Comment on "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment"

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Analyses of tropical cyclone records from the western North Pacific reveal that the recent increase in occurrence of intense typhoons reported by Webster *et al*. (Reports, 16 Sep. 2005, p. 1844) is not a trend. Rather, it is likely a part of the large interdecadal variations in the number of intense typhoons related to similar temporal fluctuations in the atmospheric environment.

Webster *et al*. (*1*) examined global tropical cyclone (TC) records and reported an increase in the number and proportion of intense TCs over the past three decades. They deliberately excluded pre-1970 data because of possible inaccuracy due to the lack of routine satellite observations. We show that, at least in the western North Pacific (WNP), this trend has actually reversed since 1998 and, more important, it is likely to be part of the large interdecadal variations of typhoon (*2*) activity that are related to similar variations in the atmospheric environment in which the typhoons are embedded.

We extracted the intensities of all WNP TCs for the period 1960 to 2004 from the Joint Typhoon Warning Center Web site (*3*). Note that because routine satellite coverage only began around 1965, some TCs before this time are likely to have gone undetected. Our reason for including part of the presatellite era [during which some aircraft reconnaissance was available (*4*)] will become clear later.

Many indices have been used to represent the average intensity of TCs in a given year (*5*–*7*). To facilitate comparison with the results in (*1*), we used two indices that are more biased toward intense typhoons: the potential destruction index [PDI, the sum of the cube of the maximum wind speed for each 6-hour period of all tropical storms and typhoons (*7*)] and the number of category 4 and 5 typhoons (NCAT45) on the Saffir-Simpson scale (*8*). We also examined the percentage of NCAT45 relative to the total number of typhoons.

The temporal variations of PDI and NCAT45 show very similar features (Fig. 1), with a peak in the 1960s, a minimum in the 1970s and early 1980s, a second higher peak in the early 1990s, a decrease in the late 1990s, and a gradual increase in the past few years. In other words, the number of intense typhoons goes through large interdecadal variations.

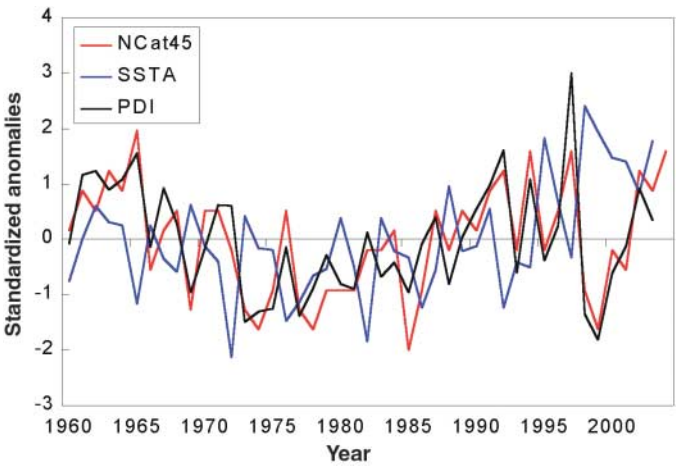

Fig. 1. Annual variations of the potential destruction index (PDI), the number of category 4 and 5 typhoons according to the Saffir-Simpson scale (NCAT45), and the SST anomalies within the area 5° to 30°N, 120° to 180°E averaged between May and November (SSTA). All series are standardized (deviation of the raw value from the mean over the entire period was calculated and then divided by the standard deviation).

Table 1. Number and percentage of typhoons in categories 4 and 5 for each of the three periods 1960–1974, 1975–1989, and 1990–2004.

	1960–1974	1975–1989	1990–2004
Number	105	75	115
Percentage	37	32	42

As in the Webster *et al*. study (*1*), we segmented the data record into three periods. In addition to the period between 1990 and 2004, a large number of category 4 and 5 typhoons also occurred between 1960 and 1974 (Table 1). However, the number of storms during this earlier period is likely to be an underestimate because some of the intense typhoons that never made landfall are likely to have gone undetected in the presatellite era. Better satellite data and analysis techniques in recent years might have also resulted in more accurate estimations of intensity, which might partly explain the larger number in the latter period.

To understand the interdecadal variations in typhoon activity, we examined the three parameters, discussed in (*5*), that are most significantly correlated with the number of typhoons: the rotational flow at around 1.5 km from the sea surface (or vorticity, VORT), the vertical wind shear of the east-west flow between 12 and 1.5 km (SHEAR), and the lower tropospheric moist static energy (MSE, representing the amount of thermodynamic energy available in the atmosphere). As shown in Fig. 2, the coefficients of the principal components (*9*) of these parameters go through interdecadal fluctuations very similar to those of typhoon intensity (represented by PDI). This result differs from Trenberth's conclusion (*10*) that "trends are evident in the environment in which Atlantic hurricanes form."

Thus, despite well-recognized uncertainties that exist in the typhoon intensity data in earlier years, an examination of the records for a longer period suggests that the increase in more intense typhoons reported in (*1*) is apparently only part of the large interdecadal variations of typhoon activity. In fact, such an increase is only obvious for the period from the late 1980s to the late 1990s (see Fig. 1), rather than a "sustained increase over a period of 30 years" as suggested in (*1*). Further, significant interdecadal variations in the atmospheric environment in which these typhoons are embedded are likely responsible for similar variations in typhoon activity, at least to some extent. A corollary of this conclusion is that, consistent with (*1*) and (*5*), local sea surface temperature (SST), which has been increasing since the 1970s, cannot explain the fluctuations in typhoon activity (see Fig. 1). Rather, atmospheric rotational flow, vertical wind shear, and thermodynamic energy are likely to be important determinants of typhoon intensity. In fact, the linear correlations between PDI and these three parameters range from 0.55 to 0.65. Because these factors go through such large interdecadal variations, it is difficult to conclude

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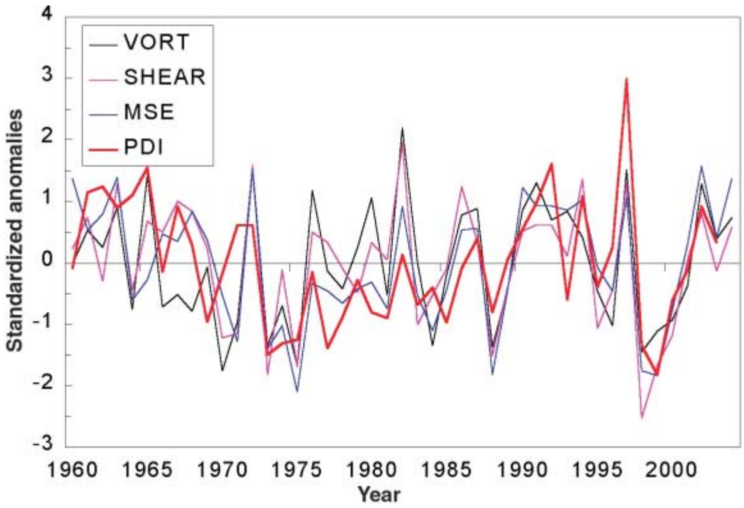

Fig. 2. Annual variations of the principal component coefficients of various parameters of the atmospheric environment. VORT, rotational flow at around 1.5 km from the sea surface; SHEAR, vertical wind shear of the east-west flow between 12 and 1.5 km, and MSE, moist static energy in the lower troposphere. All series are standardized (i.e., deviation of the raw value from the mean over the entire period was calculated and then divided by the standard deviation) values averaged between May and November each year. The time series of PDI from Fig. 1 is also reproduced for comparison.

that more intense typhoons are likely to occur in a warmer world.

References and Notes

1. P. J. Webster, G. J. Holland, J. C. Curry, H.-R. Chang, *Science* **309**, 1844 (2005).
2. Tropical storms have maximum wind speeds between 63 and 118 km hour^{-1}, and typhoons have maximum wind speeds greater than 118 km hour^{-1}.
3. Joint Typhoon Warning Center, www.npmoc.navy.mil/jtwc/best_tracks/wpindex.html
4. Aircraft reconnaissance of typhoons in the WNP was made by the Joint Typhoon Warning Center from 1959 to 1987 for selected TCs.
5. J. C. L. Chan, K. S. Liu, *J. Clim.* **17**, 4590 (2004).
6. S. J. Camargo, A. H. Sobel, *J. Clim.* **18**, 2996 (2005).
7. K. Emanuel, *Nature* **436**, 686 (2005).
8. A description of the Saffir-Simpson scale can be found at www.aoml.noaa.gov/general/lib/laescae.html
9. The Joint Typhoon Warning Center (*4*) used a statistical technique called principal component analysis (PCA) to represent the two-dimensional fields of each of these three parameters. With the PCA, the major temporal variations (called principal components) of a field can be identified. For each time period, a value (coefficient) can be assigned corresponding to the amplitude of the principal component in that period. In this particular case, a positive coefficient gives an atmospheric flow with a stronger rotational flow (VORT), a weaker vertical shear (SHEAR), and more moist static energy (MSE), all of which are favorable conditions for typhoon formation and intensification (*4*). The data for these fields come from the "reanalyses" of the U.S. National Centers for Environmental Prediction.
10. K. E. Trenberth, *Science* **308**, 1753 (2005).

11. Suggestions from C. Landsea of the U.S. National Hurricane Center and J. Kepert of the Australian Bureau of Meteorology are much appreciated. This work was supported by City University of Hong Kong grant 9610021.

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