INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **24**: 525–532 (2004)

COMPARISON OF STRATOSPHERIC ZONAL WINDS AND EL NIÑO–SOUTHERN OSCILLATION IN RECENT DECADES

R. P. KANE*
Instituto Nacional de Pesquisas Espaciais – INPE, Caixa Postal 515, 12245-970 São José dos Campos, SP, Brazil

Received 24 October 2002
Revised 28 November 2003
Accepted 28 November 2003

ABSTRACT

A comparison of the plots of the monthly and yearly values indicates that stratospheric winds and El Niño–southern oscillation (ENSO) parameters evolve differently and probably have no relationship with each other. The sharp commencement of the 1997–98 El Niño in February–March 1997 was not accompanied by any particular deviation from the general trend of the wind variation in those months. Spectral analysis for 1979 up to the present indicates that winds have only a quasi-biennial oscillation (QBO) near 2.40 years as a prominent variation, whereas ENSO has main periodicities near 3.7 and 5.0 years and a small QBO near 2.50 years, slightly but significantly different from the wind QBO. Copyright © 2004 Royal Meteorological Society.

KEY WORDS: stratosphere; troposphere; spectra; winds; ENSO

1. INTRODUCTION

A quasi-biennial oscillation (QBO) in the equatorial stratospheric zonal winds was discovered by Reed *et al.* (1961), Veryard and Ebdon (1961) and Angell and Kroshover (1962). Thereafter, several workers have studied and documented the wind characteristics of the QBO (e.g. see Naujokat (1986)). For several months the winds are westerly, and they then switch over rapidly to easterly and remain so for several months. The durations of the westerlies and easterlies change with altitude and latitude. The westerly accelerations appear first at the equator, spread with time to higher latitudes and are generally more intense than easterly accelerations. The maximum occurs later at lower altitudes, by 10–12 months from 10 to 50 mbar. These characteristics are very well defined, and from the data at any altitude it is possible to guess what must be happening at other altitudes. A theoretical explanation of the QBO was given by Lindzen and Holton (1968; Holton and Lindzen, 1972) in terms of absorption in the stratosphere of vertically propagating equatorial Kelvin and Rossby–gravity waves generated in the troposphere. Plumb and Bell (1982) produced a numerical model that reproduces many of the observed features of this QBO. The wind QBO seems to affect other parameters, notably stratospheric temperatures and ozone.

Though some workers like to reserve the term QBO for stratospheric winds only, the QBO and quasi-triennial oscillation (QTO) are often seen in tropospheric parameters and even in oceanic parameters. Hence, we will use the terms QBO and QTO in their literal sense, viz. variations of ~2–3 years and 3–4 years respectively, no matter where and in what parameters. The relationship between the tropospheric and stratospheric QBO seems to be controversial. Trenberth (1980) seems to feel that the two are unrelated. Analysis by Kane (1992, 1998) also indicated no clear relationship, whereas Yasunari (1989) indicated possible links between the two. On the Earth's surface, there is another phenomenon that has predominantly a QTO,

---

* Correspondence to: R. P. Kane, Instituto Nacional de Pesquisas Espaciais – INPE, Caixa Postal 515, 12245-970 São José dos Campos, SP, Brazil; e-mail: kane@laser.inpe.br, kane@dge.inpe.br

and larger periodicities, and also a biennial mode (Rasmusson *et al.*, 1990) that may not be related to the stratospheric wind QBO, i.e. El Niño–southern oscillation (ENSO). Barnett (1991) and Ropelewski *et al.* (1992) feel that the tropospheric QBO is mainly related to ENSO.

During the last two decades, there were two major El Niños (1982–83 and 1997–98), a moderate El Niño (1986–87) and a diffuse, weak El Niño (1991–92). In an earlier paper by Kane (1998), the data used were only up to 1995. In the present communication, a comparison is made of the stratospheric winds, some tropospheric parameters, and the Pacific sea-surface temperature (SST) anomalies, in particular during the recent 'mega' El Niño of 1997–98, to see whether the variations of these phenomena have any similarity. Spectral components are also examined.

2. DATA

The data used were obtained mostly from the Website http://www.cpc.ncep.noaa.gov/data/indices/ of the Climate Prediction Center, Camp Springs, MD, USA, and the Website http://tao.atmos.washington.edu/data_sets/chicama_sst/#anomalies for data for Puerto Chicama, Peru. The data are for 14 parameters: (1) 30 mbar and (2) 50 mbar equatorial average zonal winds (average of data from Singapore, etc.); (3) 200 mbar zonal winds equator (165–110 °W); (4, 5, 6) 850 mbar trade wind index (135 °E–180 °W) 5 °N–5 °S, west Pacific; 850 mbar trade wind index (175–140 °W) 5 °N–5 °S, central Pacific; 850 mbar trade wind index (135–120 °W) 5 °N–5 °S, east Pacific; (7, 8, 9) atmospheric pressure at Tahiti (T; 18 °S, 150 °W), Darwin (D; 12 °S, 131 °E), and their difference (T–D); (10) SST anomalies at Puerto Chicama (8 °S, 80 °W, Peruvian coast); (11, 12, 13, 14) SST anomalies in the Pacific regions; i.e. Niño $1 + 2$ (0–10 °S)(90–80 °W), Niño 3 (5 °N–5 °S)(150–90 °W), Niño 3.4 (5 °N–5 °S)(170–120 °W) and Niño 4 (5 °N–5 °S)(160 °E–150 °W), for 1979 onwards. The longitude coverage is indicated in Table I.

All data are at monthly time resolution and are simple averages across the various longitudes.

3. PLOTS

Since most of the parameters have a seasonal variation, which is not of interest here, 12-monthly moving averages were calculated to eliminate the seasonal variations. Figure 1 shows a plot of the moving averages,

Table I. Longitude coverage for the various parameters

Parameter	Longtude coverage					
	120 °E	150 °E	180 °E or W	150 °W	120 °W	90 °W
30 mbar			Equatorial zonal average			
50 mbar			Equatorial zonal average			
200 mbar			*	* * *	* * *	
850 mbar	*	* * *	* *			
850 mbar			*	* * *		
850 mbar					* *	
Tahiti (T)				*		
Darwin (D)	*					
T–D	*	* * *	* * *	* *		
Puerto Chicama						*
Niño $1 + 2$						* *
Niño 3				* *	* * *	* *
Niño 3.4			*	* * *	* *	
Niño 4		*	* * *	* *		

four values per year centred at January, April, July and October. Plots 1 and 2 are for 30 mbar and 50 mbar stratospheric equatorial zonal winds respectively (positive, westerly W; negative, easterly E) and show smooth oscillations with peak (dots) separations in the range 24–30 months (QBO, average periodicity 28 months). The peaks for 50 mbar are ∼3 months later than those for 30 mbar, as expected (Naujokat, 1986). Also, the amplitudes are smaller at the 50 mbar level. Plot 3 for the 200 mbar winds is quite different from plots 1 and 2, indicating that the QBO is absent, and the few peaks observed are irregularly spaced (36 and 51 months). Plots 4, 5 and 6 are for the trade winds (5 °N–5 °S) at 850 mbar in different longitudinal sectors. There are very few peaks, which are irregularly spaced. Plots 7 and 8 are for the atmospheric pressure at Tahiti and Darwin. The peaks are differently and irregularly spaced for both Tahiti and Darwin. Plot 9, for the difference (T–D), also shows irregular spacings. Plots 10, 11, 12, 13 and 14 are for SST anomalies at the various longitude belts of the low-latitude Pacific (mostly 5 °N–5 °S) and show irregular spacings. However, there are some common features. In some years, the anomalies are positive (shaded black), and these correspond to the occurrence of El Niños. In (T–D), representing the southern oscillation, there are corresponding decreases (also shaded black). Thus, the common features (black shadings) in plots 9–14 are well-known El Niño effects and the year-to-year variations (peaks with irregular spacings of ∼50, ∼55, ∼70 months) do not bear any similarity with stratospheric winds (plots 1 and 2). Incidentally, the minima in plots 3, 4, 5 and 6 (winds at 200 and 850 mbar; shaded black) coincide with the minima of (T–D) and the maxima of the SST in the Pacific, indicating that the El Niño effect is felt in the troposphere right up to the 200 mbar level but has no resemblance with the wind variations in the stratosphere. Kane (1998) showed that the QBO amplitudes are smaller at lower altitudes (i.e. higher pressures: 50 mbar amplitudes are lower than 30 mbar amplitudes, which are lower than 10 mbar amplitudes, etc.), and the amplitudes are almost negligible at 70 mbar. Thus, the stratospheric QBO seems to be restricted to levels above ∼100 mbar, below which the El Niño effects prevail.

El Niños are known to commence abruptly, within a month or two. In that case, the moving averages shown in Figure 1 might have suppressed some sharp month-to-month relationships. To check this possibility, Figure 2 shows the plots of monthly values for the largest El Niño event of 1997–98. Plots for the years 1996 and 1999 are also included. The following may be noted:

1. The vertical line marks the commencement of the El Niño (positive SST anomalies shown shaded black) during February–March 1997. As in Figure 1, the El Niño effects (shaded black) are seen clearly in SST, T–D and the 850 mbar level trade winds and to a smaller extent at the 200 mbar level.
2. The stratospheric levels at 30 and 50 mbar show a smooth oscillation and do not show any abnormality near the vertical line, indicating that the stratospheric QBO is unaffected by the strong El Niño.
3. The stratospheric QBO has a peak separation of only ∼22 months, which is much smaller than the average value of ∼28 months during 1979–2001. Also, contrary to what is stated in the literature (Naujokat, 1986), the switch from westerly (W, positive values) to easterly (E, negative values) winds is not abrupt; in fact, it is quite smooth. However, it is doubtful whether these deviations from the general pattern can be attributed to the El Niño event.

Thus, the stratospheric QBO and El Niño do not seem to be interrelated. Table II gives the correlation matrix. The following may be noted:

1. The 30 and 50 mbar stratospheric winds are well correlated (+0.74) with each other, but are poorly correlated (less than +0.20, often even negative) with all other parameters.
2. The 200 mbar wind (165–110 °W) is moderately correlated (+0.48) with 850 mbar-1, but well correlated (+0.76 or more) with 850 mbar-2, 850 mbar-3 (because of belonging to the same longitude zone in the Pacific, 175–120 °W) and Tahiti pressure, and has high correlations with ENSO (T–D and the various SSTs).
3. The 850 mbar-1 (135–180 °E, Australasia) is well correlated with 850 mbar-2 (175–140 °W) but not with 850 mbar-3 (135–120 °W). The 850 mbar-2 is well correlated with 850 mbar-3. Thus, parameters in Australasia are not well correlated with those of the Pacific. The 850 mbar-1 is only moderately correlated

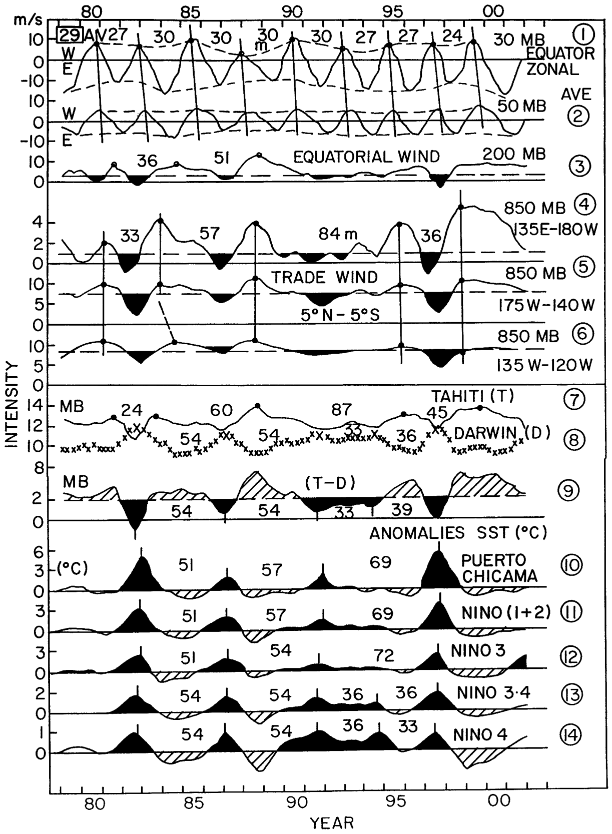

Figure 1. Plots of the 12-month moving averages (four values per year, centred at January, April, July and October) for various parameters during 1979–2001. The numbers are spacings (in months) between successive peaks (marked by dots). The portions shaded black indicate the presence of El Niño effects

with ENSO, whereas 850 mbar-2 and 850 mbar-3 are well correlated with ENSO (all these are in the Pacific).

4. Most ENSO parameters are, of course, highly correlated (+0.70 or more) with each other. The exception is Niño 4 (far west in the Pacific, near the date-line), which has lesser correlation.

A principal component analysis indicated roughly the same characteristics.

4. SPECTRA

In earlier publications (Kane 1992, 1998), the spectra of stratospheric QBO and ENSO were compared and some relationship in the QBO range was indicated. Here, using the same methodology, namely maximum entropy spectral analysis (MESA) for detecting the periodicities and multiple regression analysis (MRA) for estimating the amplitudes of the periodicities detected (and their standard errors, see details in Kane (1992, 1998)), the amplitudes were estimated for the periodicities detected in the various moving-averaged series plotted in Figure 1. The amplitudes versus periodicities are shown in Figure 3. The hatched portions are the 2σ limits and the lines protruding above this limit are significant at a better than 95% confidence level. The following may be noted:

1. In Figure 3(a), the two top plots for stratospheric winds at 30 and 50 mbar show only one very prominent periodicity (far above the hatched 2σ limit) at ~2.40 years (~29 months). In contrast, the 200 mbar

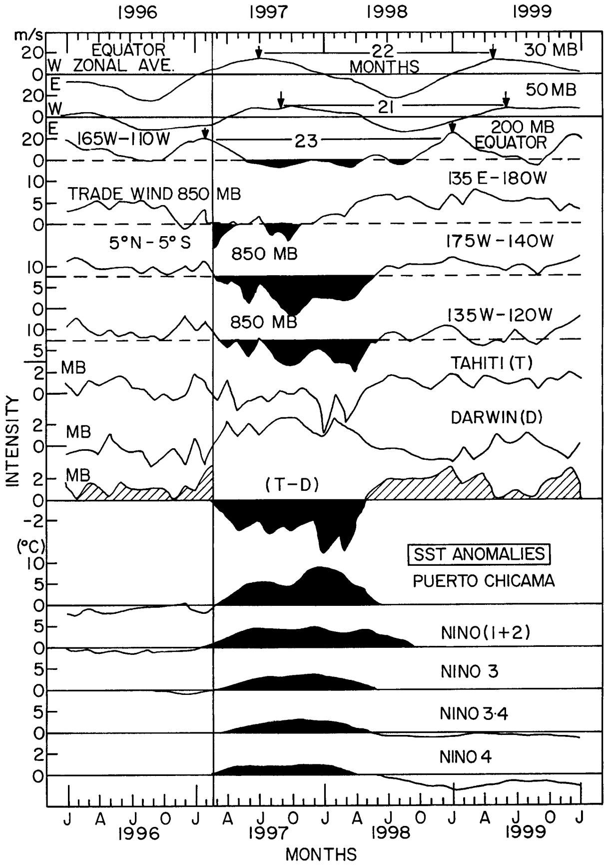

Figure 2. Plots of the monthly values for various parameters during 1996–99. The portions shaded black indicate the presence of El Niño effects. The vertical line indicates February–March 1997, the commencement of an El Niño

winds, as well as the 850 mbar trade winds (and even the atmospheric pressure at Tahiti and Darwin), show a periodicity of ~2.50 years (30 months), again far above the hatched 2σ limit. This may not look very different from the 29 months of the stratospheric winds, but MESA is very accurate in this periodicity region. Experiments with artificial samples (Kane, 1977, 1979; Kane and Trivedi, 1982) indicated that the MESA peaks are very sharp and the maximum error (upper limit) in peak determination is approximately ±0.03 years. Hence, 2.40 years is significantly smaller than 2.50 years.

2. All the other parameters have significant additional periodicities at 3.6–3.9 years and 5.2–5.6 years.
3. In Figure 3(b), the southern oscillation index (T–D) and Niño 3, Niño 3.4 and Niño 4 show a periodicity of ~2.50 years, again different from the 2.40 years for the stratospheric winds. In addition, there are significant periodicities at 3.5–3.7 years and 4.7–5.4 years.

Thus, it would seem that ENSO is characterized mainly by periodicities near 3.7 and 5.0 years, whereas stratospheric low-latitude zonal winds are characterized mainly by a QBO near 2.40 years. ENSO also has a QBO, but this is near 2.50 years, which is most probably different from the wind QBO.

5. CONCLUSIONS AND DISCUSSION

A comparison of the plots of the monthly and yearly values indicates that stratospheric winds and ENSO parameters evolve differently and probably have no relationship with each other. Spectral analysis for 1979

Table II. Intercorrelations between the 12-month moving averages of the various parameters

	30 mbar	50 mbar	200 mbar	850 mbar-1	850 mbar-2	850 mbar-3	Tahiti	Darwin	T–D	Puerto Chicama	Niño 1 + 2	Niño 3	Niño 3.4	Niño 4
30 mbar	1.00													
50 mbar	0.74	1.00												
200 mbar	−0.19	−0.13	1.00											
850 mbar-1	−0.26	0.06	0.48	1.00										
850 mbar-2	−0.09	0.04	0.81	0.68	1.00									
850 mbar-3	−0.01	−0.02	0.76	0.36	0.88	1.00								
Tahiti	−0.17	0.09	0.76	0.73	0.78	0.53	1.00							
Darwin	0.09	0.02	−0.77	−0.62	−0.90	−0.78	−0.71	1.00						
T–D	−0.14	0.03	0.83	0.73	0.92	0.73	0.91	−0.94	1.00					
Puerto Chicama	0.13	0.11	−0.78	−0.39	−0.89	−0.90	−0.56	0.80	−0.75	1.00				
Niño 1 + 2	0.09	0.08	−0.74	−0.33	−0.82	−0.85	−0.45	0.74	−0.66	0.96	1.00			
Niño 3	0.09	0.02	−0.84	−0.62	−0.95	−0.86	−0.68	0.90	−0.87	0.91	0.90	1.00		
Niño 3.4	0.09	−0.04	−0.82	−0.76	−0.95	−0.78	−0.79	0.91	−0.93	0.79	0.73	0.95	1.00	
Niño 4	0.14	−0.07	−0.67	−0.82	−0.78	−0.58	−0.76	0.79	−0.84	0.52	0.42	0.74	0.90	1.00

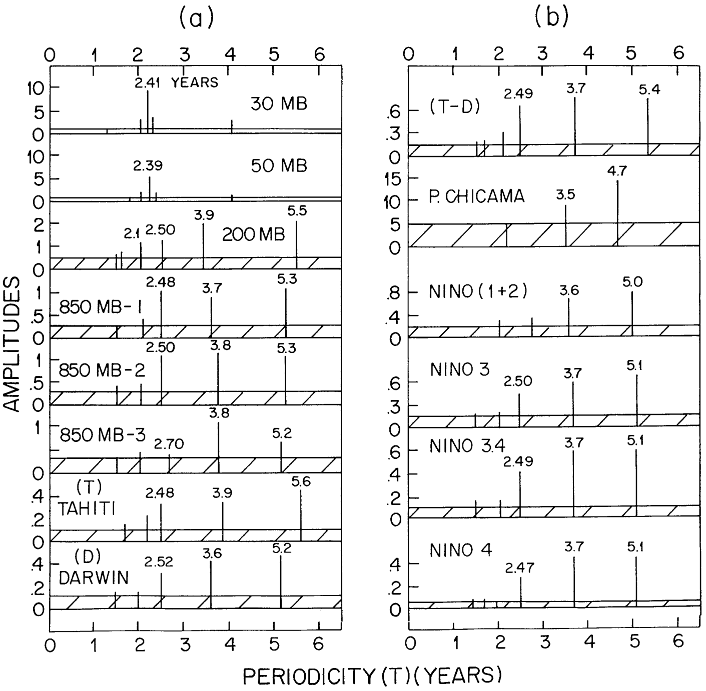

Figure 3. Amplitudes versus periodicities detected in a MESA of the 12-month moving averages of the series 1979–2001 for the various parameters. The numbers indicate periodicities in years. The hatched portions indicate the 2σ limits, and the lines protruding above this level indicate periodicities significant at a confidence level of more than 95%

onwards indicates that winds have only a QBO near 2.40 years as a prominent variation, whereas ENSO has main periodicities near 3.7 and 5.0 years and a small QBO near 2.50 years, which is slightly, but significantly, different from the wind QBO.

For the troposphere, Yasunari (1985), Gutzler and Harrison (1987) and Kawamura (1988) reported a tropospheric QBO. In addition to the ENSO mode (40–60 month period), the zonal wind in the troposphere has a component of transient east–west circulation with a QBO time scale, which shows a totally eastward propagation (Yasunari, 1989). Thus, there is some evidence that the stratospheric and tropospheric QBO are *coupled* and that these are, in turn, coupled to the QBO of the equatorial eastern Pacific SST, suggesting a dynamical link between stratospheric QBO and the large-scale coupled atmosphere–ocean system. However, Trenberth (1980) mentions that the QBO shown by tropospheric ultra-long waves of the Southern Hemisphere does not match with the stratospheric QBO. Meehl (1987) identified a biennial signal in the coupled ocean–atmosphere system in the tropical Indian and Pacific regions that does not seem to be related to the stratospheric QBO (see also Rasmusson *et al.* (1990)). In any case, the ENSO mode (40–60 months) present in the SST seems to be an independent parameter. Gray *et al.* (1992) have hypothesized a mechanism by which the stratospheric QBO influences ENSO variability, and Geller and Zhang (1991; Geller *et al.*, 1997) illustrate a mechanism by which SST variations can modulate tropical wave activity and, finally, the SST QBO would tend to force a stratospheric zonal flow oscillation with the same period as the oceanic QBO. Geller *et al.* (1997) show that an ENSO modulation of wave forcing would result in period-to-period variability in the stratospheric QBO; but, in their model, the stratospheric QBO does not just synchronize with the tropospheric long period variability. The stratospheric QBO wind variations could be strongly affected by ENSO, but in a way that does not involve simple correlation between the wind series and ENSO indices. Hence, the simple analysis in the present paper may not be able to resolve these effects. In any case, it seems that further down in the troposphere, away from the stratosphere, the ENSO modes would be more predominant for all atmospheric parameters. Ropelewski *et al.* (1992) feel that the tropospheric QBO is mainly related to ENSO.

ACKNOWLEDGEMENTS

This work was partially supported by FNDCT, Brazil, under contract FINEP-537/CT.

REFERENCES

Angell JK, Korshover J. 1962. The biennial wind and temperature oscillations of the equatorial stratosphere and their possible extension to higher latitudes. *Monthly Weather Review* **90**: 122–132.

Barnett TP. 1991. The interaction of multiple time scales in the tropical climate system. *Journal of Climate* **4**: 269–285.

Geller MA, Zhang M. 1991. Sea surface temperatures, equatorial waves, and the quasi-biennial oscillation. In *Symposium on Middle Atmospheric Science*, Kyoto; abstract QB-5.

Geller MA, Shen W, Zhang M, Tan W-W. 1997. Calculation of the stratospheric quasi-biennial oscillation for time-varying wave forcing. *Journal of the Atmospheric Sciences* **54**: 883–894.

Gray WM, Sheaffer JD, Knaff JA. 1992. Hypothesized mechanism for stratospheric QBO influence on ENSO variability. *Geophysical Research Letters* **19**: 107–110.

Gutzler DS, Harrison DE. 1987. The structure and evolution of seasonal wind anomalies over the near-equatorial eastern Indian and western Pacific Oceans. *Monthly Weather Review* **115**: 169–192.

Holton JR, Lindzen RS. 1972. An updated theory for the quasi-biennial cycle of the tropical stratosphere. *Journal of the Atmospheric Sciences* **29**: 1076–1080.

Kane RP. 1977. Power spectrum analysis of solar and geophysical parameters. *Journal of Geomagnetism and Geoelectricity* **29**: 471–495.

Kane RP. 1979. Maximum entropy spectral analysis of some artificial samples. *Journal of Geophysical Research* **84**: 965–966.

Kane RP. 1992. Relationship between QBOs of stratospheric winds, ENSO variability and other atmospheric parameters. *International Journal of Climatology* **12**: 435–447.

Kane RP. 1998. Spectral comparison of ENSO and stratospheric zonal winds. *International Journal of Climatology* **18**: 1195–1208.

Kane RP. Trivedi NB. 1982. Comparison of maximum entropy spectral analysis (MESA) and least-square linear prediction (LSLP) methods for some artificial samples. *Geophysics* **47**: 1731–1736.

Kawamura R. 1988. Quasi-biennial oscillation modes appearing in the tropical sea water temperature and 700 mb zonal wind. *Journal of the Meteorological Society of Japan* **66**: 955–965.

Lindzen RS, Holton JR. 1968. A theory of the quasi-biennial oscillation. *Journal of the Atmosphere Sciences* **25**: 1095–1107.

Meehl GA. 1987. The annual cycle and interannual variability in the tropical Indian and Pacific Ocean regions. *Monthly Weather Review* **115**: 27–50.

Naujokat B. 1986. An update of the observed quasi-biennial oscillation of the stratospheric winds over the tropics. *Journal of the Atmospheric Sciences* **43**: 1873–1877.

Plumb RA, Bell RC. 1982. A modal of the quasi-biennial oscillation on an equatorial beta-plane. *Quarterly Journal of the Royal Meteorological Society* **108**: 335–352.

Rasmusson EM, Wang X, Ropelewski CF. 1990. The biennial component of ENSO variability. *Journal of Marine Systems* **1**: 71–96.

Reed RJ, Campbell WJ, Rasmusson LA, Rogers DJ. 1961. Evidence of a downward propagating annual wind reversal in the equatorial stratosphere. *Journal of Geophysical Research* **66**: 813–818.

Ropelewski CF, Halpert MS, Wang X. 1992. Observed tropospheric biennial variability and its relationship to southern oscillation. *Journal of Climate* **5**: 594–614.

Trenberth KE. 1980. Atmospheric quasi-biennial oscillations. *Monthly Weather Review* **108**: 1370–1377.

Veryard RG, Ebdon RA. 1961. Fluctuations in tropical stratospheric winds. *Meteorological Magazine* **90**: 125–143.

Yasunari T. 1985. Zonally propagating modes of the global east–west circulation associated with the southern oscillation. *Journal of the Meteorological Society of Japan* **63**: 1013–1029.

Yasunari T. 1989. A possible link of the QBOs between the stratosphere, troposphere and the surface temperature in the tropics. *Journal of the Meteorological Society of Japan* **67**: 483–493.