NICAM Captures the Leading Weather Disturbance of the Tropics

The Madden-Julian Oscillation (MJO) is the most prevalent intraseasonal weather disturbance in the tropics. Most active during December through March, it is characterized by large regions of successive dry and wet spells that move eastward along the equator. The disturbance consists of an envelope of anomalous convection, rainfall, and east-west winds lasting approximately 30 to 60 days. First evident over the western Indian Ocean, and then above the Maritime Continent, the MJO is often still discernable as it moves over the warm western and central tropical Pacific. The signal fades over the cooler eastern Pacific, but may grow again over the tropical Atlantic. Prediction of MJO occurrences could extend weather forecasts by 2 to 3 weeks, but accurate computer simulation of the MJO has eluded forecasters and climate scientists. Now the first global cloud-system resolving model, NICAM, has captured the major features of an actual MJO event and foreshadows greatly improved prediction of these tropical wet and dry spells, and of weather in general.

The NICAM hindcast run was initialized with the actual atmospheric conditions on December 15, 2006, a few days after a wet MJO phase had begun over the western Indian Ocean. The cloud clusters in NICAM evolved over the next 30 days in a way similar to those observed in satellite images, indicating that this the model successfully captured the MJO atmospheric footprint (Figure 1 satellite image and NICAM output of the MJO). These findings were published by **Hiroaki Miura** and his colleagues at JAMSTEC in 2007 in *Science*. A follow-up analysis of the 7-km NICAM resolution simulation has now been performed by IPRC's **Ping Liu** and colleagues at the IPRC, Frontier Research Center for Global Change, and Nagoya University. Their analysis shows how closely the simulated MJO components match those observed, and how small-scale convection interacts with large-scale circulation to sustain the disturbance and to propel it on its eastward path.

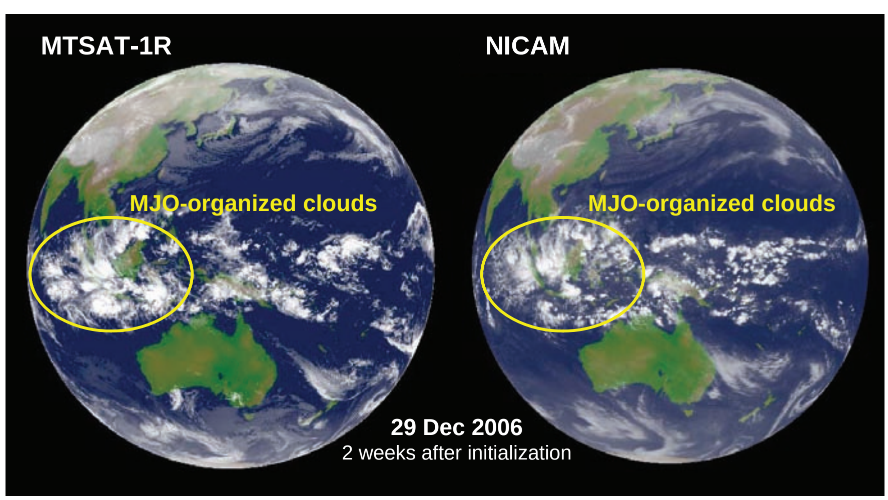

Figure 1. Comparison of the MJO in satellite images and in NICAM on December 29, 2006, 2 weeks after initialization. (courtesy of JAMSTEC)

Liu and his collaborators compared the simulated with the observed MJO using two types of measures: the MJO real-time multivariate (RMM) index as formulated by Wheeler and Hendon in 2004 (composed of the first pair of principal components derived from combined EOF analysis using outgoing long-wave radiation and zonal winds at 200 hPa and 850 hPa levels); and the averaged MJO deviations (i.e., composites of the simple anomalies) from the observed long-term mean in rainfall, winds, and specific humidity for six phases of the MJO.

The evolution of the amplitude of the MJO event is shown in Figure 2. In observations, enhanced covection is detected around December 10; in the model it is noticeable on December 15, the day the simulation began. The simulated amplitude, with its peak on December 28, follows the observed event quite closely for over 3 weeks. The geographical locations for the six successive MJO phases are displayed in the RMM diagram in Figure 3. The blue line shows the observed eastward path of the MJO from December 15 across the Indian Ocean through January 13 into the western Pacific. Gaining in strength, the disturbance moves into the eastern Indian Ocean after the first week. Travelling fairly quickly over the eastern Indian Ocean and on to the Maritime Continent, the signal continues on its journey eastward, weakening significantly, and by the time it reaches the Western Pacific, it is barely discernable. The model MJO follows the observed MJO in path and strength, except that it is stronger in late Phase 3 and early Phase 4, and it still has some strength by the end of the simulation.

A key issue is how the small-scale convection and the large-scale atmospheric circulation interact to create the MJO envelope. The "friction-induced moisture convergence" mechanism, first proposed by IPRC's **Bin Wang** in 1988 in the Journal of the Atmospheric Sciences, hypothesizes that

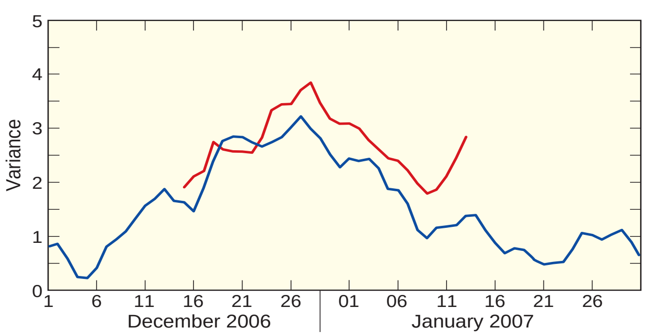

Figure 2. Evolution of the amplitude of the MJO event based on the RMM index: observations (blue) and NICAM simulation (red).

the enhanced convection produces eastward moving Kelvin waves. The sinking and returning flow of the wave warms the region east of the major convection. A low pressure (K-low) area forms in the surface layer where moist air converges mainly due to meridional wind anomalies. The accumulated moist air rises and condenses before reaching 500 hPa, releasing energy that supports the growth of the K-low and draws the major disturbance eastward (see also *IPRC Climate*, vol. 4, no.1).

Both the observations and the NICAM simulation support this mechanism of interaction between the small-scale convection and the large-scale circulation (Figures 4 and 5). Figure 4 shows the developing stage of the MJO when the wet

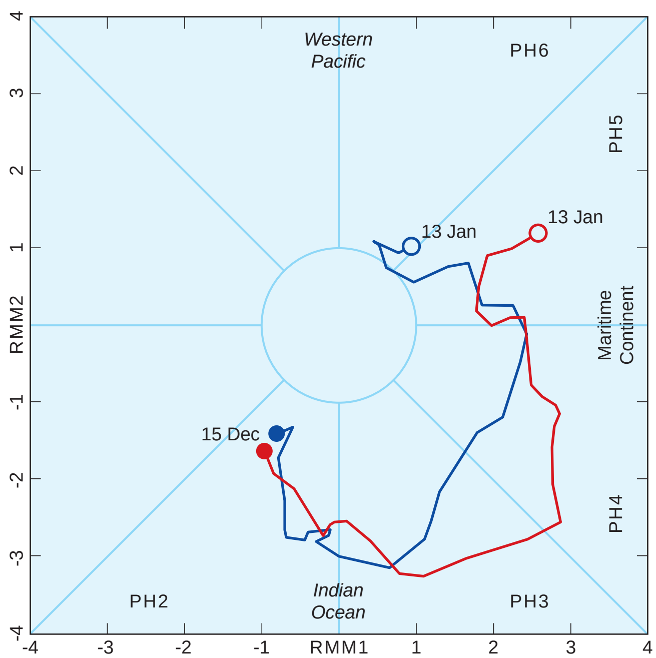

Figure 3: RMM diagram for the MJO event in observations (blue) and the NICAM (red).

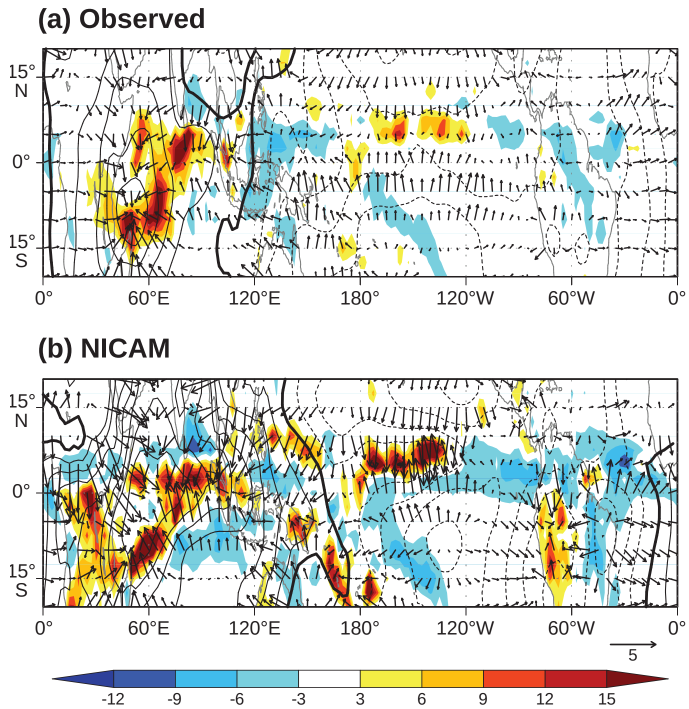

Figure 4. Composited anomalies for Phase 2 of the MJO event in (a) observations and (b) NICAM: velocity potential (contours interval is 1×10^6 m^2/s with thick black as zero) and vectors for divergent wind at 925 hPa. Shading represents precipitation rate (mm/day) from (a) Tropical Rainfall Measuring Mission (TRMM) satellite and (b) NICAM.

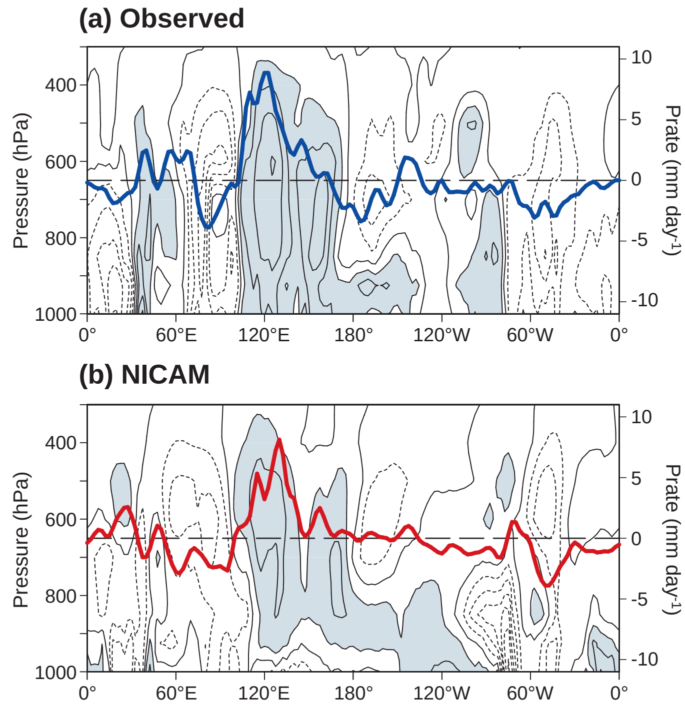

Figure 5. Specific humidity anomalies (contour interval is 0.5 g/kg; shaded areas are equal to or greater than zero). Thick blue and red lines represent precipitation rate anomalies (mm/day) in (a) TRMM and (b) NICAM, respectively. Values are averaged between 15°S and 15°N.

(dark red to yellow) phase is in the western Indian Ocean and the dry phase (blue) is in the western Pacific. During the wet phase, boundary-layer convergence—represented by positive velocity potential in the solid contours—dominates and accumulates moisture. This moisture accumulation precedes the increased rainfall in the Maritime Continent in both model and observation, showing that the accumulated moisture draws the MJO eastward.

Figure 5 reflects conditions in Phase 4 when the rainy phase has moved into the Maritime Continent as shown by the rainfall peak in the thick blue (observed) and red (NICAM) curves. Corresponding to the moisture accumulation at lower levels, specific humidity increases with height towards the west, as illustrated by the shaded areas with humidity of 0.5 g/kg or greater.

The analysis shows that for the first time a computer simulation has captured realistically the progression of the whole MJO envelope from west to east for a period of nearly 30 days after the model was let run freely. This month-long, fairly accurate "prediction" of atmospheric variability augurs well for weather forecasting. The reason for the success, Liu and his co-authors believe, is that the interaction between small-scale convection and large-scale atmospheric circulation is represented explicitly in NICAM rather than by convective parameterizations as in earlier computer models.

Though the NICAM simulation marks a milestone in simulating tropical rainfall variability, significant deficiencies remain. The simulated MJO grows faster over the Indian Ocean, and its peak strength over the Maritime Continent–West Pacific is nearly 30% stronger than observed. A large positive bias also occurs in the outgoing long-wave radiation, a bias that is probably induced by the over-simplified cloud microphysics package. IPRC scientists and their JAMSTEC colleagues will continue to work on improving simulation of the MJO to bring about more accurate weather and climate predictions.

The story is based on the following:

Liu, P., M. Satoh, B. Wang, H. Fudeyasu, T. Nasuno, T. Li, H. Miura, H. Taniguchi, H. Masunaga, X. Fu, and H. Annamalai: An MJO Simulated by the NICAM at 14-km and 7-km Resolutions. *Mon. Wea. Rev., in press.*

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