Among the various natural hazards facing humankind, tropical cyclones (TCs) are a leading cause of loss of human life and property. The formation, movement, and intensification of TCs are known to be sensitive to the large-scale weather and climate environment in which they are embedded. Hence, trying to project the anticipated changes in the climatology of TCs in response to global warming has been of great interest. One critical limitation in this endeavor has been the relatively coarse horizontal resolution (typically 100 km or more) in the coupled global climate models generally used for long-term climate projections.

A major advance in this field was made around 2005 by Akio Kitoh and his group at the Japanese Meteorological Research Institute (MRI). Kitoh ran 10-year and 20-year “time-slice” experiments with the MRI atmospheric general circulation model at 20-km horizontal resolution using prescribed sea surface temperatures (SSTs) based on lower resolution coupled model results. The demanding computations were conducted on the JAMSTEC Earth Simulator and produced the first global-climate projection in which TCs could be reasonably well-resolved. However, this early version of the fine-resolution MRI model displayed some biases in the simulated distribution of TC numbers, locations, and intensities when run for present-day conditions.

IPRC Postdoctoral Fellow Hiroyuki Murakami and Faculty Member Yuqing Wang are collaborating with Kitoh and other colleagues on analysis of a new version of the MRI model (AGCM_3.2), one that produces a much better simulation of the present-day TC climatology.

“Improvements in TCs in the new version are the result of improved large-scale vorticity and vertical velocity fields,” notes Murakami. “Above all, the new model is able to simulate extremely intense TCs. It is the first model that has successfully simulated the distribution and frequency of category 4 and 5 TCs over several decades. This ability comes from the model’s new cumulus convection scheme” (Figure 1: compare panels a and b).

How Will Tropical Cyclones Respond to Global Warming?

Figure 1. Snapshots of 48-h simulations initialized under the same initial conditions and generated using (a) the Arakawa–Schubert cumulus convection scheme in version 3.1 and (b) the new cumulus scheme, based on the Tiedtke (1989) scheme in version 3.2. Colors indicate 1-h mean precipitation (mm/day), and contours indicate instantaneous sea level pressure (hPa).
Since the model simulates present TC activity so well (see Figure 2), Murakami and his colleagues used it for global warming projections. They drove the model with the mean SST simulated by 18 models of the Coupled Model Intercomparison Project 3, which had been forced with increases in greenhouse gas concentrations described by the A1B future scenario of the Intergovernmental Panel on Climate Change. The model projections for the last quarter of this century are shown in Figure 2 and briefly described below.

**Frequency.** According to the model, the annual global number of tropical cyclones will drop 25%, with a somewhat greater decrease in the Southern than the Northern Hemisphere. This finding is generally consistent with projections reported earlier. Regional analyses, furthermore, show that the decrease is broad: all major ocean basins, except the eastern North Pacific, will see a drop in the annual number of tropical storms.

**Intensity.** In all ocean basins, except in the South Pacific Ocean, the model projections show that the average maximum wind speed is to increase (Figure 3) by 6.6% in the North Indian Ocean to 10% in the North Atlantic.

**Formation Region.** The model projects several shifts in the formation region of tropical cyclones. In the Northern Hemisphere, the formation regions tend to shift to higher latitudes: in the North Atlantic, they shift westward into the Caribbean; and in the Indian Ocean, northward into the Arabian Sea. In the western North Pacific, the formation region is projected to shift eastward toward the central Pacific.

**Frequency of Landfall.** Of greatest concern is how tropical cyclones will impact the safety of people and property in the future. Will the frequency of tropical storms approaching shorelines and making landfall go up? In line with the overall reduction of tropical cyclones globally and in individual ocean basins, the average global number of storm days per year within 200 km of a coastline drops. Regionally, however, the picture is more complicated, especially when considered together with storm intensity near coastlines. For example, in the Northwest

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**Figure 2.** Global distribution of TC tracks during all seasons for (a) observations (1979 – 2003), (b), AGCM20_3.2 (1979–2003), (c), GW projection in AGCM20_3.2. The numbers for each basin show the annual mean number of TCs. TC tracks are colored according to the intensities of the TCs as categorized by the Saffir–Simpson hurricane wind scale [e.g., tropical depression (TD), tropical storms (TSs), and C1–C5]. Ocean basins: NIO=North Indian Ocean, SIO=South Indian Ocean, WNP=Western North Pacific, ENP=Eastern North Pacific, SPO=South Pacific Ocean, NAT=North Atlantic, and SAT=South Atlantic.
Pacific, the maximum wind speed attained by tropical cyclones within 200 km of coastlines is projected to rise by 6% on average.

"Studying the dynamical and thermodynamical mechanisms responsible in the model for the impacts of global warming on tropical cyclones, we found that the projected changes in TC activity can be attributed to changes both in the tropical overturning circulation and in the local and remote effects of sea surface temperature," explains Murakami.

"For example," says Murakami, "the tendency for tropical storms to shift towards the central North Pacific is due to a slowdown of the Walker Circulation, which itself is due to a shift of the maximum surface temperature towards the central Pacific in response to global warming. Both the rising motion at 500 hPa in the ascending branch of the Walker Circulation in the western North Pacific and the downward motion in the descending branch in the central Pacific are weaker in the global warming run. Consistent with this change, the high cyclonic vorticity region at 850 mb shifts to the central Pacific in the model."

"We are confident in our finding that the yearly number of global and hemispheric tropical cyclones will on average diminish with global warming as this finding is independent of model physics in our study and has also been noted by other scientists. We are much less certain, however, about our projections for local characteristics and intensity," cautions Yuqing Wang. He adds, "A remaining, challenging issue is how global warming will impact the interannual variability of tropical cyclone activity."

This story is based on

Figure 3. Category 5 TC frequency (unit = number per 25 years per 2.5° x 2.5°): from 1979 to 2003 in (a) observations and (b) simulation; (c) projected 2075–2099, and (d) difference between present-day and projected simulation.