients for the regression are reliable. The relatively small correlation coefficients indicate a need that other systematical oscillation should be included in the regressions, such as QBO. Figure 3 shows the ozone QBO signal, R, over the tropics, Tibet and non–mountain zone at the same latitudes, and Fig. 4 shows the stratospheric wind QBO over Singapore.

From Fig. 3, QBO is shown in the interannual ozone variation over the three defined regions. The Tibet ozone QBO period is about 26–32 months with maximum 10 DU (May, 1982) and minimum −13 DU (July, 1985), the non–mountain zone 26–32 months with maximum *10 DU (May, 1982) and minimum −13 DU (July, 1985), and the Tropics 29–33 months* with maximum 11 DU (September, 1990) and minimum −9 DU (February, 1992). It is seen that the tropical ozone QBO is antiphase to ozone QBO over Tibet and the non–mountain zone. This antiphase can be caused by the inversion of MMC and eddy transportation. Compared with zonal wind QBO in the tropical stratosphere in Fig. 4, ozone QBO over the tropics is in phase with the tropical wind QBO, i.e., the ozone is in surplus phase with tropical westerly and vice versa. The ozone QBO over Tibet and non–mountain zone is antiphase to the tropical wind QBO, i.e., the ozone QBO over Tibet and non–mountain zone is in deficit phase during the tropical westerly.

The quasi–biennial oscillation is not in strictly periodical variation, therefore, to retrieve the averaged measure of ozone QBO, the " supper–imposed epoch" (SIE) method (Sitnov, 1996) is applied to the analysis. Figure 5 presents the ozone QBO signal in the three regions, i.e. the tropics, Tibet and the non–mountain zone, after SIE treatment. It can be seen from Fig. 5 that the averaged ozone QBO amplitude in the tropics is much larger than that over Tibet and non–mountain zone, with an averaged amplitude of 14 DU. The mean ozore QBO

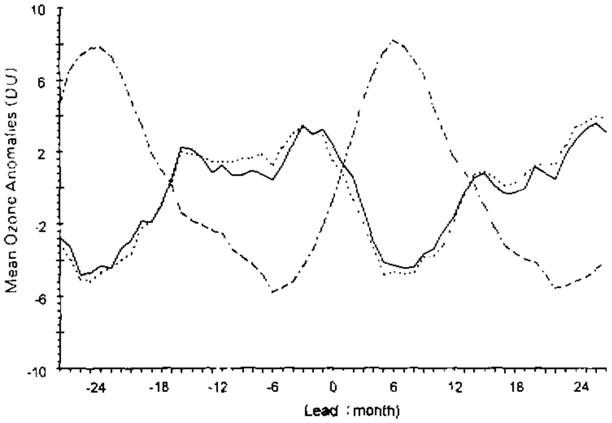

Fig. 5. Ozone QBO related to 30 hPa easterly–westerly zonal wind shift at Singapore. Solid line is for Tibet, dashed line for non–mountain zone and dot–dashed line for the tropics. (0 is the month when the Singapore zonal wind shifts into westerly phase).

amplitude in Tibet is 8 DU and that in the non–mountain region is 9 DU. The ozone QBO signal strength, over all the three selected regions, is weakened in the tropical easterly phase, due to the propagation of planetary waves, a significant factor causing ozone QBO, is suppressed under the easterly conditions (Holton, 1992). The averaged period of ozone QBO over the tropics is 30 months, and those over Tibet and non–mountain zone are 29 months. The atmospheric circulation is the forcing source of ozone variation, therefore, the ozone QBO would lag behind the tropical wind QBO for about 1, 3 and 2 months.

4. Conclusion remarks

From the study described in this article, the conclusion remarks are summarized as:

1) A clear QBO signal can be detected from the interannual ozone variation over Tibet. The Tibet QBO has a mean period of 29 months and a mean amplitude of 8 DU, which is anti–phase to the tropical stratospheric wind QBO.
2) The Tibet QBO has a smaller amplitude in the tropical easterly phase than in the westerly phase, due to the suppressed propagation of planetary waves.
3) Tibet ozone QBO phase delays about 3 months compared with the tropical wind QBO.
4) The seasonal cycle of Tibet ozone is influenced by the atmospheric mass transportation, and the interannual variation is clearly impacted by the solar activity and depletion trends.

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