Abstract. It is shown that the quasi-biennial oscillation of the equatorial lower stratosphere was correlated with mean zonal wind in the upper stratosphere, 1979-90. Correlations were positive near 60°N and 30°S during northern hemisphere (NH) winter and negative in the equatorial upper stratosphere during all seasons. Spatial autocorrelation of mean zonal wind during NH winter was actually largest in the upper stratosphere, between 10°S and 62°N, due to strong coupling between tropical and extratropical flow at upper levels.

Introduction

A relation between the tropical quasi-biennial oscillation (QBO) and northern hemisphere (NH) interannual variability was discovered by Holton and Tan (1980, 1982) and analyzed further by Wallace and Chang (1982), van Loon and Labitzke (1987), and Dunkerton and Baldwin (1991; hereafter DB). The correlation is such that when equatorial winds at 40 mb were easterly, the NH polar night jet was weaker than normal by about 8 ms⁻¹, and vice versa. DB showed that the extratropical “Holton-Tan oscillation” (HTO) was an important mode of interannual variability in NH winter, having a dipole structure between subtropics and pole with phase reversal near 45°N. Correlation with the tropical QBO in 1964-88 was shown to be statistically significant and stable. Evidence was presented by DB suggesting that planetary wave fluxes played an important, if not essential, role in the HTO.

In this paper, the scope of DB was extended to include tropics and southern hemisphere (SH) using the same National Meteorological Center (NMC) dataset, covering September 1978-90 at standard levels 1000-1 mb. Analysis methods were described in DB and additional details will be noted where necessary below.

Relation to Tropical QBO

The strongest relationship between tropical lower stratosphere QBO and extratropical flow was found during NH winter. Figure 1 shows the correlation between Singapore 40 mb zonal wind and NMC mean zonal winds during DJF season. NMC winds were derived from gradient balance, and linear interpolation was used between 10°N and 10°S. There was excellent correlation between derived winds and Singapore data, although the magnitude of NMC QBO was only ~1/3 of the actual QBO (as shown below). Small QBO amplitude resulted from interpolation across the equator; the zonal wind QBO has a Gaussian-shaped profile with half-width ~ 12° latitude (Dunkerton and Delisi, 1985). Correlation removed this difference in amplitude and any bias between time series. Correlations near 40 mb were found to be high in all months.

By contrast, the correlation with extratropical flow at upper levels depended on season. In Figure 1, high correlations were found in three regions: (i) A positive correlation existed near 60°N during DJF (HTO). (ii) Negative correlations, relatively independent of season, were found in the tropical upper stratosphere. (iii) A second, narrow region of positive correlation appeared near 30°S. This feature was present in individual months November-February, with correlations exceeding 0.70 near 5 mb, 30°S in November, December, and January. For these time series, a correlation of 0.50 is statistically significant at the 5% level.

Figure 2 shows a latitude-time plot of correlation at 5 mb, illustrating the tropical correlation and seasonal dependence of correlation near 60°N and 30°S. It is apparent that the tropical upper stratosphere QBO was not perfectly anticorrelated with 40 mb QBO during any season. Correlations were, of course, moderately negative – consistent with vertical phase progression of QBO wind regimes and formation of new east and west phases at upper levels (e.g., Groves, 1975; Belmont et al., 1974; Hamilton, 1981; Hirota et al, 1990; Dunkerton and Delisi, 1991). However, the upper-level QBO is irregular, and may be influenced by other atmospheric regions. Actual correlations were smaller, for example, than what

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might be obtained in a simple mechanistic model of the QBO.

A composite difference (40 mb east minus west category) of NMC mean zonal wind is shown in Figure 3. The rather small magnitude of tropical QBO can be attributed to interpolation across the equator, and the fact that partitioning of data was done according to the sign of 40 mb wind and therefore averaged QBO phase transitions together with QBO extrema. Consistent with DB, the HTO had smaller amplitude in 1979-90 than in 1964-88. The region of remarkably high correlation near 30°S can now be seen to have had small peak-to-peak amplitude (≈6 ms⁻¹). The polar HTO signal was slightly smaller than reported by DB due to addition of 1989 and 1990. One observes in DB’s Figure 2 a tendency for HTO to weaken or disappear around solar maxima. We will discuss the interrelationship of QBO and decadal influences on extratropical variability more fully in a subsequent manuscript.

**Teleconnection Pattern**

Following DB the “teleconnectivity” of stratospheric-troposphere mean zonal wind was calculated to determine the most significant anticorrelations between any two grid points (Wallace and Gutzler, 1981). Among other things, we found a strong out-of-phase relation between tropical and extratropical winds in the upper stratosphere during NH winter. Figure 4a shows the correlation between DJF mean zonal wind at 1 mb, 62°N and all other gridpoints (at lag zero). Anticorrelation exceeded -0.90 at 5 mb, 10°S. Obviously the direct anticorrelation between these two grid points was higher than the magnitude of correlation with 40 mb QBO. On the other hand, the correlation near 30°S was smaller than in Figure 1. This correlation was slightly larger using 62°N, 5 mb as the reference point (Figure 4b).

It can be seen that the region of high negative correlation in the tropics is an extension of the southern half of extratropical mean flow dipole previously described by DB (refer to Figure 4b, near 10 mb, 20-40°N). The combined pattern agrees with that anticipated by DB. However, it was surprising to find such high anticorrelation extending all the way to the equator and beyond. The interpretation of this result will be discussed below.

SH late winter and spring is an important season for Antarctic ozone depletion and a possible role of the QBO has been suggested (Bojkov, 1986; Garcia and Solomon, 1987; Lait et al, 1989). Similar correlation analysis indic-
cated that there was an out-of-phase relation between 30 mb QBO and midlatitude temperature in the SH lower stratosphere consistent with Lait et al. The midlatitude upper stratosphere did not reveal correlations like those of Figure 1 except for a weaker signal in May (not shown). (Unlike Lait et al, we did not low-pass filter the data in any way.) Therefore the extratropical Holton-Tan oscillation, and its subtropical summer hemisphere component, were strongest and most consistent during NH winter. Because of its effect on stratospheric temperature (DB), this oscillation can be expected to modulate Arctic ozone depletion in the future.

Wave Flux Composite

A composite difference (40 mb east minus west category) of Eliassen-Palm flux and divergence factor $D_p \cos^2 \theta$ for NDJ season is shown in Figure 5. The pattern north of 18°N is consistent with DB (note $\cos^2 \theta$ weighting here). Interestingly the dipole pattern extended in oscillatory fashion across the tropics. Since derived winds are nonunique in the tropics, we have little confidence in these features other than the basic dipole pattern and possibly the first sign reversal in northern tropics. The wind calculation assumed linear balance as in DB, interpolating between 10°N and 10°S, and the spectrum was truncated to zonal wavenumbers 1-3 near the equator.

Fig. 5. Composite difference (40 mb east minus west category) of NDJ Eliassen-Palm flux and divergence factor $D_p \cos^2 \theta$. Contour interval: 0.2 ms$^{-1}$day$^{-1}$.

Apparently the wavering by large-scale balanced flow can explain only part of the mean-flow dipole in Figures 1,3,4a,b. Notably, the upper stratospheric pattern near equator and 30°S is absent in Figure 5. It should be kept in mind that Figure 5 shows only this balanced, large-scale component of $D_p \cos^2 \theta$. Near the equator, there is an important contribution to the momentum balance from equatorial waves, gravity waves, and mean meridional circulation (Dunkerton, 1979, 1982; Hamilton, 1986; Hamilton and Mahlman, 1988; Hitchman and Leovy, 1986, 1988) – the magnitude of which cannot be determined with this dataset.

Discussion

High correlation between tropical and extratropical flow in the upper stratosphere might seem to imply that the Holton-Tan oscillation (HTO) is driven by the upper-level QBO. However, these data indicate close coupling but do not prove cause and effect. We take the point of view that the HTO, with dipole correlation pattern shown in Figure 4, is an important mode of interannual variability in the stratosphere, whatever its cause. The tropical 40 mb QBO appears to be responsible (DB) although a possible role of ENSO has been suggested (van Loon and Labitzke, 1987). The dipole pattern is consistent with planetary wavering between sub tropics and pole. The wave flux is convergent in all winters, but the location of strongest convergence varies interannually so that during 40 mb east phase it is, on average, farther north and vice versa. Convergence is also stronger in the east phase category. Dipole formation is therefore linked to a shift and intensification of planetary wave activity. The pattern might exist independently of the tropical QBO if it could be triggered by other mechanisms. However, the 40 mb QBO remains the best "explanation" of HTO.

The correlation pattern south of 20°N extends the analysis of DB, and reveals a new feature in southern sub tropics. The equatorial correlation with 40 mb QBO is mostly aseasonal and represents the initiation of new QBO phases at upper levels. The pattern near 30°S, although small in absolute magnitude, is intriguing. It may represent a weak, out-of-phase subtropical QBO as seen in numerical models (Dunkerton, 1991). However, if this were the sole explanation one would expect an aseasonal correlation. Because the largest signal is in NH winter, the seasonal cycle must be involved. One mechanism is the diabatic circulation. Horizontal advection of angular momentum is strongest in NH winter, driven by tropical heating and midlatitude body force (Dunkerton, 1991). It is reasonable to suppose that this circulation is weakly modulated by the HTO. For example, during the east phase of HTO, polar temperatures are further from equilibrium, implying stronger cross-equatorial flow and a weak easterly anomaly near 30°S. This mechanism does not explain why the 30°S correlations were slightly higher in Figure 1 compared to Figure 4.

Conclusion

Using 12 years of global NMC data 1978-90, it was shown that the tropical quasi-biennial oscillation (QBO) at 40 mb was correlated in three ways with the upper stratosphere mean zonal wind: (i) The QBO was in phase with the Holton-Tan oscillation (HTO) of polar night jet during NH winter. (ii) The 40 mb and ~5 mb tropical QBOs were out of phase. (iii) The 40 mb QBO was strongly in phase with a weak subtropical QBO near 5 mb, 30°S. Correlation (ii) was aseasonal while (i) and (iii) were observed primarily during NH winter. Spatial autocorrelation of DJF mean zonal wind displayed a similar pattern, although anticorrelation was actually largest in the upper stratosphere, between 10°S and 62°N. This does not necessarily imply that the upper-level QBO
forces the HTO (see DB). Rather, the HTO dipole is an important mode of interannual variability triggered, in part, by the 40 mb QBO. The dipole between subtropics and pole is qualitatively consistent with a horizontal shift of wave driving by planetary Rossby waves. It is believed that the subtropical QBO near 30°S represents not only a direct effect of the equatorial QBO but a remote effect of HTO communicated by the mean meridional circulation. These observations will provide a basis for further theoretical and numerical study of quasi-biennial and interannual variability of the upper stratosphere.

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References


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