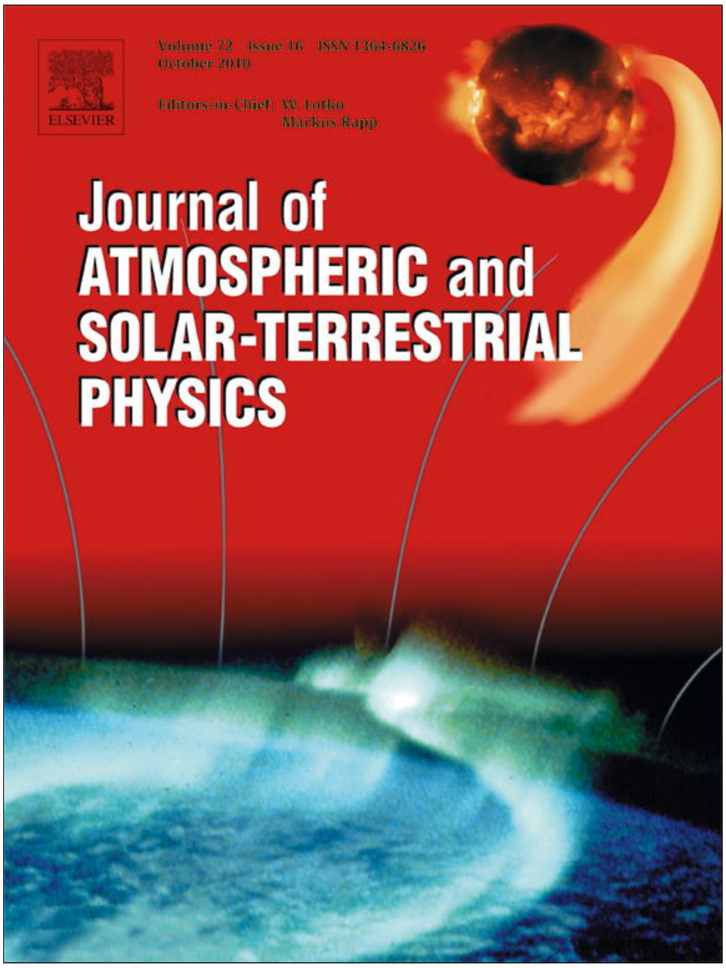
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Total ozone and equatorial zonal wind

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ABSTRACT

Spatial correlations between total column ozone observed by TOMS and equatorial zonal winds from 1979 to 2003 have been assessed. Four months and three different altitude levels have been analyzed: January and July (solstice months), April and October (equinoctial months), and 10, 30 and 50 hPa. The results are different for the months and altitudes considered. The highest correlations values appear in tropical zone at 30 hPa. The Brewer–Dobson circulation plays a key role in regulating the abundance of ozone, influenced by the quasi-biennial oscillation (QBO) circulation. Since the Brewer–Dobson is a slow circulation, correlations considering lags between one and 12 months were estimated. In this case, the highest correlations values are moving to subtropical latitudes at winter hemisphere, with different behaviors for three altitude levels considered.

1. Introduction

The quasi-biennial oscillation (QBO) in equatorial stratospheric winds, with a period varying from about 26 to 30 months, prevails over seasonal variation at heights between 18 and 30 km (100–10 hPa), descend with time in alternating series of easterlies and westerlies that attain speeds of 20–30 m/s. The discovery of the QBO in equatorial stratospheric winds by Reed et al. (1961) and Ebdon (1960) induced researchers to look for this oscillation in meteorological and geophysical parameters (for review of the QBO see Baldwin et al., 2001). The initial evidence of the QBO in total ozone, came from ground-based observations of two subtropical stations, was reported by Funk and Garnham (1962). Analyses of long time series of global satellite data from Total Ozone Mapping Spectrometer (TOMS) have clearly documented characteristics of global QBO in column ozone (Bowman, 1989; Lait et al., 1989; Chandra and Stolarski, 1991; Randel and Cobb, 1994; Tung and Yang, 1994; Kane, 1994; Randel and Wu,1996; Kane et al., 1998; Echer et al, 2004; Zossi de Artigas and Fernandez de Campra, 2010). They noticed that the variation of the total ozone column is nearly in phase with the equatorial zonal winds at 30 hPa at ± 10° latitude. An extratropical anomaly out of phase with the tropical signal, over 15–60° latitude was also observed. The extra tropical ozone QBO is seasonally synchronized, such that the QBO influence is observed only during winter–spring of each respective hemisphere.

Fadnavis and Beig (2009) said that: "possible connections between the QBO in equatorial stratospheric winds and the interannual variation of ozone have been studied by many researchers (Angell, 1988; Stolarski et al., 1991; Kinnersley and Tung, 1998; Camp et al., 2003)", and that: "those studies have been reported that the QBO influence on total ozone amounts to 1–2%".

Different methods have been used to isolate a signal in the global ozone column, which is correlated with the equatorial QBO in stratospheric zonal wind. The results indicates that the QBO signal in ozone has a seasonal dependence which is strongest during winter and autumn (Chandra and Stolarski, 1991; Kinnersley and Tung, 1998). From the estimation of lagged correlations with the Singapore wind data at a certain level, with positive and negative lags of up to 2 years, Bowman (1989), Hollandsworth et al. (1995), and Sitnov (1996) revealed a significant QBO signal even at high latitudes, but they did not considerer its seasonality (Kinnersley and Tung, 1998).

Although the equatorial QBO has been studied rather extensively, the knowledge about its global effects is still rather fragmentary. In particular, it knows little about the height dependence of the effects in middle and high latitudes (Sitnov, 2004).

Bojkov and Balis (2001) said that: "the role of the atmospheric circulation in the ozone distribution, including specific ozone changes related to the weather systems, were already recognized at the beginning of the ozone studies by Dobson et al. (1929) and were one of the reasons for their continuation in the 1930s". The first whose "comprehensively explain the role of vertical motions,

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the accompanied stratospheric temperature changes and the influence of the long planetary waves on the ozone changes were Reed (1950) and Godson (1960)" (Bojkov and Balis, 2001).

The temperature anomalies associated with the QBO winds induce a modification to the normal stratospheric circulation, known as the "Brewer–Dobson" circulation, after the pioneering deductions of Brewer (1949) and Dobson (1956) from observations of stratospheric water vapor and ozone. This circulation comprises a two-cell structure in the lower stratosphere, with upwelling in the tropics and subsidence in middle and high latitudes, and a single cell from the tropics into the winter hemisphere at higher altitudes (Plumb, 2002; Zossi de Artigas and Fernandez de Campra, 2010). The QBO circulation is superimposed on the Brewer–Dobson circulation, increasing it or weakening it, depending of the QBO phase.

In the extratropical stratosphere, large variations in ozone have been induced through the modulation of planetary Rossby waves vertical propagation and through the QBO-induced meridional circulation (Jiang et al., 2005).

The changes in stratospheric transport processes between the equator and the subtropics do not occur instantaneously. A distance-dependent time lag results between the start and the termination of the total ozone deviations observed in the subtropics, that is, when a stratospheric westerly maximum is reached above the equator, the subsidence over the subtropics continues for another 8–9 months (Zerefos et al., 1992; Echer et al., 2004).

Analyzing the associations between the QBO in equatorial stratospheric winds and the abundance of the total ozone content, the spatial correlations between total column ozone observed by TOMS and equatorial zonal wind from 1979 to 2003 has been obtained. Because the QBO signal in ozone, is strongest during winter and autumn, January, July, April and October have been chosen. The equatorial zonal wind at 30 hPa has been considered.

2. Data and analysis

The monthly mean zonal wind in the equatorial stratosphere, was taken from Berlin Stratospheric data (http://dss.ucar.edu/cdroms/karin_labitzke_strat_grids/data/qbo/). The data set, during the analyzed period, combines the observations of the radiosonde stations Canton Island (3°S, 172°W), Gan/ Maldive Islands (1°S, 73°E) and Singapore (1°N, 104°E).

The monthly mean of total column ozone from TOMS (Nimbus 7, METEOR and Earth Probe satellite) in $10 \times 30^\circ$ (Lat × Lon) means, in Dobson units, was taken from http://toms.gsfc.nasa.gov/ozone/ozoneother.html.

First, the spatial correlations are obtained without lag between both series and them, taking into account that the QBO secondary circulation have influence over the normal Brewer–Dobson circulation, negative lags between a month and 12 months are considered. The results are tested using the Student's t-test.

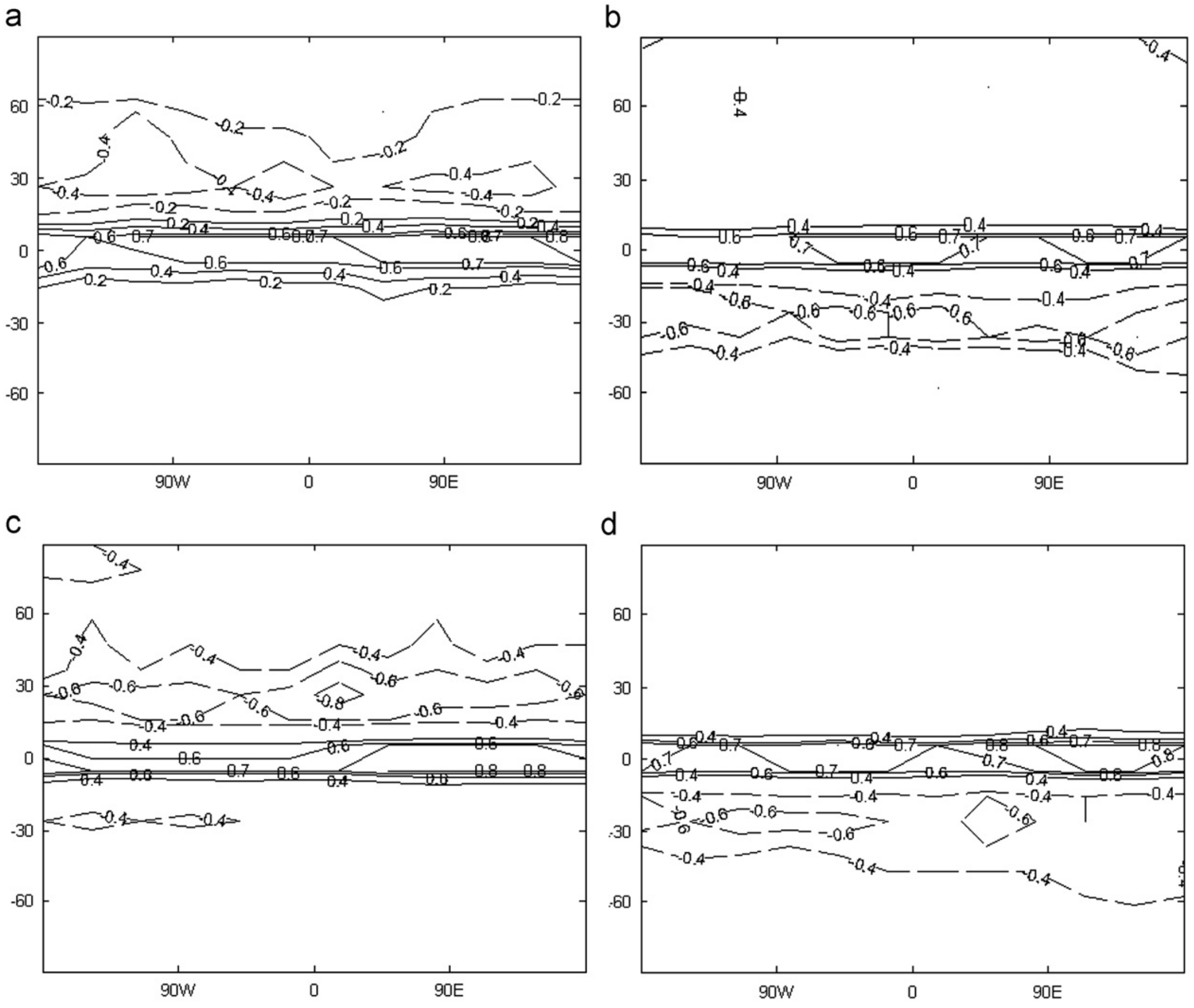

Fig. 1. Spatial correlations between total ozone and equatorial zonal wind at 30 hPa without considering lag for: (a) January; (b) July; (c) April; and (d) October.

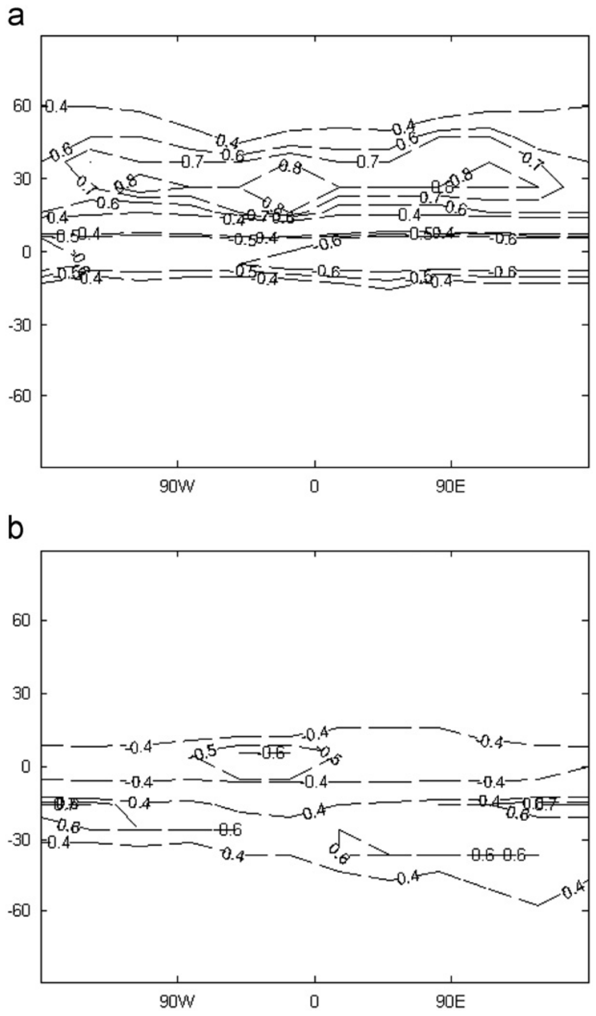

Fig. 2. Spatial correlations between total ozone and equatorial zonal wind considering nine months negative lags for January and July: (a) January–April and (b) July–October.

Fig. 1a–d show the spatial correlations without considering lag, between total ozone and equatorial zonal wind at 30 hPa for January, July, April and October, respectively. The highest correlations values (>0.7) are located in tropical zone in all the cases shown. High anti-correlations values have been observed at subtropical zone at winter–spring hemisphere, in northern hemisphere during January (Fig. 1a) and April (Fig. 1c) and in southern hemisphere during July (Fig. 1b) and October (Fig. 1d, not with zonal behavior). These results are significant at the 95% confidence level. No significant results are obtained at other latitudes.

When lags between eight and 12 months is considered, significant positive correlations (>0.7) emerged at middle latitudes in winter hemisphere in both solstice months. Only, in the case of January, a significant high anti correlation values at tropical zone, with zonal behavior, are observed. As an example, the January and July results, considering nine months negative lags are shown at Fig. 2a and b. These lags cases are indicated by January–April and July–October. These results are significant at the 95% confidence level. No significant results are obtained for other lags.

3. Discussion and conclusion

In this paper the analysis of the associations between the QBO in equatorial stratospheric winds and the abundance of the total ozone content have been done. The spatial correlations between total column ozone observed by TOMS and equatorial zonal wind from 1979 to 2003 has been obtained.

Echer et al. (2004) studying the latitudinal dependence of the QBO in total ozone using a wavelet multiresolution analysis for the period 1979–1992, found that ozone to be nearly in phase with the QBO signal (cross-correlation coefficient >0.7) in the equatorial region (0°–5° and 5°–10°) and to be out of phase (lags ˜+15 and -15 months in north and south) from 10°–15° to 55°–60° latitudinal ranges.

Our results show statistical significance correlation with values significant at the 95% confidence level between total ozone and 30 hPa equatorial stratospheric zonal wind at tropical zones, as expected, for the four months analyzed, with values >0.7. At middle latitudes, the results are significant for January and July (in winter hemisphere), April (northern hemisphere) and October (southern hemisphere) cases, showing an out of phase anomaly with the tropical signal.

When negative lags, between eight and 12 months, are considered, own results show the highest correlation absolute values, significant at the 95% confidence level at middle latitudes in both hemispheres during winter–spring periods.

This paper explore the effects of QBO on total ozone extending the period analyzed by Zerefos et al. (1992). Using other methodology, their analysis showed that the phase of the QBO is linearly varying with latitude and is symmetrical about the equator and in the tropics, and ozone is affected by the ENSO phenomenon. They mentioned that there are several total ozone deficiencies which apparently are not related to the QBO in the extratropics.

The QBO in the equatorial stratosphere would crucially affects the stratospheric dynamics in both the tropics and in mid- and high-latitudes through the wave-mean flow interaction (Shibata and Deushi, 2008).

It would be necessary to deepen in the analysis to the QBO effects on ozone total for other months of the year, not analyzed in the present paper and considering lags up to 30 months (QBO quasi-periodicity). The analysis of the QBO effects on stratospheric temperature and tracers would help to elucidate the mechanisms involved.

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