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

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Although Chan makes several valid points, his analysis confuses relationships associated with the long-term variations with those associated with shorter term variability (interannual and decadal). We present an analysis that clarifies the observations from the western North Pacific.

The results of Webster *et al*. (*1*) considered the global data set of hurricanes available from the satellite era, since 1970. A longer data set is certainly desirable, and careful analysis of the data in individual ocean basins and its interpretation in terms of the local modes of natural variability is needed to sort out the mechanisms responsible for the variations in hurricane characteristics. In his analysis of data from the western North Pacific since 1960, Chan (*2*) raises two critiques of our study: (i) that there is no trend in western North Pacific typhoon intensity and that the apparent trend we observed is part of a large interdecadal oscillation; and (ii) that there is a negative correlation of typhoon intensity with local tropical sea surface temperature (SST) and a positive correlation of typhoon intensity with atmospheric vorticity, wind shear, and moist static energy.

The data set used by Chan for the western North Pacific (*3*) is available back to 1945; this data set was also used by Emanuel (*4*) in his recent study. Emanuel concluded that the wind speeds in the data set before 1973 in this region were too high (*5*, *6*). The need for reprocessing the western North Pacific tropical cyclone data set is very clear (*7*).

Figure 1 shows the time series (smoothed by a 5-year running mean) of tropical storm characteristics in the western North Pacific for the period 1960 to 2004: total number of named tropical storms; number of category 4 and five hurricanes (NCAT45); percentage of NCAT45 relative to the total number of hurricanes (%NCAT45); and SST in the genesis region as described in (*1*).

The 5-year running mean filters interannual variability. The annual typhoon activity in the western North Pacific is generally higher during an El Niño year and lower during a La Niña year. The La Niña years of 1999, 1998, 1995, 1988, and so on, are clearly seen in Chan's figure 1 as warm anomalies that are associated with a lower frequency of NCAT45. Thus, the atmospheric changes associated with El Niño–Southern Oscillation (ENSO) events give rise to an anticorrelation (correlation coefficient of –0.3) between storm intensity and SST, which is not related to longer term variability trends. As with the ENSO, Fig. 1 shows that decadal-scale oscillations in the number of tropical storms and NCAT45 are anticorrelated with SST, a result of variations in atmospheric dynamics. The decadal oscillations in SST are referred to as central tropical Pacific variability (*8*, *9*) and have been hypothesized to be associated with a self-sustaining oscillation between the atmosphere and the ocean. The interdecadal oscillation referred to as the Pacific Decadal Oscillation (PDO) changed to a cool phase in 1946, to a warm phase in 1976, with 1998-1999 in a cool phase, and a subsequent return to the warm phase (*10*, *11*). The transition years 1946, 1976, and 1998 are seen as minima in both the number of tropical storms and NCAT45.

There are unquestionably complex and strong signals of natural variability in both the hurricane statistics and SST in the western North Pacific. However, the central tenet of our study that there is a shift in the distribution of hurricane intensity with increasing SST is not refuted by these data. The variable %NCAT45 is a far better indicator of this distribution than NCAT45 used by Chan, because NCAT45 is dominated by the large variations in total number of tropical storms. During the 1960s, both SST and %NCAT45 were relatively high.

Each of the ocean basins considered in (*1*) has different characteristic modes of natural internal variability. Although the atmospheric parameters of vorticity, wind shear, and moist static energy show a positive correlation with NCAT45 in figure 2 in (*2*), there is no statis-

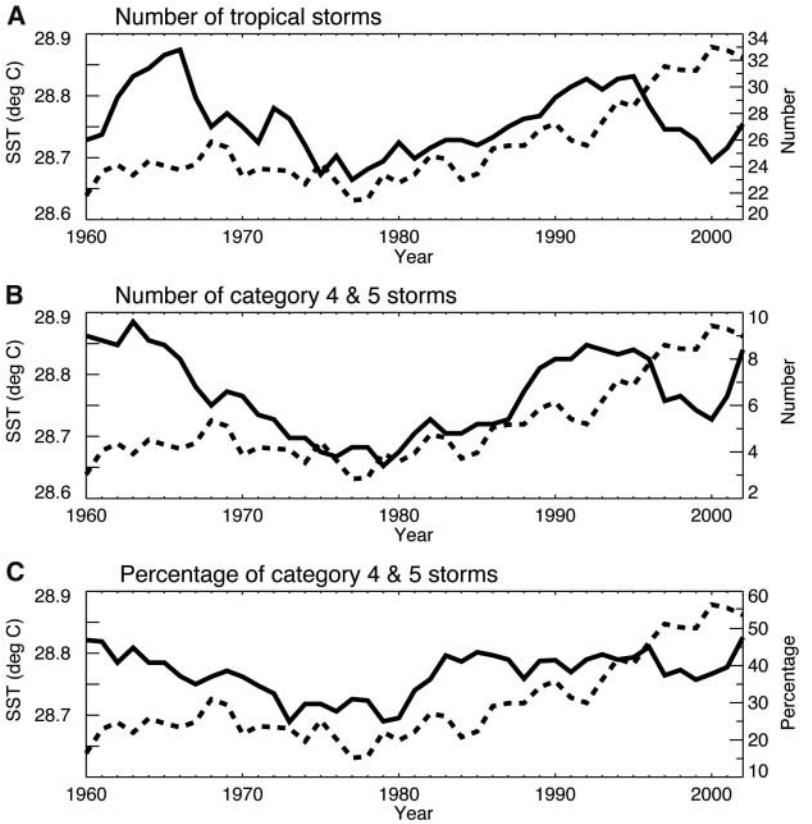

Fig. 1. SST during the typhoon season in the Northwestern Pacific Ocean (left axes, dashed lines) versus (**A**) total number of tropical storms, (**B**) number of category 4 and 5 storms, and (**C**) percentage of category 4 and 5 storms (right axes, solid lines).

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tically significant trend in any of these parameters that could be associated with a trend or multidecadal variability in NCAT45 or %NCAT45. The correlation of %NCAT45 with SST is clearly seen on multidecadal time scales since 1960. Should SSTs continue to rise under anthropogenic forcing, it is reasonable to expect that this relationship will be maintained and that there will be an associated increase in the intensity of typhoons.

References

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