Comment on "Global QBO in Circulation and Ozone. Part I: Reexamination of Observational Evidence"

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In a recent paper Tung and Yang (1994a, hereafter TY) have analyzed the quasi-biennial oscillation (QBO) in zonal-mean total column ozone as revealed in about 13 years of the *Nimbus-7* TOMS record. Their work has helped reconcile the somewhat divergent views about the structure of the ozone QBO expressed in earlier papers (e.g., Hasebe 1983; Bowman 1989; Hamilton 1989) and has greatly clarified the overall picture of how the tropical and extratropical manifestations of the ozone QBO are related. In particular, TY find that at very low latitudes the interannual ozone variations very closely follow the variations in the prevailing zonal wind, while poleward of ~10° latitude the ozone anomalies seem to depend on the interaction of the dynamical QBO and the annual cycle. One manifestation of this is the tendency for the spectrum of the ozone anomalies away from the equator to have two prominent peaks: one (near 30 months) corresponding to the dynamical QBO and one (near 20 months) at one of the expected beat frequencies between the QBO and the annual cycle. Tung and Yang argue that this is evidence for the interaction of annual and quasi-biennial ozone transport mechanisms.

The purpose of the present note is to report briefly on a slightly different (and even simpler) look at the QBO in the TOMS ozone data that confirms the conclusions of TY. In particular it will be shown that a straightforward partitioning of the ozone anomaly fields into components symmetric and antisymmetric between hemispheres can be very enlightening. A very direct demonstration of the annual cycle influence on the subtropical and midlatitude interannual ozone anomalies will also be presented. This analysis was motivated in part by a desire to obtain a simple description of the ozone QBO that could be used for comparison with the results of a numerical simulation of this phenomenon now being conducted at GFDL with a three-dimensional general circulation model.

The TOMS data is available from November 1978 through June 1993. In this study just the monthly mean, zonal mean values during 14 complete calendar years from January 1979 through December 1992 were employed (TY used data from November 1978 to December 1991). These data were first deseasonalized by removing the long-term mean for each calendar month. Then a least-squares fit to the smoothed (13-month running mean) Geneva sunspot numbers was subtracted [the sunspot numbers were obtained from http://www.ngdc.noaa.gov/; see Waldermeier (1961) for a description of these data]. A least-squares linear trend was also removed. The results were normalized by the long-term annual mean total column at each latitude (this helps to emphasize the anomalies at low latitudes). The data were then averaged into 5° latitude bins. The resulting set of anomaly time series serves as the basis for all further analysis.

Figure 1a shows the ozone anomaly field when further smoothed by Fourier reconstruction with omission of all harmonics with periods less than one year. The quasi-biennial nature of the fluctuations near the equator is quite evident. There are comparably strong anomalies away from the equator, but these display a more complicated structure. While on average there is a negative correlation between the anomalies equatorward and poleward of ~12°–13°, a prominent feature is the rather irregular continuous phase propagation of anomalies between equatorial and subtropical latitudes. Thus, for example, during the last half of 1983 a negative anomaly appears to propagate from midlatitudes in the Northern Hemisphere into the equatorial region, while in the last half of 1990 a positive anomaly appears to propagate from near the equator to higher latitudes.

Figures 1b and 1c show the symmetric and antisymmetric components of the smoothed anomaly field. The latitude–time evolution of the anomaly in these two individual components appears to be much simpler than

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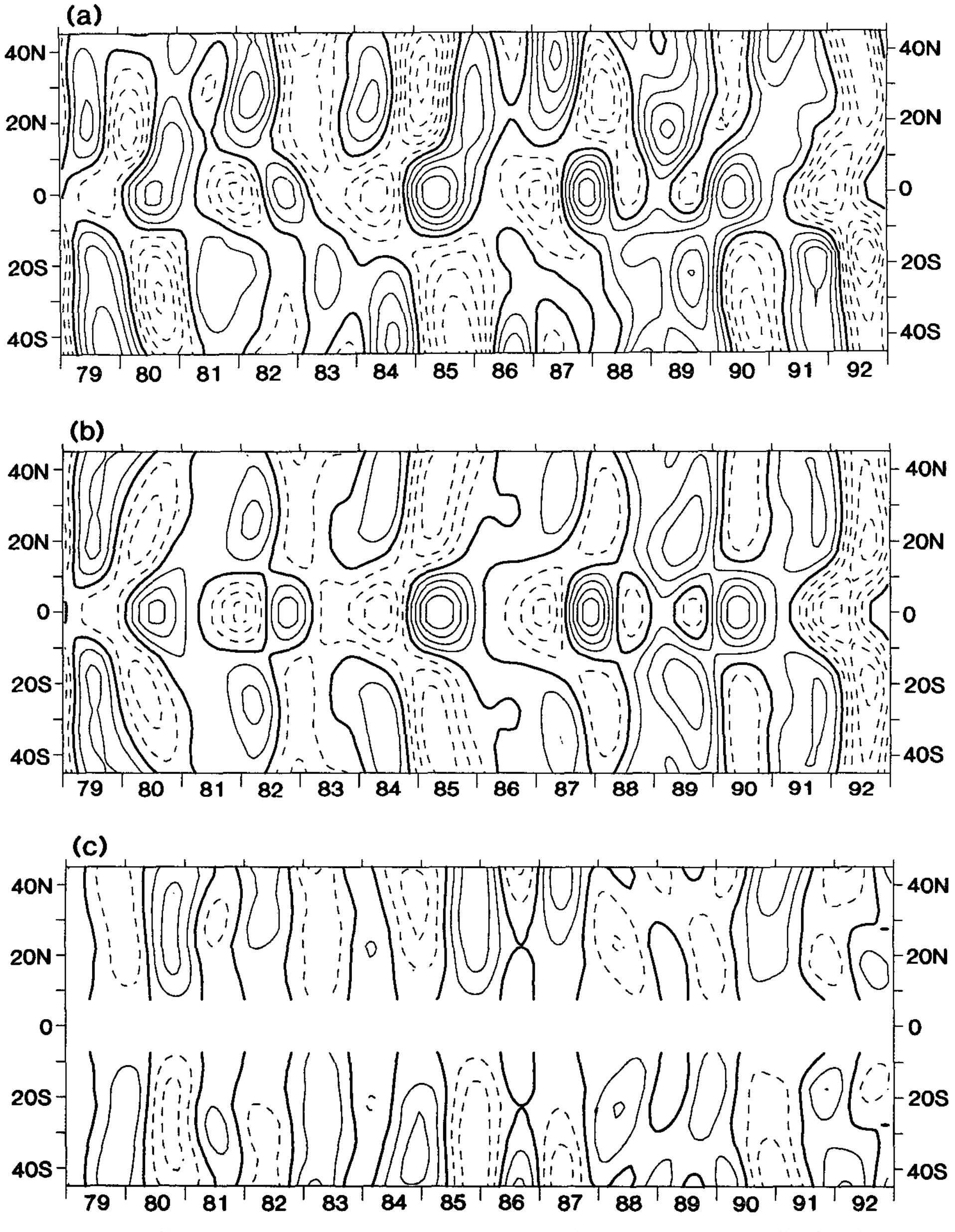

FIG. 1. (a) The filtered (all periods > 1 year) zonal mean, monthly mean ozone anomalies for 1979–1992. (b) The symmetric component. (c) The antisymmetric component. The anomalies are in percent of the mean and the contour interval is 1%. Dashed contours denote negative values.

in the full field. The symmetric component displays little meridional phase propagation (at least over most of the record) and has a fairly well-defined nodal line near 12°–13°. The antisymmetric component also has relatively little apparent phase propagation, particularly equatorward of 30°. The same procedure has also been applied to the monthly anomaly fields without the Fourier smoothing (not shown). The unsmoothed time series do display considerable month to month variability, some of which has significant meridional coherence. Even in these somewhat noisy unfiltered time series, decomposition of the anomaly into symmetric and antisymmetric components leads to considerable simplification in the appearance of the time–latitude evolution. In particular, the presence of a nodal point near 12° is much more apparent in the symmetric component than in the full field. This suggests that the decomposition of ozone anomalies into symmetric and antisymmetric components may be a useful method of analysis even for relatively short records (for which time filtering may not be practical) either from observations or from comprehensive model simulations.

The largest deviation from the simple view of Fig. 1 presented above occurs in the final year of the record, where the symmetric component displays large negative values at all latitudes for several months (and so the nodal line near 12° is not at all apparent). This large global ozone decrease in 1992 has been noted in various datasets and has been attributed to the effects of the Mt. Pinatubo eruption (e.g., Planet et al. 1994).

Figure 2 presents the power spectra of the symmetric and antisymmetric components of the ozone anomaly at different latitudes. The symmetric component peaks at or near 0.43 year^{-1} (i.e., six cycles during the 14-yr record), corresponding to a period of 28 months. The antisymmetric component peaks near 0.57 year^{-1} (i.e., eight cycles per 14 years) corresponding to a period of 21 months. This is one of the beat frequencies between the annual cycle and the dominant frequency of the symmetric component (note that $^1/_{12} - {}^1/_{28} = {}^1/_{21}$). The decomposition of the anomalies into symmetric and antisymmetric components is remarkably successful in separating the two peaks that appear in the spectrum of the total anomaly (at least off the equator). The present results are consistent with the those of TY, who found that the anomalies when filtered in narrow frequency bands near the 30-month and 20-month periods were predominantly symmetric and antisymmetric, respectively (see their Fig. 9).

There is also a smaller peak in the antisymmetric component evident in Fig. 2 near 1.42 year^{-1} (8.4 months) that would correspond to the other beat frequency ($^1/_{12} + {}^1/_{28} = {}^1/_{8.4}$). Tung and Yang also noticed this third peak in their spectra of the total anomaly. The present results show that this power is almost all in the antisymmetric component.

The 28-month period of the peak in the symmetric component is in the range of that found for the dynamical QBO (e.g., Naujokat 1986). Tung and Yang show that the ozone anomalies directly correlated with tropical stratospheric prevailing wind have a meridional modulation very similar to the symmetric component in the present Fig. 1b. This has the shape (notably the nodal line near 12°) predicted by Reed (1964) based on simple arguments of how the QBO modulation of the residual mean meridional circulation should act to alter the column ozone.

A more complicated mechanism is clearly required to account for the ~20-month oscillation seen in the antisymmetric component. As noted by TY, the likely role of the annual cycle in this higher-frequency oscil-

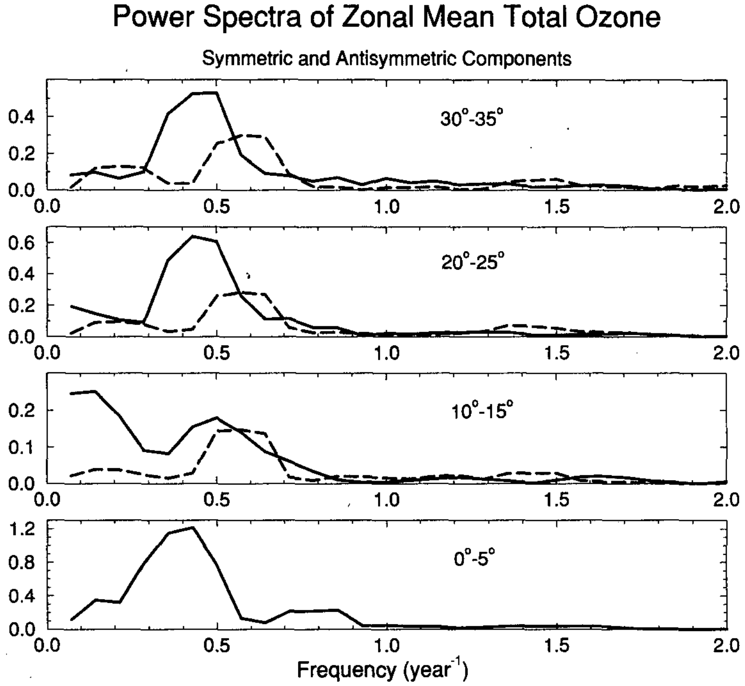

FIG. 2. Power spectra of the symmetric (solid) and antisymmetric (dashed) ozone anomalies averaged over various latitude bands. The power spectrum in each case represents the periodogram smoothed by a running average over three adjacent Fourier frequencies (i.e., a bandwidth of 0.214 year^{-1}). The power in each graph is expressed in squared percent per Fourier frequency (0.071 year^{-1}).

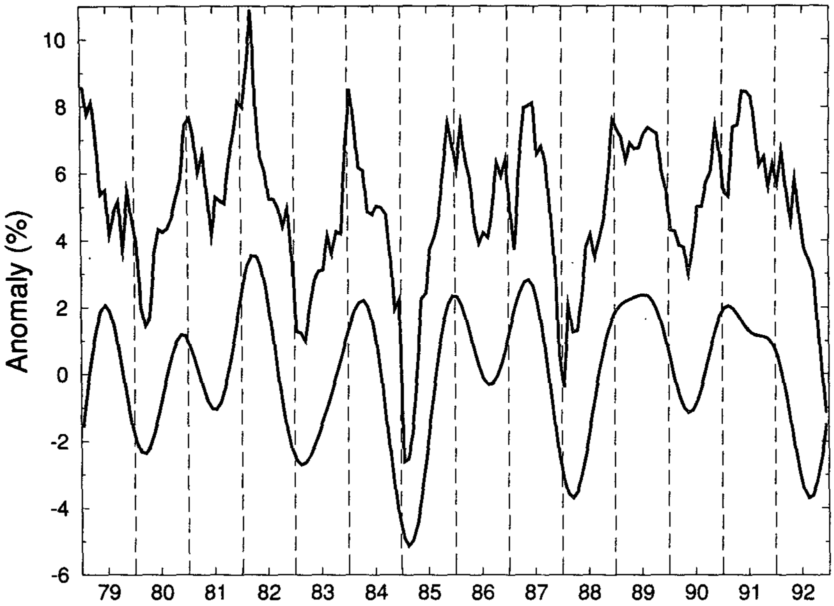

FIG. 3. Time series of the monthly anomalies averaged over the 20°–35°N latitude band. Unsmoothed values (upper curve) and filtered (all periods > 1 year) values are given. The unsmoothed curve is displaced upward 5%. The vertical dashed lines show the beginning of each calendar year.

lation is suggested by (i) the fact that the oscillation is out of phase across the equator and (ii) the fact that its period is that expected from a beating between the annual cycle and the equatorial QBO. The present note concludes with a direct examination of the possible synchronization of the extratropical ozone anomalies in the TOMS record with the annual cycle. Hamilton (1989) noted that the extreme anomalies (of both signs) in the deseasonalized ozone time series at subtropical Northern Hemisphere Dobson stations have a strong tendency to occur between December and March. With 14 complete years of the TOMS record now available, it seems reasonable to ask if the same pattern is apparent in these satellite data. Figure 3 shows the present time series of monthly ozone anomalies averaged over the 20°–35°N band. Both the unsmoothed series and that smoothed by the Fourier reconstruction are shown. Inspection of this figure does indeed suggest that the extremes occur frequently near or shortly after the beginning of the calendar year and only rarely in the July–November period. Figure 4 presents the interannual variance in the two time series of Fig. 3 calculated for each calendar month. Again the tendency for the large magnitude anomalies to occur in the December–March period is very evident. When this analysis is repeated for near-equatorial anomalies, very little seasonal dependence of the interannual variance is evident. When the analysis is applied to the 35°–20°S latitude band, the variance is much greater in the June–October period than in the remainder of the year. All of these results are consistent with the earlier findings of Hamilton (1989; based on longer single-station records) and provide additional evidence for the contention of TY that the interaction of the annual cycle and the dynamical QBO is needed to account for the observed interannual variations in the off-equatorial ozone total column. Indeed Tung and Yang (1994b) present a simple mechanistic model that reproduces the observed annual synchronization of the QBO.

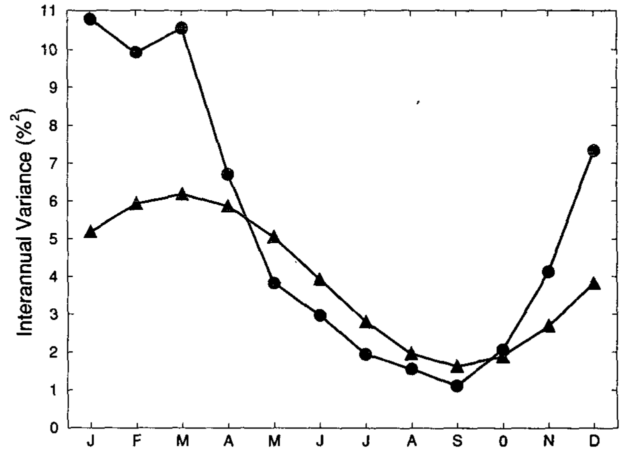

FIG. 4. Variance in the 20°–35°N anomaly timeseries over the 14-yr record for each calendar month. Values for the unsmoothed (circles) and filtered (triangles) anomalies are shown.

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