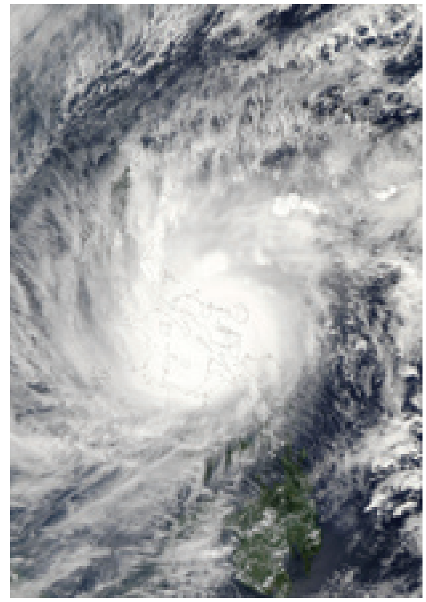
Forecasting the Intensity of Tropical Cyclones



Super Typhoon Durian (*courtesy NASA Earth Observatory*).

Forecasting the intensity of tropical cyclones remains a serious challenge for meteorologists. Track forecasts are much more likely to be accurate than intensity forecasts. A source of guidance for calculating the intensity that a tropical cyclone can reach is the theoretical concept of maximum potential intensity. This is an estimate of the highest intensity (typically characterized by the strongest surface wind) a storm can have and still fall within the constraints of thermodynamics. The maximum potential intensity is a function of such factors as atmospheric temperature structure and the temperature of the ocean surface layer. A simulated cyclone might reach theoretical maximum potential intensity in a geographically uniform environment and weak vertical shear. Few real storms, though, ever reach the theoretical maximum. The strength of real storms is capped by dynamical factors such as the environmental vertical wind shear and the movement of the storm.

IPRC scientist **Yuqing Wang**, together with his visitor **Zhihua Zeng** from the Shanghai Typhoon Institute and **Chun-Chieh Wu** from the National Taiwan University, analyzed data on western North Pacific tropical cyclones in order to get a better grasp of the relationship between the maximum intensity each storm actually reaches and environmental factors. They analyzed the "best track" data for tropical cyclones produced by the Joint Typhoon Warning Center from 1981 to 2003, together with Reynolds sea surface temperature (SST) and NCEP-NCAR reanalysis data. In addition to the usual measures for calculating maximum potential intensity—temperature of the ocean surface and of the outflow of air at the top of the storm—they looked at the impact of environmental vertical shear and storm translational speed (the speed at which a storm moves) on intensity.

Figure 1 shows the scatter diagram for intensity (the maximum surface winds), observed every six hours, plotted against the SST at the storm center for storms that packed at least 17 m/s wind. Higher SST is associated with increasing intensity, at least up to 27°C. The scatter is large, however, with weak storms found fairly often over high SST

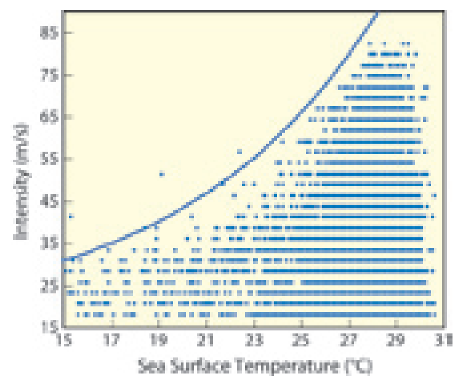


Figure 1. Scatter plot of tropical cyclone intensity (maximum surface sustained wind in m/sec) as a function of SST (°C) over the western North Pacific during 1981 to 2003. The intensity was corrected by subtracting the storm translational speed. The solid curve represents the empirical maximum potential intensity (m/s) derived for the western North Pacific. Adapted from Zeng, Wang, and Wu, *Mon. Wea. Rev.*, 2007.

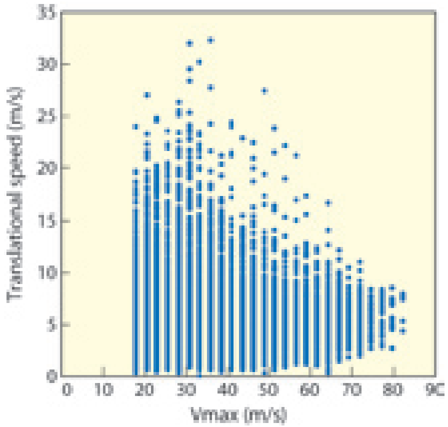


Figure 2. Scatter plot of tropical cyclone intensity (m/s) as a function of translational speed in m/s from the best track intensity data over the western North Pacific during 1981 to 2003. The most intense storms occur within a narrow range (between about 3–8 m/s). Adapted from Zeng, Wang, and Wu, *Mon. Wea. Rev.*, 2007.

during the early stages of formation, while very intense storms often have moved poleward away from the very warm ocean surfaces over which they first formed. Wang and his colleagues fitted an exponential function to the most intense storms at each SST value, shown as the solid curve in Figure 1. This represents a simple empirical determination of a maximum realizable intensity, which turns out to be considerably less than the theoretical maximum potential intensity.

The scientists analyzed in a similar way the storm intensity as a function of translational speed, the speed at which storms move (Figure 2). The most intense storms occur within a narrow range, between about 3 and 8 m/s. The overall dependence of intensity on storm speed can be readily understood. When a storm moves slowly,

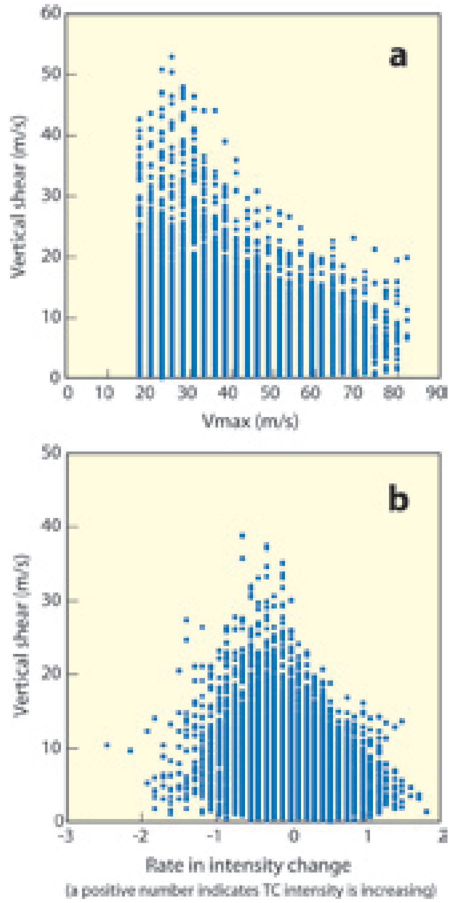


Figure 3. (**a**) Scatter plot of tropical cyclone intensity (m/s) against vertical shear (m/s) from the best track data over the western North Pacific during 1981–2003. (**b**) Scatter plot of intensity-change rate (m/s/hour) and vertical wind shear (m/s). The most intense storms are found in weaker vertical shear (20 m/s or less). Few storms intensified in shear greater than 20 m/s. Adapted from Zeng, Wang, and Wu, *Mon. Wea. Rev.*, 2007.

the winds will have time to stir up the ocean and bring cool water to the sea surface, preventing strong intensification. When a storm moves quickly, its structure typically becomes asymmetric, again limiting its ability to intensify.

Wang and his colleagues also plotted storm intensity against the environmental vertical wind shear, which was taken to be the difference in area-averaged winds between the 200 and 850 hPa levels (Figure 3a). They furthermore plotted the rate of change in storm intensity (computed from the 6-hour data) as a function of the environmental wind shear (Figure 3b). The plot shows that generally the most intense storms are found in weaker vertical shear. There is a fairly well-defined critical point: hardly any storms intensified when the environmental shear was greater than 20 m/s.

On the basis of these analyses, Wang and his colleagues developed a new empirically based maximum intensity formula. The formula includes, in addition to SST and the temperature of the air flowing out the top of the tropical cyclone, the effects of translational speed and vertical wind shear. This provides an explicit representation of the thermodynamic and environmental dynamic factors that determine a storm's maximum realizable intensity.

Of course, most storms still do not reach this new maximum, and other factors must be limiting the intensity of tropical cyclones. A particularly important factor is the response of the inner core of the tropical cyclone to environmental conditions and the underlying ocean cooling. With help of the numerical hurricane model he has developed, Wang is now investigating how the internal structure of a tropical cyclone interacts with environmental factors to affect the ultimate storm strength.

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