GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L06702, doi:10.1029/2009GL037163, 2009

Click Here for Full Article

# Influence of stratospheric quasi-biennial oscillation on tropical cyclone tracks in the western North Pacific

Chang-Hoi Ho,[1] Hyeong-Seog Kim,[1] Jee-Hoon Jeong,[2] and Seok-Woo Son[3]

Received 3 January 2009; revised 6 February 2009; accepted 12 February 2009; published 19 March 2009.

[1] The possible influence of the stratospheric quasi-biennial oscillation (QBO) on tropical cyclone (TC) passages in the western North Pacific (WNP) is examined using TC data recorded by the Tokyo Typhoon Center and the QBO index derived from reanalysis data. The influence is observed to be significant. The number of TCs approaching the East China Sea is large during the westerly phase of the QBO; however, during the easterly phase, the number of TCs approaching the eastern offshore of Japan is large. This difference in the TC tracks is found to be related to the background flow change associated with the QBO. However, the total number of TC events over the WNP and the sum of the number of TCs approaching the aforementioned two regions appear to be unrelated to the QBO phases. **Citation:** Ho, C.-H., H.-S. Kim, J.-H. Jeong, and S.-W. Son (2009), Influence of stratospheric quasi-biennial oscillation on tropical cyclone tracks in the western North Pacific, *Geophys. Res. Lett.*, *36*, L06702, doi:10.1029/2009GL037163.

## 1. Introduction

[2] It has been shown that the stratospheric quasi-biennial oscillation (QBO) is able to modulate tropical cyclone (TC) activities over various oceans [*Gray*, 1984; *Shapiro*, 1989; *Gray et al.*, 1992; *Chan*, 1995; *Jury et al.*, 1999]. Its influence on TC activities is especially pronounced in the North Atlantic basin [*Gray*, 1984; *Gray et al.*, 1992; *Elsner et al.*, 1999]. During the westerly phase of the QBO (W-QBO), more intense TCs (i.e., hurricanes) are found to form in the North Atlantic, while the reverse is true during the easterly phase of the QBO (E-QBO). This QBO-TC relationship has been inferred from changes in the horizontal wind over TCs and from changes in the vertical wind shear associated with the QBO in the upper troposphere. TCs in the western North Pacific (WNP) have also been associated with the QBO; however, these TCs have received less attention. By performing cross-spectral analysis, *Chan* [1995] has shown that the QBO and the TC activity in the WNP have in-phase fluctuations with a periodicity of 28 months. This coherent fluctuation is also related to the vertical wind shear in the tropical upper troposphere.

[3] While the above-mentioned studies have investigated the relationship between the number/intensity of TCs and the QBO, very few studies have examined the existence of a link between TC tracks and the QBO. This is presumably because TC tracks are more sensitive to subtropical circulations than to tropical circulations [e.g., *Chan and Gray*, 1982; *Ho et al.*, 2004, 2005; *Kim et al.*, 2005]. *Ho et al.* [2004] have suggested that on interannual and decadal time scales, TC tracks in the WNP are primarily modulated by the extension and strengthening of the subtropical WNP high. Since the WNP high may not be directly linked with the QBO, which occurs in the deep tropics, a relationship between the QBO and TC tracks is unlikely to be observed in the WNP.

[4] However, it has been suggested that the QBO may affect not only tropical circulations but also subtropical and extratropical circulations. *Mukherjee et al.* [1985] have shown that the Indian summer monsoon is highly sensitive to the QBO. By comparing climate models that consider the QBO with those that do not consider the QBO, *Arpe et al.* [1998] and *Giorgetta et al.* [1999] have further shown that the QBO-related interannual variability of large-scale circulations over the Asian monsoon region and adjacent ocean basins may be caused by Rossby wave trains excited by tropical convection, which is influenced by the QBO. This remote influence of the QBO on the subtropical and extratropical circulations suggests that the QBO may also affect TC tracks. In the present study, it is newly found that TC tracks in the WNP are indeed sensitive to QBO phases.

## 2. Data

[5] The TC data are obtained from the Tokyo Typhoon Center and are for the period 1976–2007. All available TC tracks are used without separating them into those of tropical storms and typhoons. Considering that the TCs are the most active during the boreal summer, only extended summer months (June–October) are examined. The observed TC tracks are then grouped according to the QBO phases.

[6] The QBO phases are determined by using the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis data. The data are indexed by calculating the vertical wind shear between 50 and 70 hPa using the zonally and monthly averaged zonal wind data, as in work by *Huesmann and Hitchman* [2001]. This index is known to represent the QBO better than radiosonde observations at a single station (e.g., Singapore station). See *Huesmann and Hitchman* [2001] for further details. Each phase of the QBO is identified by the extreme values of the calculated index. For the time period 1976–2007, data for a total of 11 years are considered (see Table 1) for each of the two phases—the W-QBO and E-QBO. For the two QBO phases, the total number of TCs observed is 224 and 214, respectively. For

[1]Climate Physics Laboratory, School of Earth and Environmental Sciences, Seoul National University, Seoul, Korea.
[2]Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden.
[3]Department of Atmospheric and Oceanic Sciences, McGill University, Montreal, Quebec, Canada.


0094-8276/09/2009GL037163$05.00

**Table 1.** QBO Years Selected in This Study

| | Years Selected |
|---|---|
| Westerly QBO years | 1978, 1980, 1985, 1988, 1990, 1995, 1997, 1999, 2002, 2004, 2006 |
| Easterly QBO years | 1977, 1979, 1984, 1992, 1994, 1996, 1998, 2001, 2003, 2005, 2007 |

each QBO phase, composite analyses are performed for the TC tracks, outgoing longwave radiation (OLR), and background circulations. The OLR and background flows have been obtained from the National Oceanic and Atmospheric Administration [*Liebmann and Smith*, 1996] and the NCEP-NCAR reanalysis data [*Kalnay et al.*, 1996], respectively.

[7] The statistical significance for the TC passage is tested by using the non-parametric Mann-Whitney *U* test [*Mann and Whitney*, 1947]. The Mann-Whitney *U* test is particularly chosen in this study because the number of TC shows a non-Gaussian distribution [*Chu and Chen*, 2005; *Ho et al.*, 2006]. Although not shown, the significant areas in all composite fields determined by using this test are somewhat smaller than those obtained by using the bootstrap test.

## 3. Results

[8] Figures 1a and 1b show the spatial distribution of TC tracks in the WNP during the two QBO phases. To reduce confusion of many TC tracks, the contour map for the mean number of TCs for 5° × 5° grid box is overlapped in Figures 1a and 1b. It can be seen that more TCs occur over the East China Sea during the W-QBO (Figure 1a); on the other hand, during the E-QBO, more TCs occur over the eastern offshore of Japan (Figure 1b). This difference is more evident in Figure 1c, which shows the difference in the number of TCs between the W-QBO and the E-QBO for each 5° × 5° grid box. Two regions are especially found to have large differences, again indicating that more TCs approach the East China Sea (125°E–135°E, 25°N–35°N) during the W-QBO and the eastern offshore of Japan (150°E–160°E, 25°N–35°N) during the E-QBO. Considering the climatological mean number of TCs (about 2–3 for each 5° × 5° grid box), the difference between the numbers of TCs passing over these two regions is considerable and statistically significant at the 95% confidence level, as shown by the shaded region in Figure 1c.

[9] Composite analyses, however, do not necessarily isolate the QBO influence. For instance, the seesaw-like pattern shown in Figure 1c might also be related with the El Nino-Southern Oscillation (ENSO), which has been known to affect TC tracks. To filter out the possible influence of the ENSO, the same analyses were carried out by ignoring the ENSO years. It is found that although the total number of TCs is more closely related to the QBO if the ENSO years are omitted, the QBO-TC track relationship is essentially unchanged (figure not shown). This negligible influence of the ENSO on the QBO-TC track relationship is presumably because the QBO and ENSO indices are not correlated with each other for the analysis time period (correlation coefficient of 0.08 for the summer mean indices).

[10] The interannual variability of the number of TCs throughout the WNP, over the East China Sea, and over the eastern offshore of Japan is shown in Figure 2. The East China Sea and the eastern offshore of Japan are shown in dashed boxes in Figure 1c. It can be seen that the sum of the numbers of TCs over these two regions and the total number of TCs throughout the WNP do not correlate with the QBO index: the correlation coefficients are 0.04 and 0.03, respectively. These values are much smaller than those provided by *Chan* [1995], who has suggested an increase in the WNP TCs during the W-QBO and a decrease during the E-QBO. This discrepancy may arise from the different analysis periods considered in the two studies—1958–1988 in Chan's study and 1976–2007 in the present study. Although it is beyond the scope of this study, we notice that a similar disagreement has also been found in the North Atlantic basin; the QBO-TC relationship proposed by *Gray* [1984] is no longer valid and the QBO index is not utilized for seasonal forecasts of North Atlantic hurricanes any more

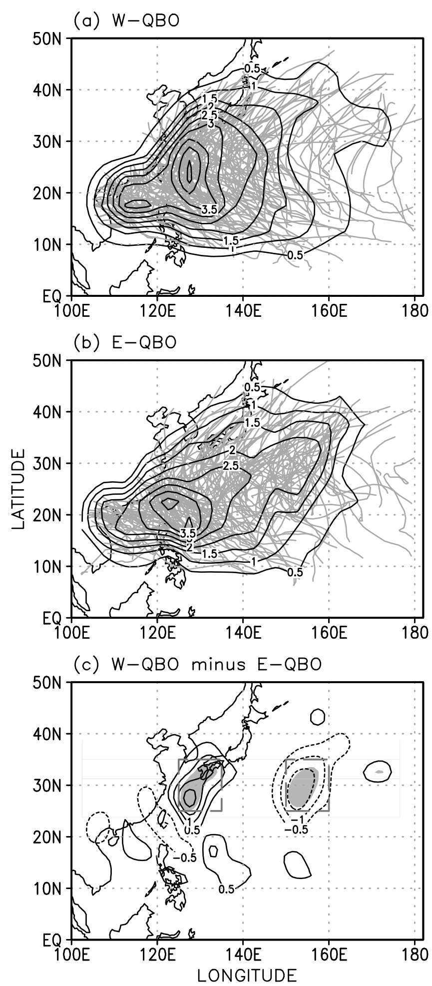


**Figure 1.** TC trajectories (gray lines) and the mean number of TCs for each 5° × 5° grid box (contour) during the (a) W-QBO and (b) E-QBO. (c) The difference in the number of TCs between the W-QBO and the E-QBO for each 5° × 5° grid box. The zero line is omitted. Unit is year$^{-1}$.

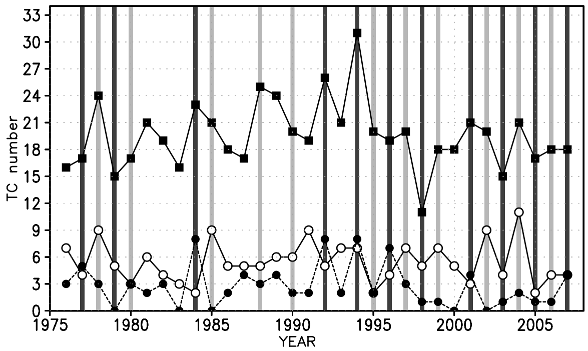


**Figure 2.** Time series of the total number of TCs over the WNP (solid squares), number of TCs over the East China Sea (125°E–135°E, 25°N–35°N) (open circles), and number of TCs over the eastern offshore of Japan (150°E–160°E, 25°N–35°N) (solid circles). The light (dark) gray vertical bars denote the W-QBO (E-QBO) phase.

(C. Landsea, personal communication, 2006). While further studies are needed, these results suggest that the QBO-TC relationship has changed with time worldwide.

[11] Despite the negligible difference in the total number of TCs between the two QBO phases, the TCs in the two regions (shown within boxes in Figure 1c) are considerably influenced by the QBO; the correlation coefficient between the TCs crossing the eastern offshore of Japan and the QBO index and that between the TCs crossing the East China Sea and the QBO index are −0.48 and 0.44, respectively. Moreover, although not significant, the numbers of TCs in these two regions are negatively correlated with each other. All these observations suggest that the QBO plays an important role in modifying TC tracks in the WNP.

[12] We next consider the possible reasons for the systematic difference in the TC tracks between the two phases of the QBO. There are at least three possibilities—changing location of TC genesis without changes occurring in individual TC tracks, changes in actual TC tracks, and both these changes occurring simultaneously. If the QBO modifies the conditions favorable for the TC genesis and shifts all TC activities eastward or westward, it could result in different TC tracks without any changes in individual TC tracks. Previous studies have suggested that changes in the cross-tropopause wind shear associated with the QBO affect TC genesis in various Ocean basins [*Gray et al.*, 1992; *Chan*, 1995]. Figure 3a presents the difference in the absolute wind shear between 50 and 200 hPa in the tropics. Similar to previous studies [e.g., *Collimore et al.*, 2003], a strong shear is found over Indonesia, while a weaker shear is observed over 150°E–180° and 10°N. However, this wind shear change does not affect the location and numbers of TC genesis in the WNP (figure not shown). Here, the location of TC genesis was identified by retracing the path of the TCs passing over the East China Sea and the eastern offshore of Japan.

[13] The difference in the background flow between the W-QBO and the E-QBO is presented in Figures 3b and 3c. The differences in the OLR (OLR′) and 500-hPa geopotential height (Z′) between the two QBO phases are observed to reveal changes in the tropical convection and mid-latitude circulation caused by the QBO. The tropospheric layer mean flow (i.e. steering flow) is also superimposed in Figure 3c as it is closely associated with TC tracks [*Chan and Gray*, 1982; *Kim et al.*, 2005]. It is evident that Z′ and the associated flow changes show a wave-train pattern, which exhibits a barotropic structure as similar to Figure 6 of *Giorgetta et al.* [1999]. These changes are statistically significant, and more importantly, they are consistent with the difference in the TC tracks between the two QBO phases; that is, more TCs occur along the western boundary with positive Z′ at 150°E and 30°N. This observation suggests that the different TC tracks in the two QBO phases are mainly a result of different background flows.

[14] To understand the change in the wave-train pattern in Figure 3c, we further examine OLR′ (Figure 3b). In the tropics, OLR′ has a positive value around Indonesia, but is negative around 150°E–180°, indicating a weak convection in the former region and a stronger convection in the latter region during the W-QBO. This response of convective

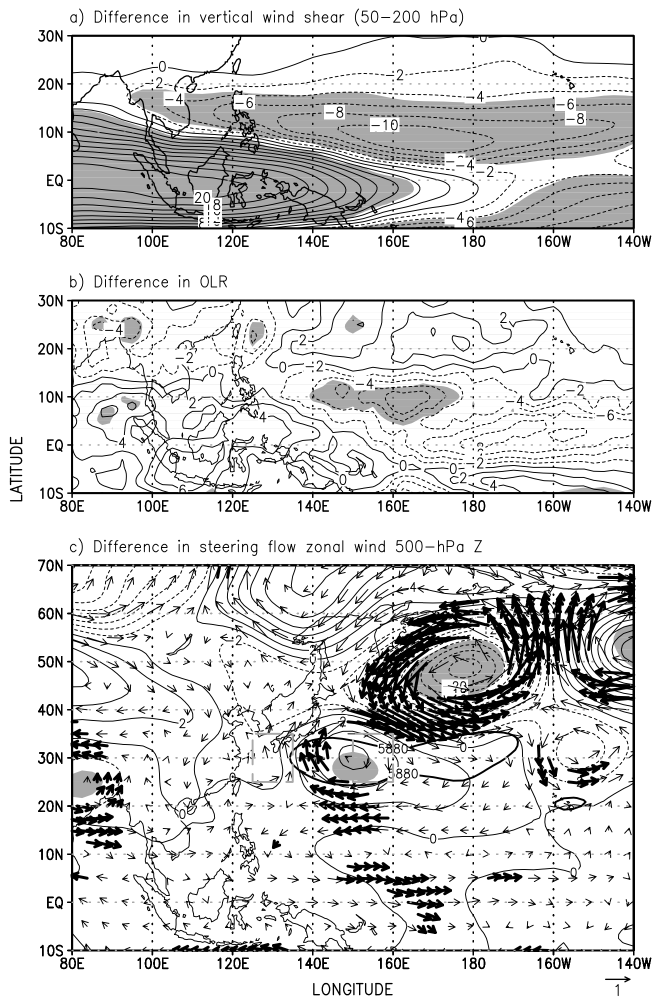


**Figure 3.** The difference in the (a) absolute vertical wind shear [m s$^{-1}$] between 50 and 200 hPa, (b) OLR [W m$^{-2}$], and (c) 500-hPa geopotential height [gpm] (contour) and the tropospheric layer-mean wind [m s$^{-1}$] (vector) between the W-QBO and the E-QBO. The thick contour in Figure 3c is the climatological 5880 gpm line at 500 hPa. The gray shadings and bold vectors denote regions significant at the 95% confidence level.

activities to the QBO is somewhat different from that inferred in a previous study [*Collimore et al.*, 2003]. By examining highly reflective cloud data, the authors of the previous study showed that although statistically insignificant, summer convection tends to be strong during the W-QBO around 150°E–180° and around Indonesia [see *Collimore et al.*, 2003, Figure 5c]. The discrepancy between these results and those of the present study might result from the different analysis periods (1971–1987 in the work by *Collimore et al.* [2003] and 1976–2007 in this study) and the different averaging periods (June–August in *Collimore et al.* [2003] and June–October in this study) considered.

[15] The wave-train pattern in Figure 3c is likely to be related to the strong convection around 150°E–180° and 10°N, and this convection might excite Rossby wave trains that propagate toward mid-latitudes, as suggested by *Giorgetta et al.* [1999]. The positive $Z'$ around 150°E and 30°N is in fact quite consistent with the Gill-type response of the flow to the enhanced convection around 150°E–180° and 10°N. Considering the climatological mean extension of subtropical WNP high in Figure 3c, this positive $Z'$ around 150°E and 30°N indicates more westward expansion of WNP high during the W-QBO. It has been suggested that the QBO may affect the tropical convection by modifying the tropopause height, static stability, and vertical wind shear in the upper troposphere. More specifically, on the basis of the zonally averaged field, it has been suggested that the W-QBO is accompanied by weak convection in the deep tropics in addition to a low tropopause, strong static stability, and strong vertical wind in the upper troposphere [*Collimore et al.*, 2003]. Although a detailed investigation is needed to establish the causal relationship between the W-QBO and these accompanying phenomena, the zonally asymmetric $OLR'$ that closely resembles the shear difference in Figure 3a suggests that the strong convection around 150–180°E and 10°N during the W-QBO is associated with a QBO-related wind shear change across the tropopause.

## 4. Discussion

[16] The present study shows that on the interannual time scale, TC tracks in the WNP are quite sensitive to the stratospheric QBO; they tend to frequently approach the East China Sea during the W-QBO and the eastern offshore of Japan during the E-QBO. This sensitivity is found to be related to changes in the extratropical circulation caused by the QBO. Analyses identical to those carried out in this study are currently being performed for other basins, including the eastern North Pacific and southern Indian Ocean. Preliminary results show that the QBO has a non-negligible influence on TC tracks even in these basins.

[17] The result of this study has important implications for seasonal forecasts of TCs. Since the QBO is quasi-periodic, it could be utilized for improving seasonal forecasts of TC activities in the WNP. However, the QBO is not represented adequately by general circulation models, and therefore, its application to dynamical forecasts is somewhat questionable. Nonetheless, we believe that our findings would be useful for making statistical forecasts.

[18] **Acknowledgments.** This work was funded by the Korea Meteorological Administration Research and Development Program under grant CATER 2006-4204. Hyeong-Seog Kim was supported by the BK21 project of the Korean government. Jee-Hoon Jeong's contribution is the contribution 24 from TELLUS, the Centre of Earth System Science at University of Gothenburg. The authors sincerely thank two anonymous reviewers for the critical valuable comments.

## References

Arpe, K., L. Dumenil, and M. A. Giorgetta (1998), Variability of the Indian monsoon in the ECHAM3 model: Sensitivity to sea surface temperature, soil moisture, and the stratospheric quasi-biennial oscillation, *J. Clim.*, *11*, 1837–1858.

Chan, J. C. L. (1995), Tropical cyclone activity in the western North Pacific in relation to the stratospheric quasi-biennial oscillation, *Mon. Weather Rev.*, *123*, 2567–2571.

Chan, J. C. L., and W. M. Gray (1982), Tropical cyclone movement and surrounding flow relationships, *Mon. Weather Rev.*, *110*, 1354–1374.

Collimore, C. C., D. W. Martin, M. H. Hitchman, A. S. Huesmann, and D. E. Waliser (2003), On the relationship between the QBO and tropical deep convection, *J. Clim.*, *16*, 2552–2568.

Chu, P.-S., and H. Chen (2005), Interannual and interdecadal rainfall variations in the Hawaiian islands, *J. Clim.*, *18*, 4796–4813.

Elsner, J. B., A. B. Kara, and M. A. Owens (1999), Fluctuations in North Atlantic hurricane frequency, *J. Clim.*, *12*, 427–437.

Giorgetta, M. A., L. Bengtsson, and K. Arpe (1999), An investigation of QBO signals in the east Asian and Indian monsoon in GCM experiments, *Clim. Dyn.*, *15*, 435–450.

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

Gray, W. M., C. W. Landsea, P. W. Mielke Jr., and K. J. Berry (1992), Predicting Atlantic seasonal hurricane activity 6–11 months in advance, *Weather Forecast.*, *7*, 440–455.

Ho, C.-H., J.-J. Baik, J.-H. Kim, D.-Y. Gong, and C.-H. Sui (2004), Interdecadal changes in summertime typhoon tracks, *J. Clim.*, *17*, 1767–1776.

Ho, C.-H., J.-H. Kim, H.-S. Kim, C.-H. Sui, and D.-Y. Gong (2005), Possible influence of the Antarctic Oscillation on tropical cyclone activity in the western North Pacific, *J. Geophys. Res.*, *110*, D19104, doi:10.1029/2005JD005766.

Ho, C.-H., J.-H. Kim, J.-H. Jeong, H.-S. Kim, and D. Chen (2006), Variation of tropical cyclone activity in the South Indian Ocean: El Niño–Southern Oscillation and Madden-Julian Oscillation effects, *J. Geophys. Res.*, *111*, D22101, doi:10.1029/2006JD007289.

Huesmann, A. S., and M. H. Hitchman (2001), The stratospheric quasi-biennial oscillation in the NCEP reanalyses: Climatological structures, *J. Geophys. Res.*, *106*, 11,859–11,874.

Jury, M. R., B. Pathack, and B. Parker (1999), Climatic determinants and statistical prediction of tropical cyclone days in the southwest Indian Ocean, *J. Clim.*, *12*, 1738–1746.

Kalnay, E., et al. (1996), The NCEP/NCAR 40-year reanalysis project, *Bull. Am. Meteorol. Soc.*, *77*, 427–471.

Kim, J.-H., C.-H. Ho, C.-H. Sui, and S.-K. Park (2005), Dipole structure of interannual variations in summertime tropical cyclone activity over east Asia, *J. Clim.*, *18*, 5344–5356.

Liebmann, B., and C. A. Smith (1996), Description of a complete (interpolated) outgoing longwave radiation dataset, *Bull. Am. Meteorol. Soc.*, *77*, 1275–1277.

Mukherjee, B. K., K. Indira, R. S. Reddy, and R. B. V. Murty (1985), Quasi-biennial oscillation in stratospheric zonal wind and Indian summer monsoon, *Mon. Weather Rev.*, *113*, 1421–1424.

Mann, H. B., and D. R. Whitney (1947), On a test of whether one of two random variables is stochastically larger than the other, *Ann. Math. Stat.*, *18*, 50–60.

Shapiro, L. (1989), The relationship of the QBO to Atlantic tropical storm activity, *Mon. Weather Rev.*, *117*, 1545–1552.

---

C.-H. Ho and H.-S. Kim, Climate Physics Laboratory, School of Earth and Environmental Sciences, Seoul National University, Seoul 151-747, Korea. (hoch@cpl.snu.ac.kr)

J.-H. Jeong, Department of Earth Sciences, University of Gothenburg, SE-405 30 Gothenburg, Sweden.

S.-W. Son, Department of Atmospheric and Oceanic Sciences, McGill University, Montreal, QC H3A 2K6, Canada.