The stratospheric QBO signal in the NCEP reanalysis, 1958–2001

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Received 14 February 2003; revised 5 May 2003; accepted 20 May 2003; published 8 July 2003.

[1] The spatiotemporal evolution of the zonal wind in the stratosphere is analyzed based on the use of the NCEP reanalysis (1958–2001). MultiTaper Method-Singular Value Decomposition (MTM-SVD), a frequency-domain analysis method, is applied to isolate significant spatially-coherent variability with narrowband oscillatory character. A quasibiennial oscillation is detected as the most intense coherent signal in the stratosphere, the signal being less intense in the lower levels. There is a clear downward propagation of the signal with time at low latitudes, not evident at mid and high latitudes. There are differences in the behavior of the signal over both hemispheres, being much weaker over the SH. In the NH an anomaly in the zonal wind field, in phase with the equatorial signal, is detected at approximately 60°N. Two different areas at subtropical latitudes are detected to be characterized by wind anomalies opposed to that of the equator. *INDEX TERMS:* 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3334 Meteorology and Atmospheric Dynamics: Middle atmospheric dynamics (0341, 0342); 3362 Meteorology and Atmospheric Dynamics: Stratosphere/troposphere interactions. **Citation:** Ribera, P., D. Gallego, C. Peña-Ortiz, L. Gimeno, R. Garcia-Herrera, E. Hernandez, and N. Calvo, The stratospheric QBO signal in the NCEP reanalysis, 1958–2001, *Geophys. Res. Lett.*, *30*(13), 1691, doi:10.1029/2003GL017131, 2003.

1. Introduction

[2] The stratospheric quasibiennial oscillation (QBO) was first documented by *Reed et al.* [1961] and *Veryard and Ebdon* [1961]. The QBO is defined as a roughly gaussian oscillation, symmetric about the equator and with a 12° half width, in the direction of the stratospheric zonal flow. The period of the oscillation varies from 20 to 36 months from cycle to cycle, and a mean value of 28 months has been observed during the second half of the 20th century [*Maruyama*, 1997].

[3] The QBO signal propagates downward through the whole equatorial stratosphere, with new phases initiated in the upper stratosphere (~2 hPa) [*Hamilton*, 1998; *Baldwin et al.*, 2001].

[4] Some extratropical links have been found closely related to this oscillation. The location and intensity of the polar vortex in both hemispheres, and thus, the temperature of the polar stratosphere, are influenced by the phase and intensity of the QBO [*Holton and Tan*, 1980; *Baldwin and Dunkerton*, 1998, 2001; *Gray et al.*, 2001; *Naito*, 2002; *Thompson et al.*, 2002].

[5] On the other hand, variations in the stratospheric conditions may have indirect effects in the troposphere. It is mostly accepted that the intensity of the polar vortex has an indirect effect over the extratropical circulation in the troposphere, favoring changes in the values of the North Atlantic Oscillation/Arctic Oscillation (NAO/AO) index, and thus, affecting temperature and precipitation over extensive areas [*Baldwin and Dunkerton*, 1999; *Coughlin and Tung*, 2001; *Thompson et al.*, 2002].

[6] Finally, some authors have pointed out the possibility of the QBO influencing the intensity of the monsoons and depression systems in the tropical areas, where both the Asian and the Australian monsoons are characterized by a period of approximately two years [*Balachandran and Guhathakurta*, 1999; *Indeje and Semazzi*, 2000; *Munot and Kothawale*, 2000; *Chattopadhyay and Bhatla*, 2002].

[7] In this paper, the MTM-SVD methodology [*Mann and Park*, 1999] has been used to isolate spatially-coherent patterns of narrowband variability that are present in stratospheric zonal wind climate fields simultaneously during the latter half of the 20th century. QBO has been detected as the only clear source of oscillatory variability on interannual timescales, and its temperature signal at different height levels has also been analyzed using the same methodology as in *Ribera and Mann* [2002, 2003].

2. Data and Methods

[8] The MTM-SVD technique is applied to the zonal wind anomaly datasets at different pressure levels to isolate statistically significant narrowband oscillations. Each grid point time series is first Fourier transformed using the MTM approach with three orthogonal tapers. The three independent spectral estimates Y(f) computed for each of the M time series (M being the number of observatories) are organized in a M x 3 matrix A(f) for which a singular value decomposition is performed at each frequency f. The left and right singular vectors so obtained are used to reconstruct the temporal (LFV spectrum) and spatial patterns of the signal associated with a given frequency.

[9] The LFV spectrum is used to identify the significant oscillatory bands. It must be read as a classic Fourier spectrum, though it represents the joint spectrum of every observatory included in the dataset. When the significant frequencies are detected, MTM-SVD is able to reconstruct the evolution of the spatial pattern associated to those frequencies through a complete cycle. For further details see *Mann and Park* [1999].

[10] In this study, 1958 to 2001 monthly data of zonal wind and temperature in multiple stratospheric levels (200,

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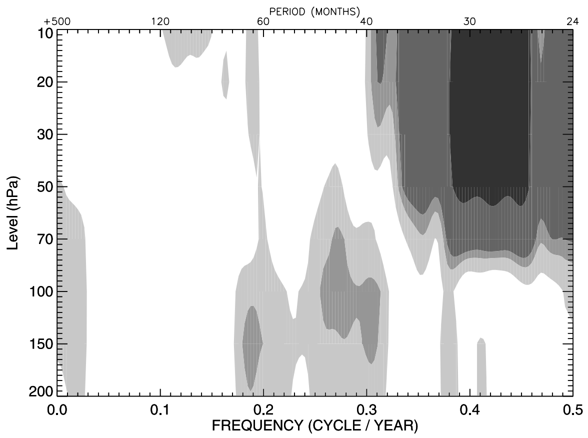

Figure 1. LFV spectrum of the 10, 20, 30, 50, 70, 100, 150 and 200 hPa global zonal wind datasets. Contours represent 50%, 95% and 99% significance levels. Black contour represent highest LFV values.

150, 100, 70, 50, 30, 20 and 10 hPa) from the NCEP-NCAR reanalysis have been used [*Kalnay et al.*, 1996; *Kistler et al.*, 2001]. The spatial resolution of the data is 5° latitude by 5° longitude, covering the whole globe (90°N and 90°S not included). Monthly gridpoint data were deseasonalized, converted into standardized anomalies, and then weighted by a gridpoint areal extent factor (cosine of latitude).

[11] For every level, the zonal wind dataset was independently analyzed and then, the one with the most intense QBO signal (30 hPa) was used to project the signal in every other level and variable. The expression of that signal was determined through projection of the 30 hPa signal on to all other data fields, since it resulted the level with the highest QBO signal. This latter step was accomplished through the use of highly reduced (factor of 0.001) gridpoint weighting factors in the analysis of the second data field, while zonal wind data at 30 hPa is not downweighted by this factor [see *Mann and Park*, 1999; *Ribera and Mann*, 2002, 2003 for details]. The simultaneous analysis of the behavior of zonal wind and temperature at these levels provides the opportunity to follow the horizontal and vertical evolution of the detected climate signals.

3. Analysis

[12] Eight independent LFV spectrums of the zonal wind fields have been performed, one for every pressure level (Figure 1). In high levels (10 to 70 hPa) a broad band of statistically significant variability with periods ranging from two to three years (from f = 0.33 to f = 0.45 cycle-per-year) is evident, coinciding with the mean period described by previous studies as the most characteristic for QBO during the second half of the 20th century [*Maruyama*, 1997; *Huesmann and Hitchman*, 2001; *Hamilton and Hsieh*, 2002], while in low levels (100 to 200 hPa), no significant period is found in this band. The most intense QBO signal is detected in the 30 hPa level (not shown). An extended spectral analysis of the 30 hPa u-wind data, including shorter periods, showed the existence of additional oscillatory bands centered in 20 and 8 months, like those described by *Baldwin and Tung* [1994]. It also detected additional bands centered at 15, 12 and 10 months.

[13] Seven evolutive LFV spectra (not shown) were obtained based on performing the MTM-SVD analysis in a moving 20 year window of the zonal wind field at every pressure level [*Mann and Park*, 1999]. These spectra confirm a robust quasibiennial oscillation throughout the whole analyzed period in every level but 100 and 200 hPa. No other signal is detected as consistent during the whole analyzed period.

[14] Figure 2 includes the 28 months evolution of the vertical profiles of mean values of five zonal belts centered over the equator, and 30 and 60 degrees latitude bands in both hemispheres. They were obtained based on the spatial reconstruction and projections of the evolution of the QBO (28 months oscillation) at different pressure levels.

[15] The equatorial band (Figure 2C) is characterized by a downward propagation of the signal from 10 hPa to 70/100 hPa. For month 0, the most intense westerlies are located at 30 hPa, but 6 months later it is at 50 hPa while very intense easterlies are observed at 10 hPa. During the next 14 months, the easterly flux propagates downward and at the end of this period, a new westerly flux begins at 10 hPa.

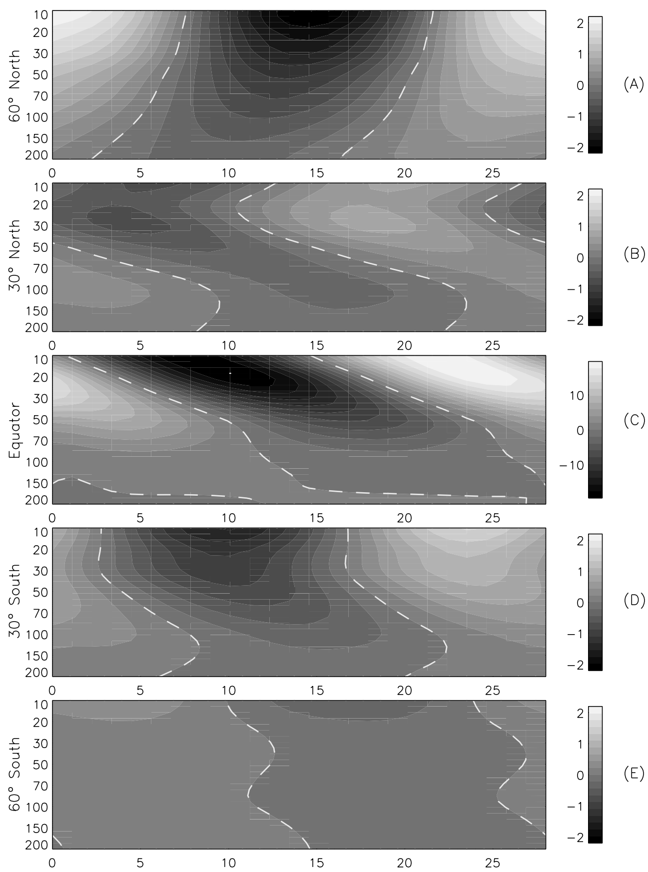

Figure 2. Evolution through a whole 28.6 months oscillation of the vertical profile from 200 to 10 hPa of the zonally averaged u-wind anomalies centered over: (A) 60°North (65°–55°N); (B) 30° North (35°–25°N); (C) the equator (5°N–5°S); (D) 30° South (25°–35°S) and (E) 60° South (55°–65°S). Discontinous lines represent the zero wind anomaly line. Anomalies expressed in m/s.

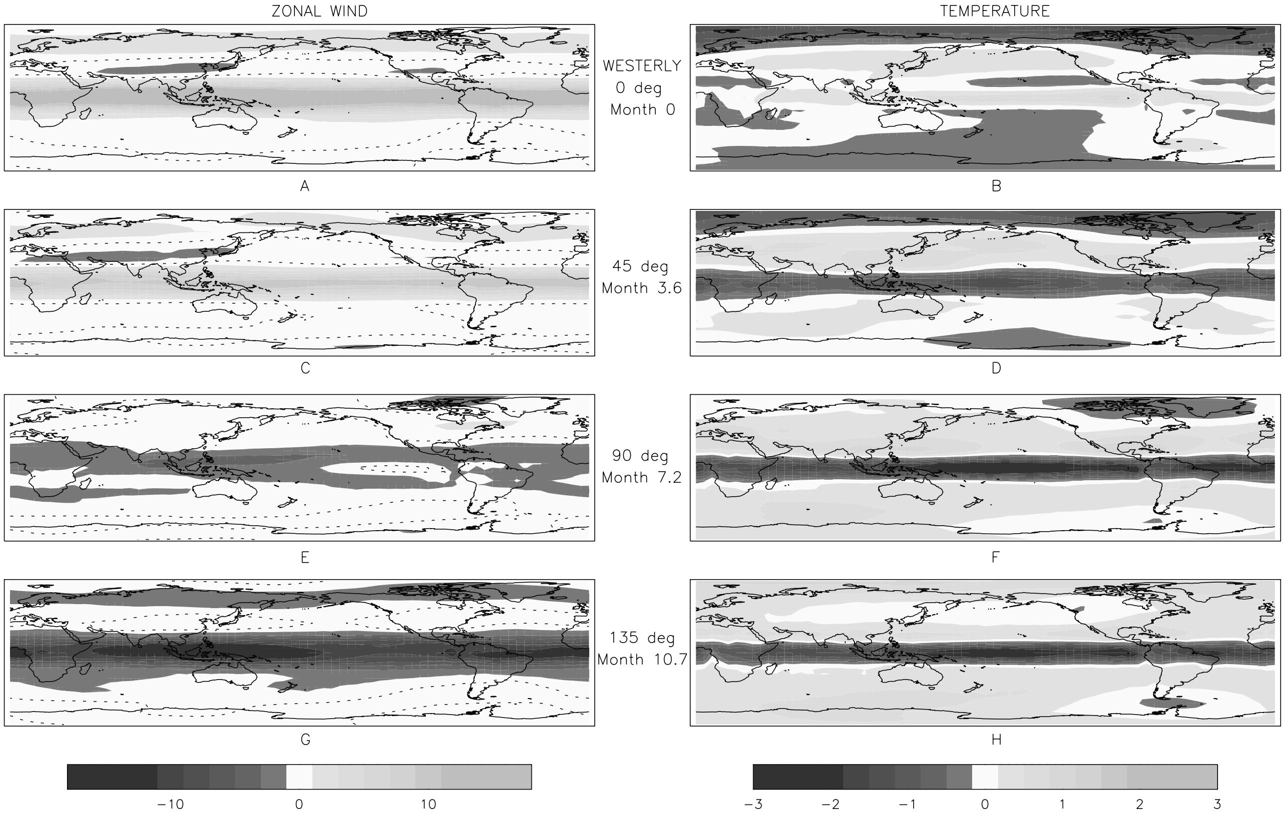

Figure 3. Spatial reconstruction of the 28.6 months QBO for zonal wind and temperature in the 30 hPa pressure level from westerly to pre-easterly phases. Wind anomalies in m/s, and temperature anomalies in Celsius (u = 0 m/s represented by the dotted line).

This result is consistent with previous analysis of the QBO propagation in the tropical areas [*Naujokat*, 1986; *Hamilton*, 1998; *Gray et al.*, 2001; *Baldwin et al.*, 2001].

[16] Zonal mean of zonal wind anomalies associated with the QBO phases for high latitudes are characterized by the same sign for the whole vertical structure of the analysed fields (Figure 2, 60° latitude bands). This seems to confirm a direct influence of the QBO over the stratospheric polar vortex in both hemispheres, with a more intense signal in the NH [*Baldwin and Dunkerton*, 1998, 1999, 2001; *Naito*, 2002; *Thompson et al.*, 2002], which will be later confirmed with the analysis of the evolution of the 30 hPa temperature field (Figure 3).

[17] Finally, the analysis of the subtropical areas shows a situation between that observed over the Equator and over subpolar latitudes. In the NH the signal seems to propagate downward with time, but about 5 months out of phase with the equatorial signal, and with much less intense anomalies. In the SH, the subtropical signal resembles more that of the subpolar areas, with a vertical transmission of the signal more intense than that observed at higher latitudes.

[18] Detailed spatial maps of the evolution of the QBO signal at 30 hPa are shown in Figure 3. The reconstruction follows the evolution of the signal through one half cycle in 45° phase increments, from westerly QBO phase (i.e., maximum intensity of the zonal flow from the west over the Equator), defined as phase 0°, to pre-easterly QBO phase (135°) conditions. Anomalies at 180° phase would be, by construction, opposite to those observed at 0° phase. The most intense zonal wind anomaly over the equator is detected at 0° phase, with a deceleration of the westerly flow over this area evident in the 45° phase, and a change in the sign of the flow in the 90° phase. An easterly flow intensifies during the 135° phase.

[19] The analysis of the evolution of the extratropical situation shows an intensification of the magnitude of the NH stratospheric jet during the westerly phase of the QBO (Figure 3). This intensification starts about 4 months before the maximum westerly QBO phase and is broken less than 4 months after it. In lower latitudes, less intense signals with opposite sign are detected over southern Asia and southern USA. The first band is most probably associated to the link between the QBO and synoptic situations over the north Indian oceans and the South Asian monsoons described by *Balachandran and Guhathakurta* [1999], *Munot and Kothawale* [2000] and *Chattopadhyay and Bhatla* [2002]; while the second band is not referenced but may have similar effects over the area of the Gulf of Mexico.

[20] On the other hand, during the QBO westerly phase, when in-phase temperature is analyzed, colder than normal conditions are observed over both polar regions, though more intense in the NH (Figure 3), as expected from previous studies [*Salby and Callaghan*, 2000; *Baldwin and Dunkerton*, 2001]. The equatorial area is dominated by slightly warmer than normal conditions and so are mid-latitude NH areas over Asia and the Pacific. Figure 3-B exhibits a broad warm region in the NH mid latitudes, which can be interpreted as an amplification of the Aleutian

High by invoking the planetary wave amplification mechanism [*Harvey and Hitchman*, 1996]. In the SH the area over the Pacific Ocean is mostly covered by slightly negative temperature anomalies, while the rest of the mid latitudes remain close to their mean temperature.

[21] The evolution of the temperature field shows a very intense trend for warmer than normal temperatures to cover the whole extratropical latitudes in the transition from westerly to easterly phase of the QBO (0° to 180°), while the equatorial area becomes colder. A heat transport from the equator to the poles occurs during the transition from QBO westerly to easterly phase, leading to warmer low latitudes and colder high latitudes. It ends in the transition from easterly to westerly phase. A similar evolution is found for the 10, 20 and 50 hPa levels, the signal starting its propagation at the higher levels (not shown).

4. Conclusions

[22] In this paper we have shown how the application of the MTM-SVD method can be used to characterize the evolution of the QBO signal through its projection in a multi-level and multi-variable dataset.

[23] Our results confirm some features obtained by previous studies, as the downward vertical propagation with time of the QBO signal in the zonal wind over the equatorial area, its influence over the stratospheric jet and thus, over the polar temperature anomalies.

[24] Some additional features have been evidenced. The intensity of the anomalies of both temperature and zonal wind is higher in the northern than in the southern hemisphere. The vertical propagation of zonal wind anomalies in the extratropical areas has been characterized, showing an asymmetric behavior between both hemispheres. In the NH, they are similar to the equatorial pattern, while in the SH, they resemble the situation in higher latitudes. Finally, the analysis suggests a mean meridional heat propagation (dissipation) from the westerly (easterly) to the easterly (westerly) phases of the QBO.

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