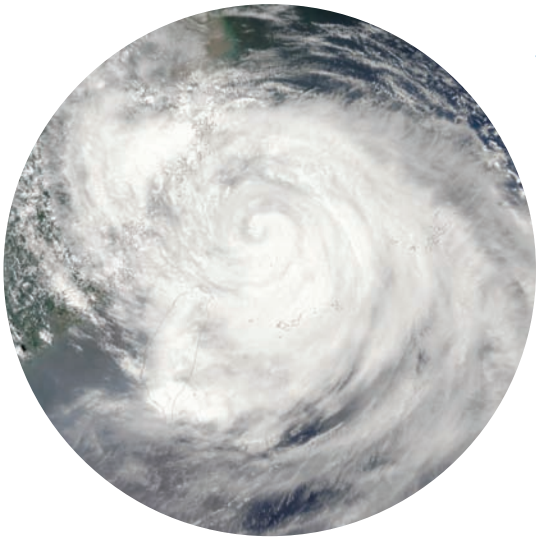

What Controls Tropical Cyclone Size and Intensity?

The white shimmering clouds that spiral towards the eye of a tropical cyclone can tell us much about whether or not the storm will intensify and grow larger, according to computer modeling experiments conducted by IPRC's **Yuqing Wang**. Scientists have speculated for some time that the outer spiral rainbands could impact significantly a storm's structure and intensity, but this process is not yet completely understood. With the cloud-resolving tropical cyclone model he had developed, the TCM4, Wang conducted various experiments in which he was able to increase or decrease the activity of the outer rainbands. These changes impacted the strength and size of the storms the model generated.

In their mature phase, strong tropical cyclones typically develop a structure characterized by a clear eye at the center and an eyewall with strong convection and high winds surrounded by the rainbands. The inner rainbands are located about two to three times the radius of maximum wind; beyond lie the outer rainbands. Some tropical cyclones are midgets that stretch less than 200 km across, others grow into giants, their rainbands extending over hundreds of km. The largest tropical cyclones are seen in the western Pacific; over the Atlantic they tend to be smaller.

The amount of rain produced in the outer spiral rainbands is closely related to heating or cooling rates due to evaporation or condensation in the rainbands. In some experiments, Wang changed TCM4's cooling rate in the outer rainbands by changing the rate of melting of snow and graupel and the rate of evaporation of rain, melting snow and graupel. In other experiments, he changed the heating rate by changing the rate of condensation, moisture-deposition

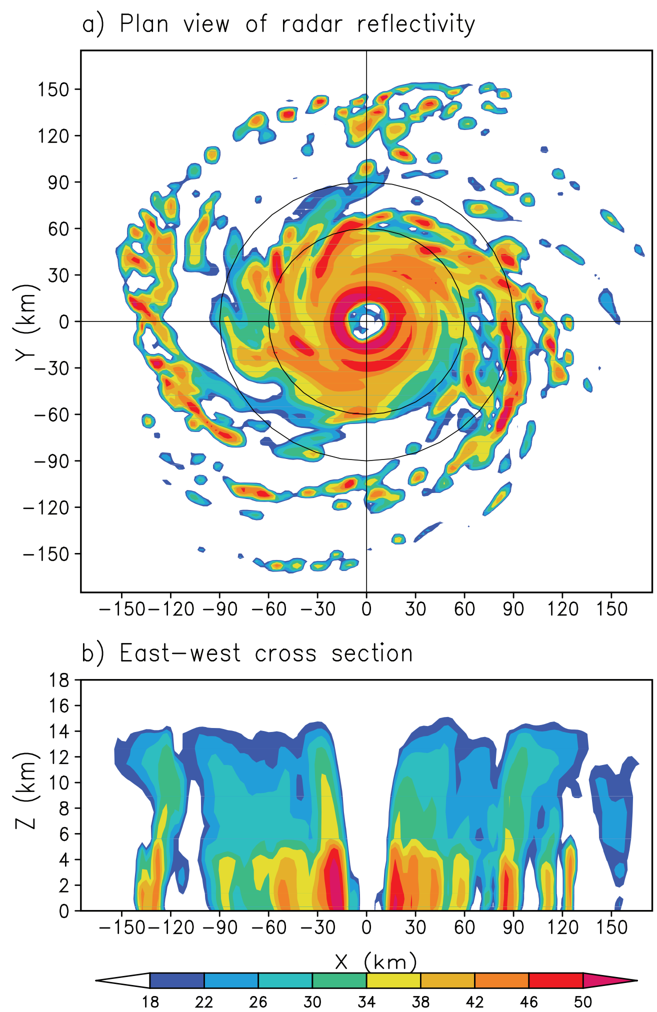

Figure 1. Model-simulated radar reflectivity (in dBZ) after 9 h of simulation in the control experiment (after the model has been spun up for a tropical cyclone-like vortex on an f-plane in a quiescent environment): (a) plan view and (b) vertical cross-section along the east-west direction across the storm center. Two circles in (a) show the radii of 60 km and 90 km from the storm center, respectively.

and freezing. For the control storm he did not tinker with the heating and cooling rates (Figure 1). By systematically

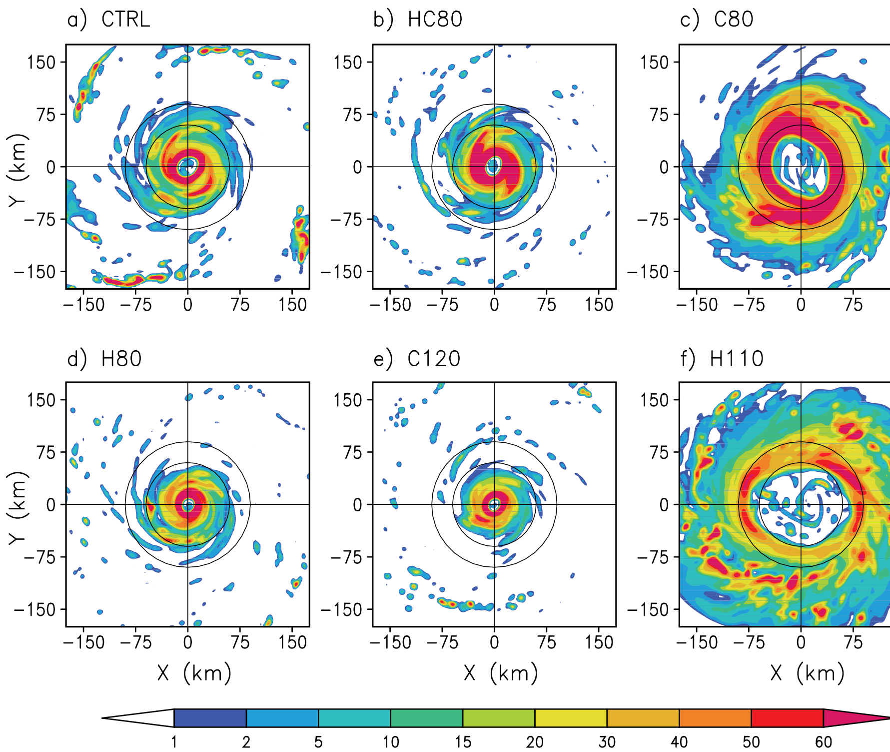

Figure 2. Plan views of rain rate (mm/h) of the tropical cyclones simulated in TCM4 after 120 h of simulation: (a) CTRL with default settings, (b) in HC80, both heating and cooling rates are reduced by 20%, (c) in C80, cooling rate is reduced by 20%, (d) in H80, heating rate is reduced by 20%, (e) in C120, cooling rate is increased by 20%, and (f) in H110, heating rate is increased by 10%. The changes in the experimental cyclones were introduced beyond a radius of 60 km from the storm center. The two circles in each panel show 60-km and 90-km radius from the storm center, respectively.

altering heating and/or cooling rates associated with the rainband activity in the TCM4 storms, he was able to study how these manipulations impacted the evolution of storm intensity, size, and structure.

The most powerful storm in Wang's suite of experiments reached a central surface pressure of 887 hPa and a wind speed of about 280 km per hour, compared to the control storm of 905 hPa and 250 km per hour (Figure 2). To create this intense storm, Wang had lowered both the heating and cooling rates in the outer rainbands. It was probably the lowered heating rate that dampened the rainbands' activity and made the winds so intense, for in the only other storm with winds more powerful than the control storm, Wang had increased the cooling rate. The storm with increased heating rate never reached the wind speed of the control storm. In short, cooling in the outer spiral rainbands intensifies winds; heating in the outer spiral rainbands puts a lid on their intensity—at least in TCM4.

Decreasing the heating rate—or increasing the cooling rate—not only made for more intense winds but also for storms with a smaller eye and a more compact core (eye, eyewall, and moat) than the control storm. Increasing the heating rate, on the other hand, resulted in tremendous growth of the eye and eyewall and the biggest storm in the experiment. This was also the storm that developed a typical secondary, or concentric, eyewall as a result of the axisymmetrization of the inward propagating spiral rainbands. As the secondary eyewall formed and contracted, the inner eyewall started to weaken and was eventually replaced by the secondary eyewall. A second concentric eyewall cycle took place, in which the secondary eyewall formed, and as it contracted, the inner eyewall weakened and broke up, leaving a very large, single-eye structure.

Wang sought to understand why altering the cooling or heating rate alters the intensity and size of a tropical cyclone. For one thing, he found that cooling increases the downdrafts in outer spiral rainbands. This finding is supported by research by MIT's **Kerry Emanuel**, who showed that in tropical cyclones, shallow clouds with little rain lead to strong downdrafts. The downdrafts keep the boundary layer relatively dry and reduce deep convection outside the core, concentrating the net convective mass flow in the inner core and increasing intensity. Such downdrafts outside the inner core result in higher pressure outside the core, increasing the radial pressure gradient and accelerating the winds near the core. Thus, rather than limiting the intensity of storms, as has been proposed by others, downdrafts in the outer rainbands act to keep the inner core compact with strong winds.

For another, the TCM4 experiments showed that storm changes in structure and intensity were due mostly to hydrostatic pressure adjustment in response to changed cooling or heating rates in the outer spiral rainbands: heating outside the core decreased the surface pressure outside the core, decreasing the horizontal pressure gradient across the radius of maximum wind and weakening the winds in the lower troposphere. Heating also expanded the inner core of the storm. In contrast, cooling outside the core increased surface pressure outside the core and the pressure gradient across the radius of maximum wind, resulting in stronger winds.

In a real cyclone, the cooling or heating rate of the outer rainbands is affected by the relative humidity of the surroundings—the more moisture available, the more heating can occur. The TCM4 experiments therefore imply that large storms are more likely to develop in an environment with high relative humidity that leads to condensation, freezing and deposition, and thus to more heat in the outer rainbands. Small, intense storms are more likely to develop in a drier environment in which evaporation of cloud droplets, rain water, and melting snow and graupel are more likely to cool the rainbands. These two scenarios would explain, at least partly, why hurricanes travelling across the Atlantic tend to be smaller and more intense than the typhoons that travel across the western Pacific. North Atlantic hurricanes are often affected by the dry Saharan Air Layer, whereas the storms in the western Pacific usually form in the moisture-rich, low-pressure monsoon trough. The high background vorticity in the western Pacific monsoon trough may also be conducive to large storms. The tropical cyclones that affect Hawai'i tend to be small because of the shallowness of the moist surface layer and the low humidity above the trade wind inversion.

The difference in the large-scale moisture fields over the North Pacific and the North Atlantic can also explain why **D. Hawkins** and **M. Helveston** at the Naval Research Laboratory in Monterey found that about 80% of the intense tropical cyclones over the western North Pacific develop a concentric eyewall in their lifetime compared to only about 40% of the intense ones in the North Atlantic.

Wang's tropical cyclone modeling study helps to pinpoint the processes that control a tropical cyclone's intensity and overall structure: cooling seems to favor powerful winds and a compact storm; heating, in contrast, seems to favor large inner cores but limits wind intensity. Since heating or cooling outside the inner core region depends on the environmental relative humidity near the core, the TCM4 results indicate that the presence of a deep, moist layer near the core should make for large tropical cyclones, annular hurricanes, and concentric eyewalls, whereas a dry environment should produce small, compact tropical cyclones without concentric eyewalls. What is needed now are observational studies to confirm these implications from the present idealized TCM4 simulations.

Hurricane hunter Dewie Floyd flies into the eye of Hurricane Katrina. Photo courtesy of NOAA.

This story is based on Wang, Y., "How do outer spiral rainbands affect tropical cyclone structure and intensity?" which will appear in the Journal of the Atmospheric Sciences.

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