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Using the tropical cyclone best track data from the U.S. Department of Defense's Joint Typhoon Warning Center (JTWC), Webster *et al.* [2005] found that between the two consecutive 15-year periods of 1975-1989 and 1990-2004, the percentage of typhoons in the western North Pacific meeting the definition of categories 4 and 5 on the Saffir-Simpson Hurricane Scale has increased from 25% to 41% of all typhoons in that ocean basin.

However, an analysis of the best track data from the Regional Specialized Meteorological Centre (RSMC) Tokyo (Japan) as well as that of the Hong Kong Observatory (HKO; Hong Kong, China) indicates that, in contrast to Webster *et. Al.'s* [2005] findings, there was no increase in western North Pacific category 4-5 typhoon activity. Furthermore, neither RSMC-Tokyo nor HKO best track data suggest an increase in western North Pacific tropical cyclone destructiveness as measured by the potential destructive index (PDI).

RSMC-Tokyo was established in 1989 under the aegis of the World Meteorological Organization (WMO) to provide operational as well as non-real-time tropical cyclone products in the western North Pacific. Its best track data Web site (http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/Besttracks/bst7680.txt) hosts best track data to 1951. These data show a decrease in the proportion of category 4-5 typhoons from 18% to 8% between the two periods of 1977-1989 and 1990-2004 (Table 1; intensity estimates in terms of sustained maximum winds first became available in RSMC-Tokyo best track data in 1977).

The result is the same if the analysis is extended to include 2005. This downward trend is statistically significant at the 5% level (all significant tests are based on t tests). The trend signifies a falling tendency in typhoon intensity in the western North Pacific in recent years, contrary to the results of Webster et al. [2005]. This falling trend was also noted by Kamahori et al. [2006] in their recent study on the variability in intense cyclone days in the WNP using RSMC-Tokyo's best track data.

HKO also is a WMO-designated tropical cyclone warning center for an assigned area of responsibility (AOR) in the western North Pacific. The best track database that it compiles goes as far back as 1884, and best track data from 1987 and onward are available online (http://www.weather.gov.hk/publica/pubtc.htm/). As with the data from RSMC-Tokyo, HKO best track data show a decrease in the proportion of category 4-5 typhoons, from 32% to 16%, between 1975-1989 and 1990-2004. This result, statistically significant at the 5% level, also remains unchanged if the end year is extended to 2005.

Accounting for Discrepancies

One likely reason for the discrepancy in the reported trends in category 4-5 typhoons obtained from the JTWC and RSMC best track databases is the use of one-minute average wind speeds to estimate tropical cyclone intensity by JTWC and 10-minute averages by RSMC-Tokyo. This difference results in JTWC intensity estimates typically being higher for tropical cyclones with maximum winds exceeding 100 knots.

Another difference is that RSMC-Tokyo uses a Dvorak technique that was modified according to the study of Takemura and Osano [1989] to assess tropical cyclone intensity. This modified technique causes tropical cyclones below typhoon strength to be assessed as stronger than what the traditional Dvorak technique would give, and causes intense typhoons to be assessed as weaker. These variations already have been pointed out in the U.S. Naval Research Laboratory Tropical Cyclone Forecasters Reference Guide (available at http://www.npmoc.navy.mil/jtwc/pubref/References/GUIDE/chap1/se100.htm).

HKO uses the Dvorak technique without modification but multiplies the one-minute wind speed by a factor of 0.9 to convert to 10-minute averages. HKO's best track intensity estimates also take into account available observations from ships and land stations nearby as well as other information, such as ocean surface winds from the Sea-Winds scatterometer on board QuickSCAT.

The discrete nature of the Saffir-Simpson scale [Kantha, 2006], whereby

a small difference in the maximum winds in a typhoon might cause that typhoon to be assigned a different Saffir-Simpson category, might yet be another contributing factor to the differences in trends. On satellite images, a typhoonusually is identified by the presence of an eye, whereas the assignment of intensities beyond that is probably more subjective. This observation is supported by Figure 1, which shows that the annual total number of all typhoons extracted from the three best track data sets agrees closely with each other, but the series of category 4-5 typhoons diverge.

Typhoon Nida, which occurred in the western North Pacific in May 2004, can serve as an illustration of the classification of the same typhoon into different Saffir-Simpson categories by different best track data.

JTWC, RSMC-Tokyo, and HKO all classified Nida as a typhoon. On the basis of maximum one-minute winds of 140 knots given by JTWC best track intensity, Nida would be a Category 5 typhoon. However, RSMC-Tokyo best track data give Nida's maximum 10-minute winds as 95 knots. Comparing this intensity with the equivalent 10-minute wind thresholds in the Saffir-Simpson scale for Category 3 of about 85-99 knots (converted from the corresponding one-minute thresholds using a factor of 0.88 as suggested in Table A-2 of the Tropical Cyclone Forecasters Reference Guide) would make Nida a Category 3 typhoon. Similarly, the maximum 10-minute winds of 105 knots given by HKO best track data would place Nida in Category 4, the equivalent 10-minute wind thresholds in the Saffir-Simpson scale for Category 4 being about 100-119 knots. Thus, in a category 4-5 trend analysis, Nida would be counted using JTWC and HKO best track data, but excluded using that of RSMC-Tokyo. Another example is Typhoon Herb in 1996 (described below in connection with tropical cyclone related monetary damage).

Typhoon Destructiveness

In terms of PDI, which is the sum of the cube of the maximum wind speed for all tropical storms and typhoons [Emanuel, 2005], JTWC best track data show a statistically significant (at the 5% level) increase between the two 15-year time periods, RSMC-Tokyo best track data show a slight increase that is not statistically significant, while HKO best track data show a slight decrease that also is not statistically significant (Table 2).

If the accumulated cyclone energy (ACE)-the sum of the square of the maximum wind speed for all tropical storms and typhoons – is considered, then one again finds for the western North Pacific that only JTWC best track data show a statistically significant upward trend between 1979-1989 and 1990-2004 (Table 3). No statistically significant change is elicited from RSMC-Tokyo and HKO best track data. The results for RSMC-Tokyo and HKO are unchanged if extended to 2005. These results are in line with those reported in a recent study by Klotzbach [2006], who found that the ratio of the mean ACE in 1996-2005 to that of 1986-1995 was about 0.95 using JTWC best track data. The respective ratios using RSMC-Tokyo and HKO best tracks are about 0.89 and 0.91.

Annual tropical cyclone-related damage in monetary terms (not normalized) sustained by the 14 member countries and territories of the Economic and Social Commission for Asia and the Pacific (ESCAP)/WMO Typhoon Committee in the western North Pacific (see http://www.tcsphilippines.org/aboutus/aboutUs.htm) are available from the annual ESCAP/WMO Typhoon Committee Annual Review (the 2002 edition can be accessed from http://www.wmo.ch/web/www/TCP/Publications/PTC-Review2002.pdf) from 1985 onward.

This data is plotted in Figure 2 together with the annual PDIs computed from the JTWC, RSMC-Tokyo, and HKO best tracks. One can see that the peak damage sustained in 1996-due mainly to the damage inflicted by Typhoon Herb in China in late July and early August of that year, which accounts for some 60% of the total damage sustained by ESCAP/WMO members that year – does not coincide with peak PDIs. Herb was a Category 5 typhoon based on JTWC best track maximum one-minute wind speed of 140 knots. However, both RSMC-Tokyo and HKO best tracks give maximum 10-minute winds of 95 knots for Herb, making it a Category 3. The possibility for the same typhoon to be categorized differently also implies that different best track data might lead to different results in the study of damage associated with category 4-5 typhoon activity.

The correlation coefficients between the annual tropical cyclone-related

damage in monetary terms and the annual PDIs are 0.47, 0.38, and 0.22 for JTWC, RSMC-Tokyo, and HKO best track data, respectively. Of these three correlation coefficients, only the correlation with the JTWC PDI is statistically significant (marginally at the 5% level) using the t test. The 1996 data have been excluded in the correlation analysis, as otherwise the monetary damage data do not meet the condition of normality required for hypothesis testing of statistical significance. No significant correlation was found for the annual ACEs. It is useful to remember that losses depend not only on the level of tropical cyclone activity or intensity, but also on other factors such as the degree of community preparedness and the effectiveness of warning systems.

Likely Implications

There is much discussion recently as to whether the trends found in tropical cyclone intensity and potential destructiveness are linked to human-induced warming environment or to natural multidecadal oscillations [Webster et al., 2005; Emanuel, 2005; Landsea, 2005; Pielke, 2005; Chan, 2006; Anthes, 2006; Mann and Emanuel, 2006]. However, from the divergence in the trends obtained from the JTWC, RSMC-Tokyo, and HKO best track data, it would appear that the causes of discrepancies in these trends need to be better understood and the trends themselves need to be further ascertained so that the attribution of physical causes can be made more unequivocally.

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Table 1. Percentage of CAT45 typhoons for different periods using HKO's and RSMC-Tokyo's best track data. For both RSMC-Tokyo and HKO, the downward trend is statistically significant at the 5% level (marked with *). Statistical significance was not indicated in Webster *et al*. (2005).

Webster *et al*. (2005)		RSMC-Tokyo		HKO	
Period	Percentage	Period	Percentage*	Period	Percentage*
1975-1989	25	1977-1989	18	1975-1989	32
1990-2004	41	1990-2004	8	1990-2004	16

Table 2. Power Dissipation Index (PDI, in unit of 10^6 kt^3) for different periods using different best track data. Only JTWC's trend is statistically significant at the 5% level (marked with *).

JTWC		RSMC-Tokyo		HKO	
Period	PDI*	Period	PDI	Period	PDI
1975-1989	227	1977-1989	159	1975-1989	164
1990-2004	319	1990-2004	188	1990-2004	155

Table 3. Accumulated Cyclone Energy (ACE, in unit of 10^4 kt^2) for different periods using different best track data. Only JTWC's trend is statistically significant at the 5% level (marked with *).

JTWC		RSMC-Tokyo		HKO	
Period	ACE*	Period	ACE	Period	ACE
1975-1989	279	1977-1989	220	1975-1989	224
1990-2004	365	1990-2004	264	1990-2004	226

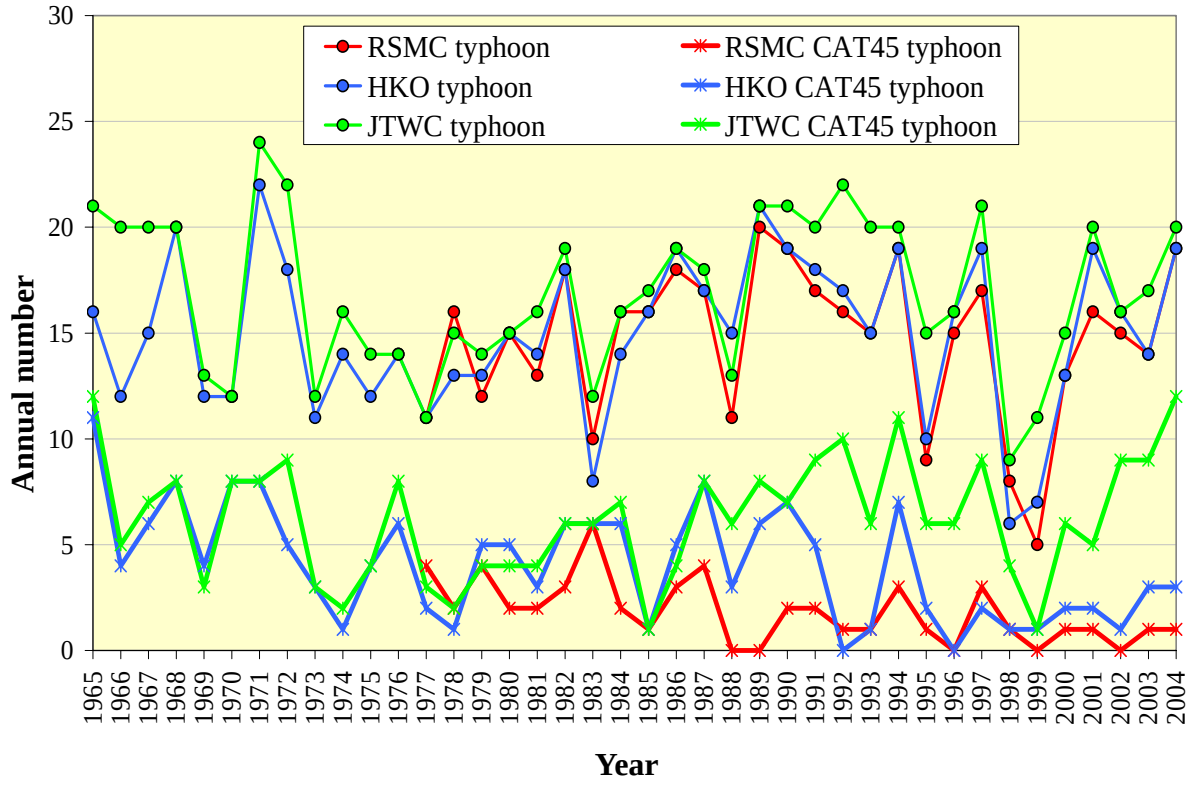

Fig. 1. Annual number of typhoons and category 4-5 typhoons in the western North Pacific as compiled from the Joint Typhoon Warning Center (JTWC), the Regional

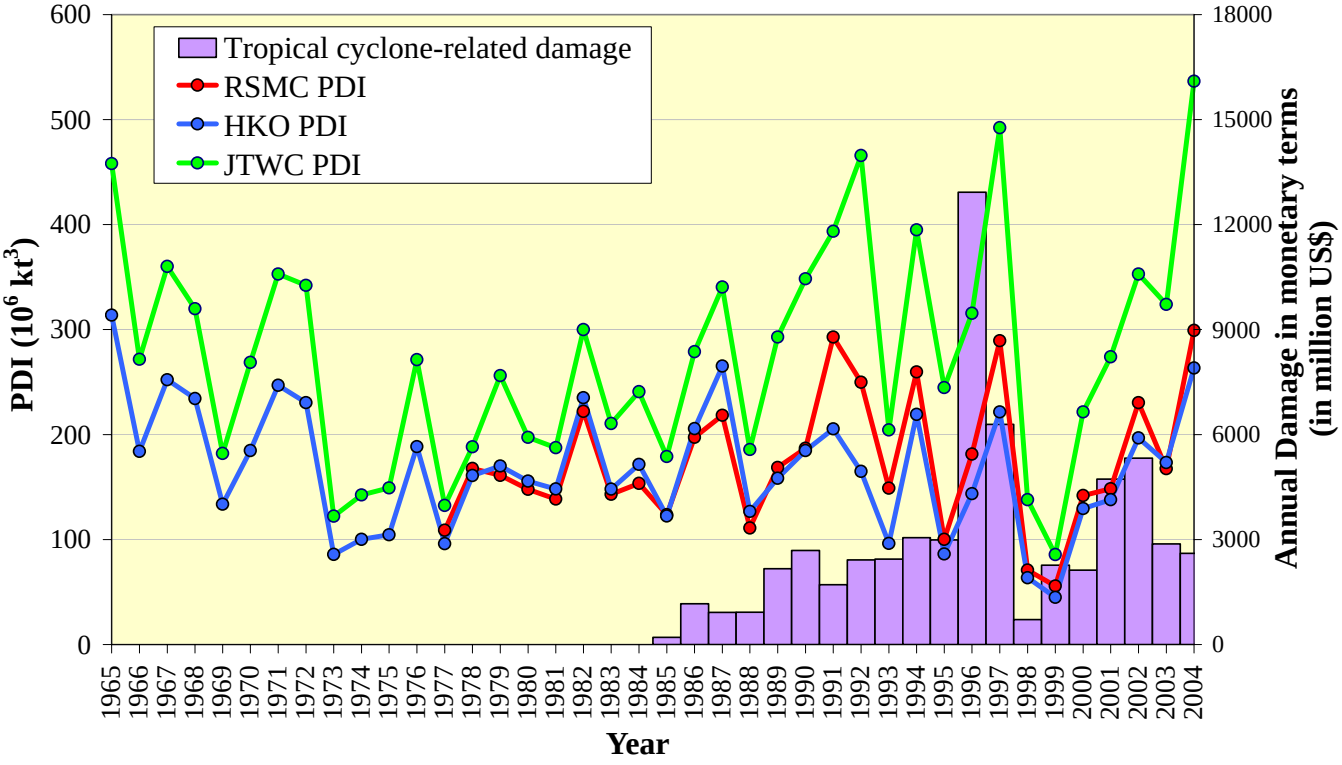

Fig. 2. Annual Power Dissipation Index (PDI) using different best track data and tropical cyclone-related damage sustained by ESCAP/WMO Typhoon Committee Members in the WNP.