Why do some thunderstorm cloud-clusters grow into a powerful, destructive tropical cyclone? Recently NICAM, the first computer model that explicitly represents cloud systems over the whole globe has been developed. Created for the JAMSTEC Earth Simulator, this model has captured, for the first time, the whole lifespan—from before birth to decay—of two tropical cyclones, whose tracks, dates, and atmospheric conditions matched cyclones that actually occurred over the Indian Ocean. This is the conclusion of IPRC’s Hironori Fudeyasu and Yuqing Wang and their Japanese colleagues M. Satoh, T. Nasuno, H. Miura, and W. Yanase, after careful analyses of some of the first NICAM output. Figure 1 shows how closely the observed tracks and dates of the storms match those that NICAM generated. This cutting-edge, global cloud-resolving model promises greatly improved weather forecasting and unprecedented opportunities for finding out more about how cyclones form and evolve.

The results of the study are all the more exciting because this NICAM experiment was run not with simulation of tropical cyclones in mind, but the Madden–Julian Oscillation (MJO; see previous story). Because the MJO is most active from December through March, NICAM had been started up with observed atmospheric conditions on December 15, 2006 and was run freely through January 16, 2007.

The simulation is already answering some fundamental questions about tropical cyclones. Atmospheric scientists, for example, have been debating whether large-scale atmospheric disturbances such as the MJO contribute in any significant way to tropical cyclone formation. The NICAM experiment answers the question clearly, at least for the Indian Ocean: The two storms formed within the MJO depression, first Bondo in the western Indian Ocean, and then not quite two

Figure 1. Storm tracks of Bondo and Isobel (blue: Joint Typhoon Warning Center best track data; red: NICAM simulation). Numbers refer to days from end of December 2006 to beginning of January 2007.
weeks later, Isobel in the eastern Indian Ocean.

The scientists compared the simulated and observed Isobel in great detail. First detected in satellite images over the eastern Indian Ocean at 06 on the Universal Time Clock (UTC) on January 2, 2007, Isobel grew into a storm with a minimum sea-level pressure of 984 hPa and peak winds of 40 knots. It moved southward and made landfall nearly 24 hours later on the northwest coast of Australia, where it dissipated. In NICAM, a storm was detected in the sea-level pressure field over the northeastern Indian Ocean already on December 29. As the storm moved southward, it intensified, reached a minimum sea-level pressure of 965 hPa and peak winds of around 60 knots on January 2, and then dissipated on January 5. Figure 2 shows the match between the observed and the simulated sea-level pressure. Although the simulated storm formed a few days earlier, was stronger, and made landfall one day later on the northwest coast of Australia than the real Isobel did, it is still remarkable how well the model captured the storm after running freely for 2½ weeks.

Further comparisons showed that NICAM also reproduced the large-scale atmospheric conditions over the Maritime Continent in which Isobel was born, namely the movement of the MJO into the region on December 28–29 and the northerly cross-equatorial flow originating from the cold surge over the South China Sea. The cross-equatorial flow, the MJO, and the equatorial westerly wind burst provided the large-scale conditions favorable for the genesis of Isobel in both observations and the NICAM simulation (Figure 3).

Isobel did not develop a typical eyewall, but a large, broken one with little convection in its southeastern section (Figure 3c). The NICAM simulation reproduced this broken eyewall structure and the stronger convection in the western than the eastern section of the eyewall (Figure 3d). It is remarkable that this took place after the model had run freely from the initial atmospheric conditions for 18 days.

The NICAM experiment throws light on another major debate in tropical cyclone formation. The “bottom-up” theory holds that vortical hot towers, horizontally small, but intense, cumulonimbus convection cores with strong updraft and upward heat transport, merge to form a single vortex. The “top-down” theory proposes that the mesoscale vortices that form associated with stratiform precipitation in the mid-troposphere develop downward following the weak subsidence of the stratiform precipitation.

The NICAM results support the bottom-up theory. Following the sequence of events in Figure 4, one can see how the large-scale flows set the stage for the formation of the tropical cyclone vortex. The westerly wind bursts of the MJO meet the easterly

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**Figure 2.** Central sea-level pressure of Isobel from the Australian Bureau of Meteorology best track data (blue) and from NICAM simulation (red) during December 2006 and January 2007.

**Figure 3.** Observed and simulated Isobel on January 2, 2007: (a) Equivalent black body temperature (Tbb in K) from CPC-Infrared Radiation and 850-hPa winds from NCEP analysis and (b) outgoing longwave radiation flux (OLR, W/m²) and 850-hPa winds from NICAM simulation at 0000 UTC and surface rain rate (mm/ hour) derived from (c) TRMM-TMI at 0920 UTC and (d) NICAM simulation at 2230 UTC. In (c) and (d) the X indicates the position of the storm center.
trades, creating cyclonic shear and organized rainbands with deep convection that reaches into the upper levels of the troposphere (about 15 km high) and a group of cyclonic vortices, ranging from several tens to hundred km in diameter. These mesoscale vortices start to merge and form a single concentric vortex with monopole potential vorticity.

A closer look at Figure 5 shows how, within the rainband and mesoscale vortex region, smaller regions that are less than 100 km in diameter and have high cyclonic potential vorticity, merge to form the single concentric vortex.

The two sets of panels in Figure 5 illustrate the effect of the merging vortical hot towers. At 00 UTC three separate towers are distinguishable with strong upward motion (red-orange shades) that somewhat warm the upper troposphere up to 15 km high (green patches) and are paralleled by strong rainfall. The sea-level pressure, however, shows no storm signal yet. At 18 UTC, a single tower has formed with an intense vortex (blue and purple shades) approximately 100 km wide; there is strong upward motion (red shades), greatly increased convection and warming of the upper troposphere, precipitation, and a distinct signal in the sea-level pressure.

Having found support for the vortical hot tower, bottom-up theory, Fudeyasu and Wang are now planning to use Wang’s mesoscale tropical cyclone model (TCM4; Wang 2007) to experimentally isolate the processes by which potential vorticity gets redistributed and merges, a study for which NICAM at present is too cumbersome. They also wish to explore the large-scale environmental conditions and the internal dynamics associated with the organization of the convective and mesoscale cloud features of both Isobel...
and Bondo, storms that differed greatly in observed size, strength, and lifespan.

In summary, this first major NICAM simulation has furnished a wealth of data on tropical cyclone formation. Moreover by being able to capture atmospheric events up to nearly 3 weeks after it was initialized, NICAM foreshadows accurate weather prediction up to 2 weeks. Fudeyasu and Wang attribute the model’s success to the simultaneous realistic simulations of both the large-scale circulation, such as the MJO and the cross-equatorial flow, and the embedded mesoscale convective systems, such as vortical hot towers.

This story is based on the following:


Figure 5. Vertical cross-sections of potential vorticity (PVU), vertical velocity (m/s), warm anomaly (K), sea-level pressure (hPa), precipitation rate (mm/h) at 00 UTC (upper panels) and 18 UTC (lower panels) December 28. Location of the cross-sections is marked by dashed lines in Figure 4.

(images of TC Bondo on pages 13 and 15 are courtesy of NASA Earth Observatory)