NOTES AND CORRESPONDENCE

Tropical Cyclone Activity in the Western North Pacific in Relation to the Stratospheric Quasi-Biennial Oscillation

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24 January 1994 and 18 January 1995

1. Introduction

In a study of a possible relationship between the El Niño–Southern Oscillation (ENSO) phenomenon and the interannual variations in tropical cyclone (TC) activity in the western North Pacific (WNP), Chan (1985) found two peaks in the cross-spectrum between the time series of such variations in TC activity and that of a Southern Oscillation index (which is defined as the sea level pressure difference between Easter Island and Darwin). One peak is at the well-known Southern Oscillation frequency with a period of about 3–3.5 years. The other peak has a period of about 26 months, which suggests that the TC variations at this frequency may be related to the quasi-biennial oscillation (QBO) in the stratosphere. Fluctuations in TC activity at this latter frequency in the Atlantic have been documented before (Angell et al. 1969; Shapiro 1982, 1989). However, these authors did not attempt to relate such fluctuations to the QBO in either the sea level pressure or the zonal winds in the equatorial stratosphere. Gray (1984) has also linked variations in Atlantic hurricane frequency to the stratospheric QBO. Gray et al. (1992b) further discussed how this QBO is related to tropical convection and ENSO. The theory suggests that during the westerly phase of the QBO, vertical shear of the zonal winds in the upper troposphere off the equator tends to be smaller and thus provide a favorable environment for TC development. As evidence of this theory, they showed that intense typhoons and hurricanes tend to occur more often in westerly phase years than in easterly phase years by a factor of about 3. Lau and Chan (1993) have also suggested that during the westerly phase of the QBO, deep cyclonic flow tends to prevail over the tropical regions during the summer and thus favors TC development.

In this note, these ideas are tested by correlating the time series of TC activity over the WNP with those representing the QBO. It will be shown through cross-spectral analyses that TC activity over the WNP is indeed related to the QBO.

2. Data and methodology

a. Data

Because winds in the lower equatorial stratosphere have very little longitudinal variations, time series of the zonal winds at 50, 30, and 10 hPa at Balboa (9°N, 80°W) are used to represent the stratospheric QBO, although these data are to be correlated with TC activity over the WNP. The time periods in which these wind data are available are 1951–88 (50 hPa), 1952–88 (30 hPa), and 1958–88 (10 hPa). These time series will be labeled as Q5, Q3, and Q1, respectively.

To investigate the extent to which QBO affects TC activity, three time series of the monthly number of TCs (provided by the Joint Typhoon Warning Center, Guam) are considered: 1) the ALL series consisting of all TCs that occurred over the WNP, 2) the TSTY (tropical storm/typhoon) series being the ALL series without tropical depressions (i.e., excluding TCs with maximum sustained winds less than 17 m s^{-1}), and 3) the TY series consisting only of TCs that had reached typhoon intensity (maximum sustained winds of at least 33 m s^{-1}). While the data for these three series span the years 1947–88, only truncated series are used when correlated with the three QBO series because the latter have different starting years.

b. Methodology

Each time series is first standardized; that is,

$$X'_{ij} = \frac{X_{ij} - \bar{X}_j}{\sigma_j},$$

where X'_{ij} and X_{ij} are the standardized and raw data, respectively, for the jth month of the ith year, and $\bar{X}_j$

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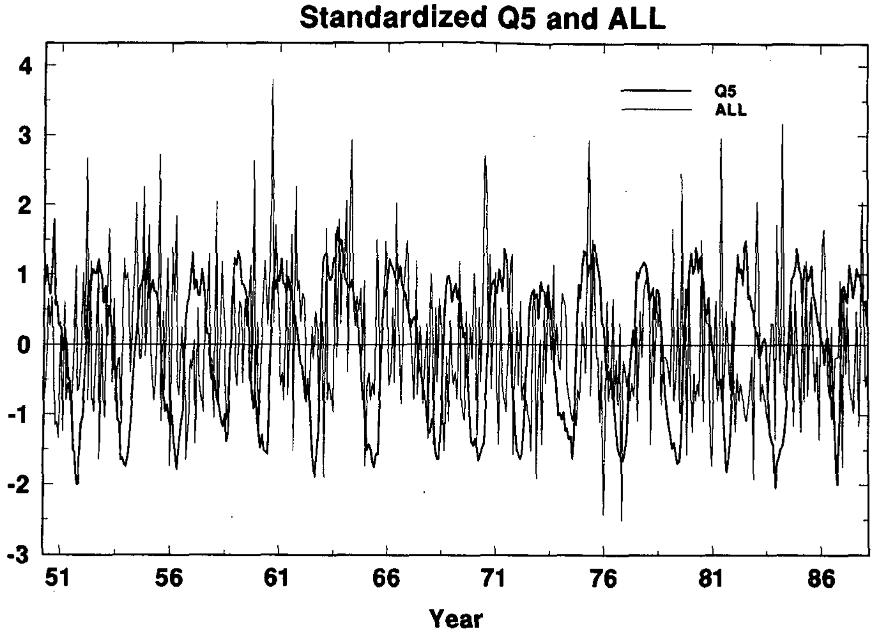

FIG. 1. The standardized time series of stratospheric zonal winds at 50 hPa (Q5) and TC activity over the western North Pacific (ALL).

and σ_j are the mean and standard deviation of the jth month, respectively. An example of the standardized Q5 and time series ALL are shown in Fig. 1. It can be seen that large positive values in the Q5 series generally correspond to high TC activity. This will be discussed in further detail in section 4.

Chan (1985) has shown that the spectral peak of the TC activity series at the ENSO period (36–42 months) has a much larger amplitude than that at the QBO period. Therefore, in order to study the latter oscillation, it would be better if the low frequency part can be removed. At the same time, the annual signal should also be reduced to a minimum. Therefore, a "differenced low-pass Gaussian filter" (WMO 1966) with cutoff points at 20 and 40 months is applied to all the standardized time series. In other words, oscillations with periods between 20 and 40 months are kept almost intact, while those longer than 40 or shorter than 20 months are largely removed. It should also be noted that the response curve is the same as that of a simple Gaussian filter and always nonnegative (WMO 1966).

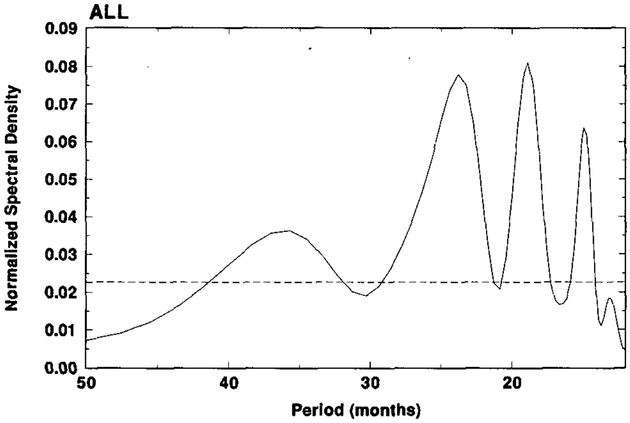

FIG. 2. The normalized spectrum of the standardized ALL series for the period 1951–88. The dashed line indicates the spectral density of a white-noise process.

Each QBO and TC series is then spectrally analyzed with a Tukey–Hanning spectral window with various window widths. Because of the well-known characteristics of the stratospheric QBO (see, e.g., Trenberth 1980), the power spectra of these series will not be shown. Only those from the TC activity series will be discussed in section 3.

To study the relationship between TC activity and QBO, the method of cross-spectral analysis is used by again applying the Tukey–Hanning window. The results of these analyses are presented in section 4.

3. Spectral analyses of tropical cyclone activity

In all the series of TC activity (i.e., the ALL, TSTY, and TY series for all available years as well as the truncated ones), two major peaks appear, one at around 23–25 months and the other at 18 months. The peak corresponding to the 37–44 months has been largely removed by the bandpass filter. An example of this is given in Fig. 2 that shows the power spectrum of the 1951–88 ALL series. Using the formula given by Chatfield (1984), the bandwidth for most of the spectra is around 4 months. Therefore, the peak at around 23–25 months should be well correlated with the QBO, which

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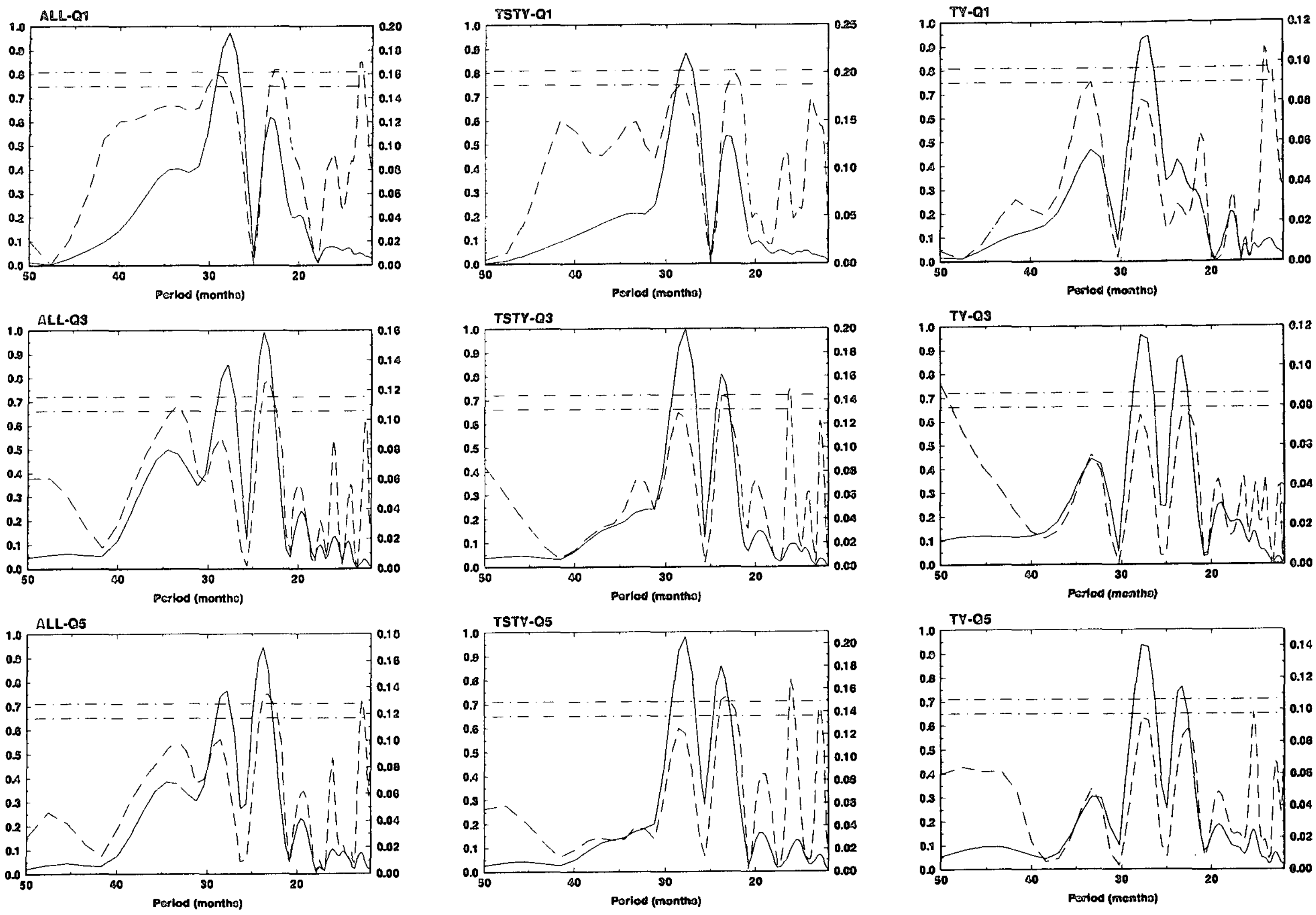

FIG. 3. Cross-spectrum (solid, scale on right axis) and coherence (dashed, scale on left axis) between each of the QBO series (Q1, Q3, and Q5) and each of the TC series (ALL, TSTY, and TY). The label on each graph indicates which cross-spectrum and coherence are shown. The two horizontal dot–dashed lines indicate the 90% and 95% significance level of the coherence.

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TABLE 1. Phase difference (months) between each of the QBO series (Q1, Q3, and Q5) and each TC series (ALL, TSTY, and TY) at the 28-month period. A positive number indicates that the QBO series leads the TC series.

	Q1	Q3	Q5
ALL	−12	−4	1
TSTY	−11	−4	1
TY	−9	−1	4

has a distinct spectral peak at around 28 months. These results are shown in the next section. The physical meaning of the 18-month peak is, however, not clear.

4. Cross-spectral analyses

A cross-spectral analysis is performed between each QBO series and each of the three TC series, giving a total of nine cross-spectra (Fig. 3). In each cross-spectrum, a spectral window of 200 is used. It can be seen that in all the nine cross-spectra, two peaks appear at around 24 and 28 months. In most of the cases, the 28-month peak is the dominant one. However, the coherence associated with this peak is generally smaller than that at the 24-month period. In fact, the value of the coherence for the 28-month peak is barely significant at the 90% confidence level (calculated from the formula given in Panofsky and Brier 1958).

These results can be interpreted in the following way. Although the QBO has a dominant spectral power at approximately 28 months, it also has an appreciable oscillation with a 24-month period. The reverse is true for the TC series. Therefore, when the two series are correlated, oscillations at both frequencies show up as distinct peaks in the cross-spectrum. However, the double peak also reduces the coherence of each peak, and these can only pass the significant test at about 90%. This does not mean, however, that the two series are not correlated at these two frequencies. The fact that the double peaks occur in almost all of the cross-spectra suggest that the two series are indeed correlated. However, because in most cases the peak at the 28-month period is more dominant and it is unlikely that TC activity affects the stratospheric winds on a planetary scale, this peak should be studied rather than that at 24 months.

At the 28-month period, the phase difference between each QBO series and all the TC subseries is essentially the same (Table 1). The stratospheric zonal winds at 10 hPa lag TC activity by approximately 10 months, while those at 30 (50) hPa lag (lead) by about 2 months. The phase shift from 10 to 50 hPa is consistent with the phase difference among the winds at these levels.[1]

These results imply that TC activity over the WNP is likely to increase when the lower-stratospheric winds begin to strengthen from the west. In other words, the westerly phase of the QBO corresponds to an increase in TC activity. This result is consistent with that of Gray (1984) for Atlantic hurricanes and the hypothesis of Gray et al. (1992b).

5. A possible mechanism

Gray et al. (1992b) hypothesized that during the westerly phase of the QBO, while the stratospheric winds near the equator are from the west, those in the Tropics are easterly. At the same time, tropical 200-hPa zonal winds are also easterly. As a result, an area of small vertical shear develops over the Tropics away from the equator. This reduction in shear favors deep convection and hence TC development. This mechanism may therefore explain the results obtained in this paper. Since convection associated with tropical storms and typhoons is more likely to extend into the lower stratosphere, this mechanism should be more effective in enhancing/suppressing the development of these more intense systems. This may be the reason why the cross-spectral amplitudes for the TSTY and TY series of the 28-month period are higher than those for the ALL series.

The hypothesis of Gray et al. (1992b) implies that a cyclonic shear must exist between the Tropics and the equator in the lower stratosphere during the westerly phase of the QBO. This is also found by Lau and Chan (1993). In other words, TC activity should be high when the shear of the zonal winds in the lower stratosphere in the Tropics is cyclonic.

To determine the validity of this statement, the relative vorticity at 50 hPa in the deep Tropics over the western North Pacific is calculated from the data of Lau and Chan (1993). July zonal winds at Singapore (1.4°N, 104°E) and Kota Kinabaru (6°N, 114°E) are used. The relative vorticity so determined is plotted in

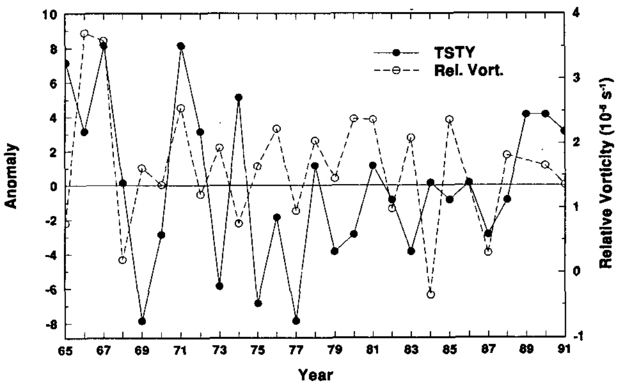

FIG. 4. Time series of the anomaly in the annual number of tropical storms/typhoons (solid) and of the relative vorticity (10^{-5} s^{-1}) in July over the tropical western North Pacific (dashed).

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[1] Cross-spectral analyses among the QBO series indicate that at the 28-month peak, the Q5 series leads the Q3 and Q1 series by about 4 and 11 months, respectively, while the Q3 series leads the Q1 series by about 7 months (not shown). See also Holton (1992).

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Fig. 4, together with the anomaly in the annual number of tropical storms/typhoons over the WNP. It can be seen that except in the vicinity of ENSO years, an increase in relative vorticity does correspond to an increase in TC activity. Therefore, hypothesis advanced by Gray et al. (1992b) appears to be supported by this present result. However, the fact that opposite changes occur in the vicinity of ENSO years suggests that the QBO is only one factor in modifying TC activity and that ENSO appears to be a stronger modulator. This is reasonable since the TC activity has a stronger power at the ENSO frequency (Chan 1985).

6. Discussion and conclusions

This note presents evidence through cross-spectral analyses that the stratospheric QBO is related to TC activity over the western North Pacific. The two time series are almost in phase at the 28-month period, which means that the westerly phase of the QBO corresponds to a larger number by TCs. This relationship is stronger for the more intense TCs, namely tropical storms and typhoons. The relationship appears to be a result of the decrease in the upper-tropospheric vertical shear over the Tropics during summer associated with the westerly phase of the QBO, as hypothesized by Gray et al. (1992b). Their hypothesis also implies that the meridional shear of the lower stratospheric zonal winds in the Tropics is strongly cyclonic in westerly phase years. TC activity is indeed found to be higher when the relative vorticity in the lower stratosphere is large, thus verifying the hypothesis to a certain extent.

Of course, QBO is only one of the many factors that affect TC activity. Indeed, during ENSO years or thereabouts, the QBO–TC relationship does not seem to hold very well. This is consistent with findings of Gray (1984) and Gray et al. (1992a, 1993). Nevertheless, this study points out that the QBO not only affects TC activity in the Atlantic, but to a certain extent it also modulates TC activity in the WNP.

Acknowledgments. The following individuals are thanked for their contributions: Professor W. M. Gray of Colorado State University for the QBO data, Mr. Frank Wells of the Joint Typhoon Warning Center for the TC activity data, Mr. Robert Lau and Mr. M. Y. Chan of Royal Observatory Hong Kong for the July zonal wind data, and last but not least, Ms. M. K. Yu for her professional help in manuscript preparation.

This research is partly supported by the U.S. Office of Naval Research Grant No. N00014-92-J-1042.

REFERENCES

Angell, J. K., J. Korshover, and G. F. Cotten, 1969: Quasi-biennial oscillations in the "centers of action." *Mon. Wea. Rev.*, **97**, 867–872.

Chan, J. C. L., 1985: Tropical cyclone activity in the northwest Pacific in relation to the El Niño/Southern Oscillation phenomenon. *Mon. Wea. Rev.*, **113**, 599–606.

Chatfield, C., 1984: *The Analysis of Time Series: An Introduction.* 3d ed. Chapman and Hall, 286 pp.

Gray, W. M., 1984: Atlantic seasonal hurricane frequency. Part I: El Niño and 30 mb quasi-biennial oscillation influences. *Mon. Wea. Rev.*, **112**, 1649–1668.

——, C. W. Landsea, P. W. Mielke Jr., and K. J. Berry, 1992a: Predicting Atlantic seasonal hurricane activity 6–11 months in advance. *Wea. Forecasting,* **7**, 440–445.

——, J. D. Sheaffer, and J. A. Knaff, 1992b: Influence of the stratospheric QBO on ENSO variability. *J. Meteor. Soc. Japan,* **70**, 975–994.

——, C. W. Landsea, P. W. Mielke Jr., and K. J. Berry, 1993: Predicting Atlantic basin seasonal tropical cyclone activity by 1 August. *Wea. Forecasting,* **8**, 73–86.

Holton, J. R., 1992: *An Introduction to Dynamic Meteorology.* 3d ed. Academic Press, 511 pp.

Lau, R., and M. Y. Chan, 1993: Equatorial stratospheric flow patterns and quasi-biennial/pentaennial oscillations. *East Asia and Western Pacific Meteorology and Climate,* W. J. Kyle and C. P. Cheng, Eds., World Scientific, 31–38.

Panofsky, H. A., and G. W. Brier, 1958: *Some Applications of Statistics to Meteorology.* Pennsylvania State University Press, 224 pp.

Shapiro, L., 1982: Hurricane climatic fluctuations. Part I: Patterns and cycles. *Mon. Wea. Rev.*, **110**, 1007–1013.

——, 1989: The relationship of the QBO to Atlantic tropical storm activity. *Mon. Wea. Rev.*, **117**, 1545–1552.

Trenberth, K. E., 1980: Atmospheric quasi-biennial oscillations. *Mon. Wea. Rev.*, **108**, 1370–1377.

World Meteorological Organization, 1966: *Climate Change.* Tech. Note No. 79, WMO, Geneva, 79 pp.

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