High-impact Tropical Weather: Hurricanes

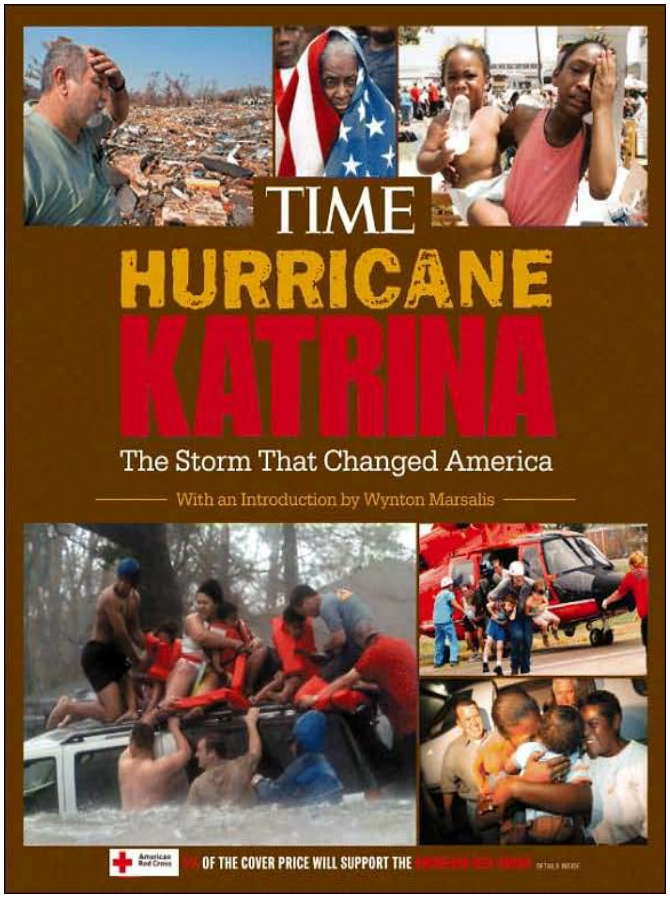
Each year tropical cyclones (TCs) cause tremendous economic losses and many fatalities throughout the world. Examples include Hurricane Katrina (2005), which is the costliest Atlantic hurricane in history, and TC Nargis, which is one of the 10 deadliest TCs of all time.

Hurricane Katrina (2005)

- Cat 5, 902 hPa, with two stages of rapid intensification
- The sixth-strongest Atlantic hurricane ever recorded.
- The third-strongest landfalling U.S. hurricane ever recorded.
- The costliest Atlantic hurricane in history! ($75 billion)
- http://en.wikipedia.org/wiki/Hurricane_Katrina

Severe Tropical Storm Nargis (2008)

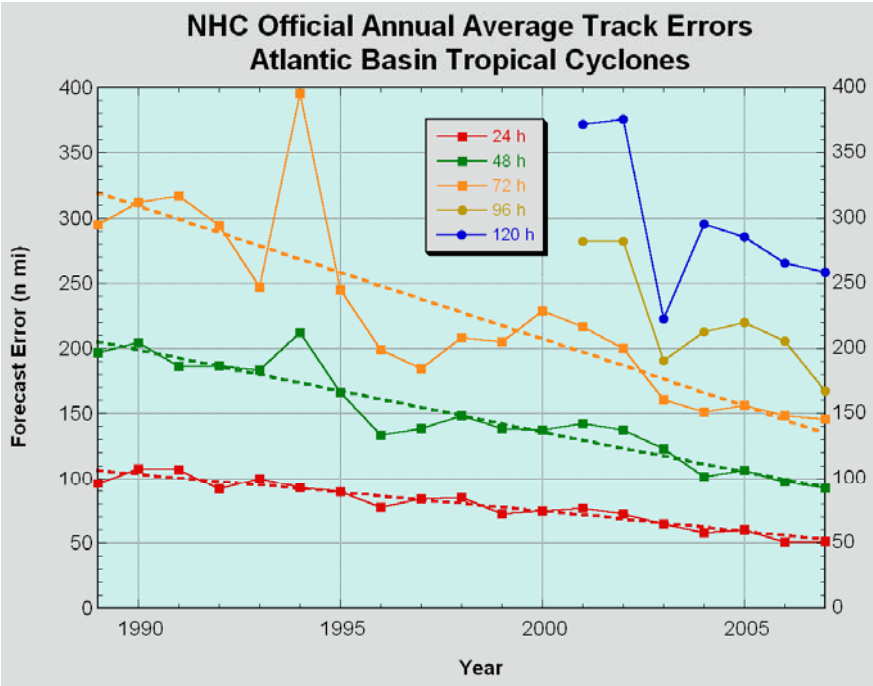
- Deadliest named cyclone in the North Indian Ocean Basin
- Short lifecycle: 04/27-05/03, 2008; identified as TC01B at 04/27/12Z by the Joint Typhoon Warning Center (JTWC).
- Very intense, with a Minimum Sea Level Pressure of 962 hPa and peak winds of 135 mph (~Category 4)
- High Impact: damage ~ $10 billion; fatalities ~ 134,000
- Affected areas: Myanmar (Burma), Bangladesh, India, Srilanka



Progress of Hurricane Forecasts
(by National Hurricane Center)

Track Errors

better



Intensity Errors

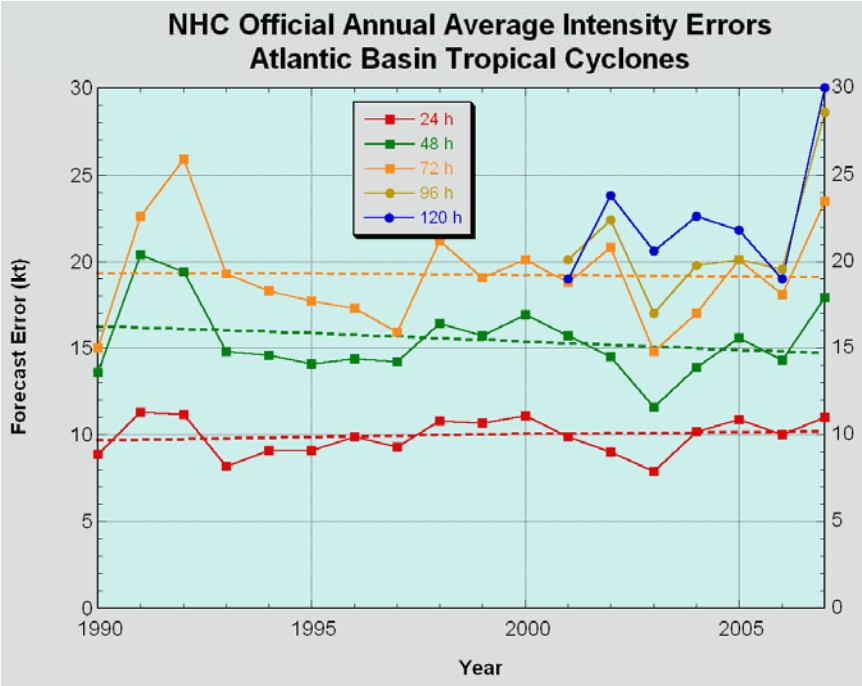


Figure: The progress of hurricane forecasts by National Hurricane Center. Horizontal axis indicates year, and vertical axis shows forecast errors. Lines with different color show different forecast intervals. *During the past twenty years, track forecasts have been steadily improving (left panel), but Intensity forecasts have lagged behind (right panel).*

NASA Major Supercomputers

Columbia Supercomputer (ranked 2nd in late 2004)

- **Based on SGI® NUMAflex™ architecture** 20 SGI® Altix™ 3700 superclusters, each with 512 processors Global shared memory across 512 processors
- **10,240 Intel Itanium® 2 CPUs**; Current processor speed: 1.5 gigahertz; Current cache: 6 megabytes
- **20 terabytes total memory;** 1 terabyte of memory per 512 processors

Pleiades Supercomputer (ranked 3rd in late 2008)

- **92 Compute Cabinets** (64 nodes per cabinet; 2,560 nodes; 2 quad-core processors per node)
- **quad-core Xeon 5472 (Harpertown) CPUs,** speed - 3GHz; Cache - 12MB per CPU
- **51,200 cores in total** (512 cores per cabinet)
- **50+ TB memory in total,** 1 (8) GB memory per core (node)
- **500+ TB disk spaces**
- **InfiniBand, 6,400 compute nodes**

Biswas, R., M.J. Aftosmis, C. Kiris, and **B.-W. Shen**, 2007: Petascale Computing: Impact on Future NASA Missions. Petascale Computing: Architectures and Algorithms, 29-46 (D. Bader, ed.), Chapman and Hall / CRC Press, Boca Raton, FL.

Concurrent Visualization System V2.0

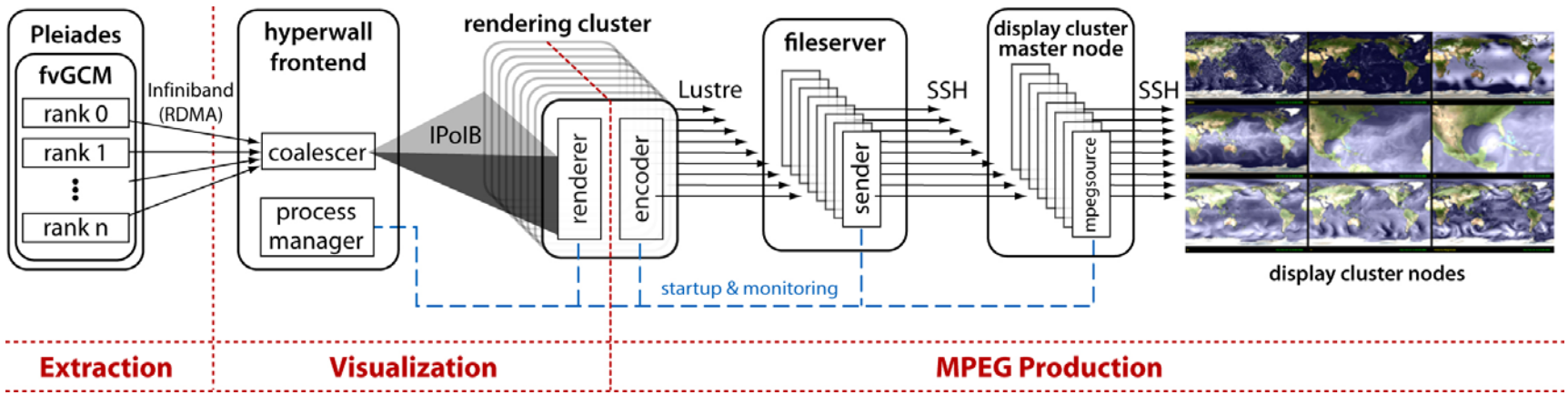
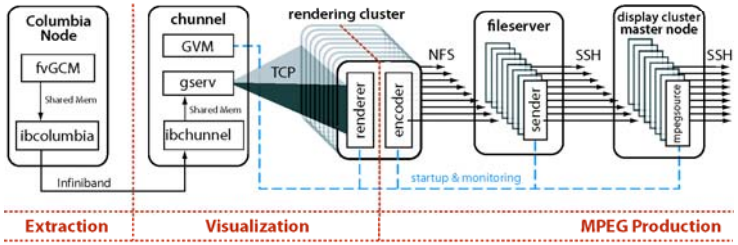


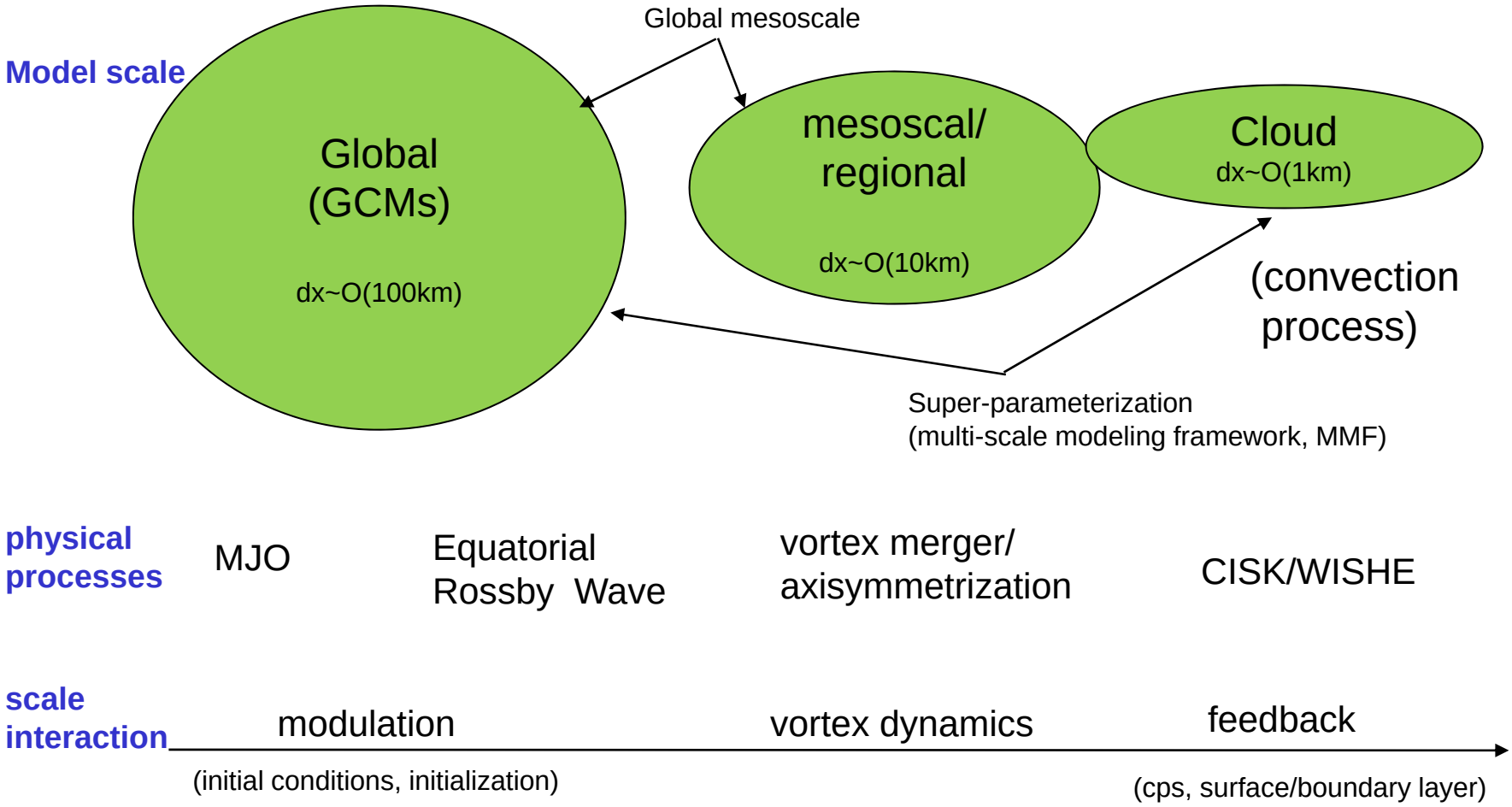
Figure : The newly developed Concurrent Visualization (CV) System (Version 2, top panel). Rounded rectangles indicate systems, and rectangles indicate processes. The whole system (from left to right panels) consists of a computing node ("Columbia Node"), a middle-layer system ("coalescer"), and the hyperwall-2 128-node 8-core/node rendering cluster. These systems are used for data extraction, handling, and visualization; and for MPEG image production and visualization display. The first generation CV system (Version 1) is shown in the right panel for comparison.



Shen, B.-W., W.-K. Tao, G. Bryan, C. Henze, P. Mehrotra, J.-L. F. Li, S. Cheung, 2009: High-impact Tropical Weather Prediction with the NASA CAMVis: Coupled Advanced multi-scale Modeling and concurrent Visualization Systems. Supercomputing conference 2009, Portland, Oregon, November 14-20, 2009.

Green, B., C. Henze, B.-W. Shen, 2010: Development of a scalable concurrent visualization approach for high temporal- and spatial-resolution models. AGU 2010 Western Pacific Geophysics Meeting, Taipei, Taiwan, June 22-25, 2010. (submitted)

Multiscale Interactions of TC Formation

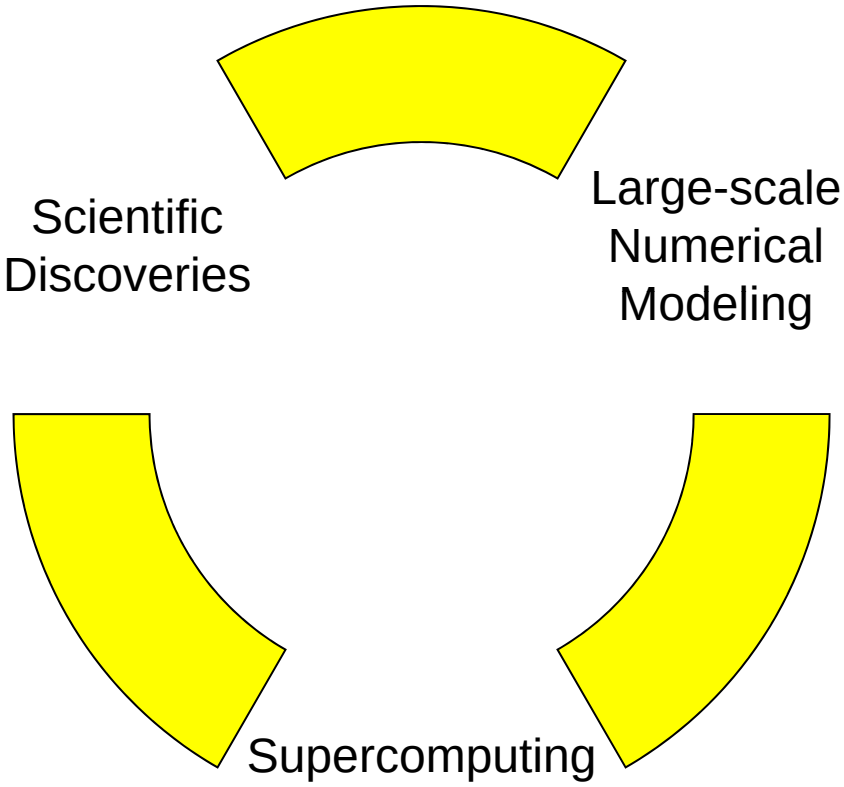


CISK: conditional instability of second kind; **CPs:** cumulus parameterizations; **MMF:** multiscale modeling framework; **MJO:** Madden-Julian Oscillation; **TC:** Tropical Cyclone; **WISHE:** Wind induced surface heat exchange;

A Science-Driven Approach

Goals:

- **to explore** the power of supercomputing technology (e.g., supercomputers and visualization systems) on the advancement of global weather and hurricane modeling;
- **to discover** how hurricanes form, intensify, and move with advanced numerical models;
- **to understand** the underlining mechanisms (how realistic the model depiction of TC dynamics)
- **to extend** the lead-time of hurricane predictions (and high-impact tropical weather predictions): from short-term (~5days) to extended-range (15~30 days) forecasts

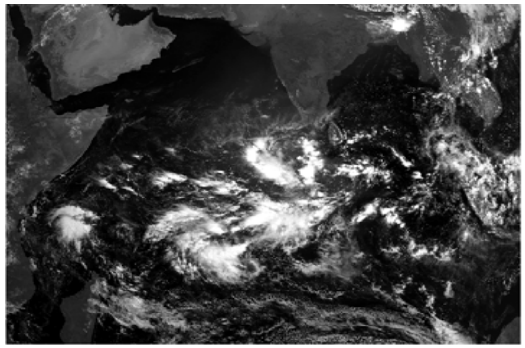


Upscaling to a Mission-Driven Approach

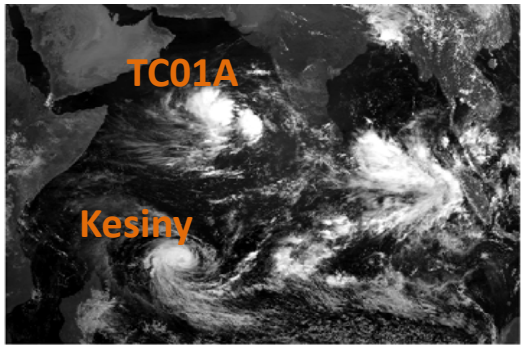
Simulation and Visualization of Twin Tropical Cyclones

Previous studies suggest that twin tropical cyclones (TCs), symmetric with respect to the equator, may occur associated with a large-scale Madden-Julian Oscillation (MJO). Here, it is shown that high-resolution simulations of twin TCs associated with the MJO in 2002 are in good agreement with the satellite observations.

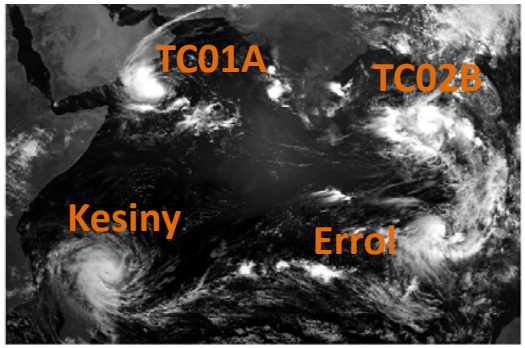
0630 UTC 1 May 2002



0000 UTC 6 May 2002



0000 UTC 9 May 2002



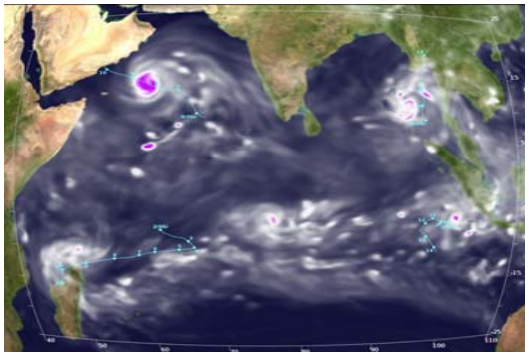


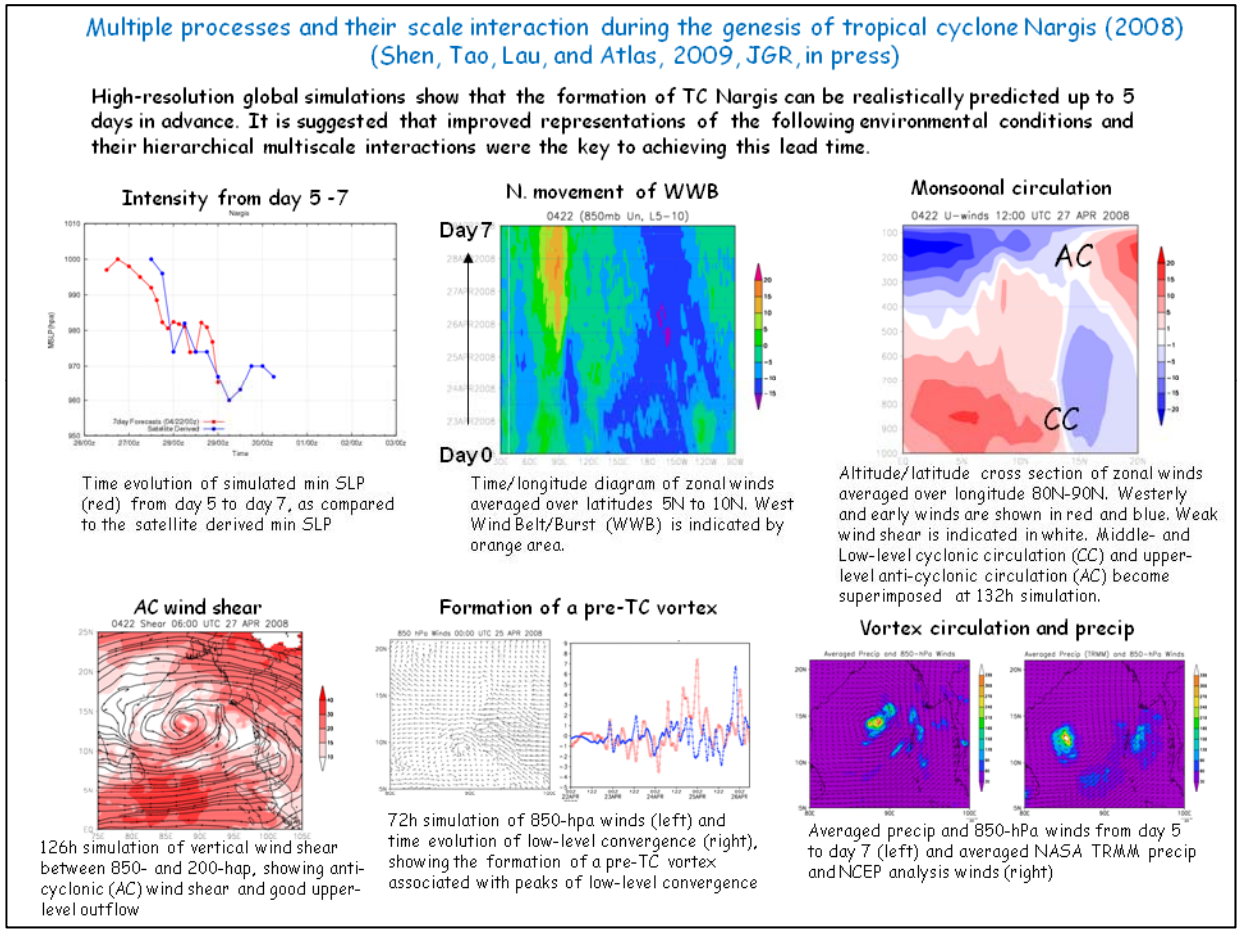
*Figure : Predictions regarding the formation of twin tropical cyclones in the Indian Ocean: (a) MJO-organized convection over the Indian Ocean at 0630 UTC 1 May 2002. When the MJO moved eastward, two pairs of twin TCs appeared sequentially on 6 May (b) and 9 May (c), including TC 01A, Kesiny, TC 02B and Errol. Two TCs (01A and 02B) with anti-clockwise circulation appeared in the Northern Hemisphere, while two TCs (Kesiny and Errol) with clockwise circulation in the Southern Hemisphere; (d) Four-day forecasts of total precipitable water, showing realistic simulations of TC's formation and movement (see **Shen et al.**, 2010 for details).*

Shen, B.-W., W.-K. Tao, R. Atlas, Y.-L. Lin, C.-D. Peters-Lidard, J.-D. Chern, K.-S. Kuo, 2009: Forecasting Tropical Cyclogenesis with a Global Mesoscale Model: Preliminary Results for Twin Tropical Cyclones in May 2002. (to be submitted)

The need of 3D Visualizations for the representation of multiscale interactions

High-resolution simulations with this model show that the formation of TC Nargis can be realistically predicted up to 5 days in advance. It is suggested the improved representation of the environmental conditions (listed in the figure) and their hierarchical multiscale interactions were the key to achieving this lead time.

Though these multiple processes and their scale interactions can be realistically simulated with the advanced global mesoscale model, presentation of these processes in a simple form for education and outreach purposes becomes very challenging. To achieve this goal, 3D visualizations will be illustrated in the next slide.



Shen, B.-W., W.-K. Tao, W. K. Lau, R. Atlas, 2009: Improving Tropical Cyclogenesis Prediction with a Global Mesoscale Model: Hierarchical Multiscale Interactions During the Formation of Tropical Cyclone Nargis (2008). (submitted to JGR, in press).

3D Visualization of Multiscale Processes associated with the Formation of Nargis (2008)

The 3D visualization is to illustrate (1) the formation of a pair of low-level vortices; (2) the transformation of the northern vortex into the TC Nargis; (3) the suppression of the southern vortex.

This visualization is produced by the NASA CAMVis information system with the following configurations:

- Model: NASA fvGCM;
- Visualization: CVs v2.0
- Model spatial resolution: 1/4 degree;
- time step: 900 seconds in physics,
  45 seconds in dynamics;
- # of horizontal grid points: 1000x721;
- simulation length: 7 days;
- I/O: every physics time step;
- file size: 716 GB with 61 vertical levels
- wall-time: 2 hours with 240 CPUs

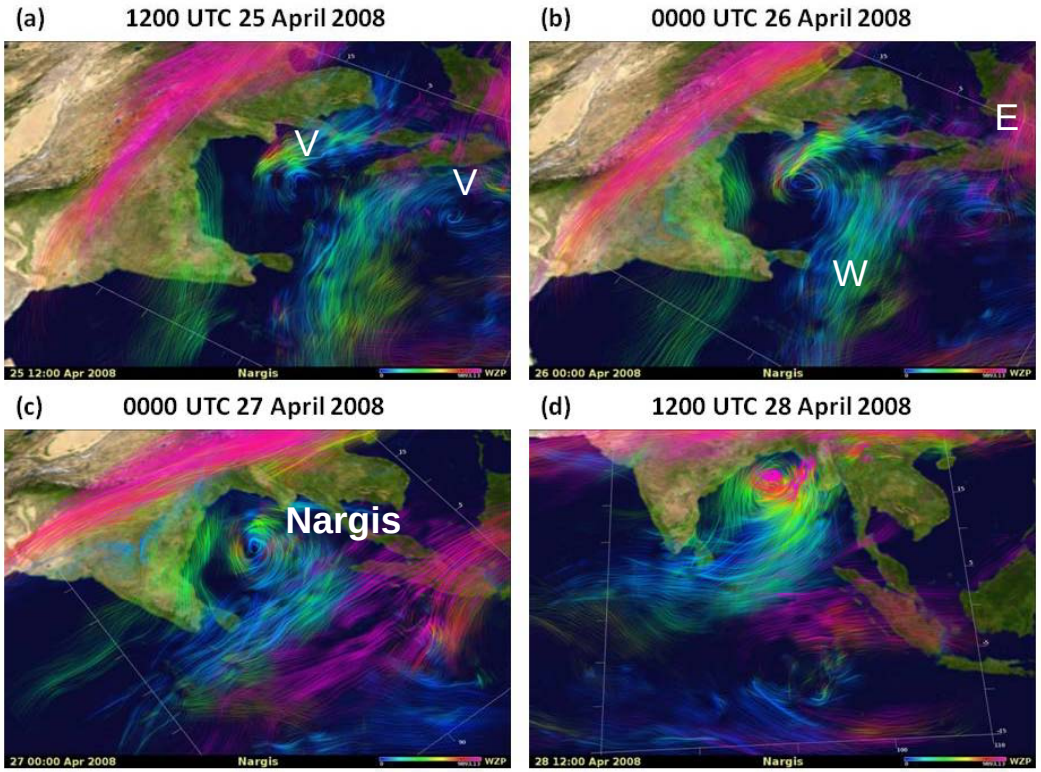


Figure : Realistic 7-day simulations of the formation and initial intensification of TC Nargis (2008) initialized at 0000 UTC April 22, 2008, showing streamlines at different levels. Low-level winds are in blue and upper-level winds in red: (a) formation of a pair of low-level mesoscale vortices (labeled in 'V') at 84h simulation. (b) intensification of the northern vortex (to the left) (c); formation of TC Nargis associated with the enhancement of the northern vortex; (d) intensification of TC Nargis associated with upper-level outflow and moist processes, indicated by the enhanced upper-level outflow circulation. Approaching easterly upper-level winds (labeled in 'E') increase the vertical wind shear, suppressing the enhancement of the southern vortex (to the right) in panel (b).

15-day Simulations of an MJO in May 2002

Accurate prediction of tropical activity at sub-seasonal scales is crucial for extending numerical weather prediction beyond 2 weeks. Among the challenges of this goal is accurate forecasting of a Madden-Julian Oscillation (MJO). This figure is to show that both the fvGCM and fvMMF can realistically simulate the MJO up to 15 days.

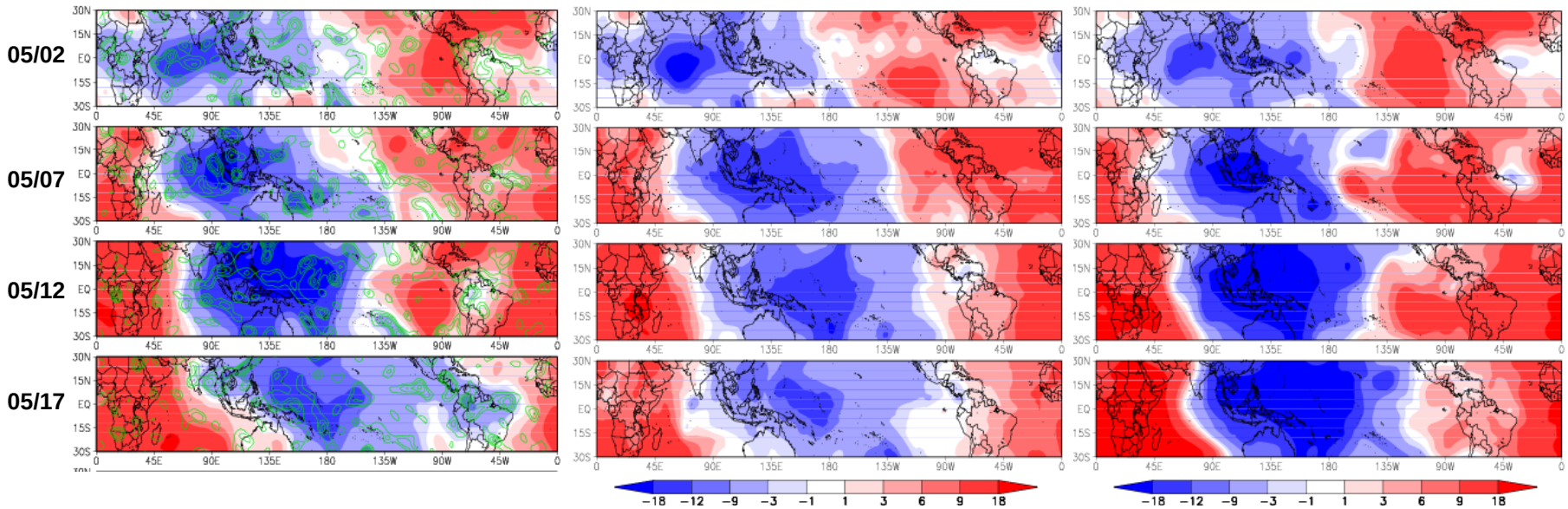


Figure. Velocity potential at 200 hPa every 5 days in May 2002 from NCEP analysis (left panels), 15-day fvGCM model predictions at 1/8 degree resolution (middle panels), and 15-day fvMMF model predictions (right panel). The velocity potential plots showed the observed and predicted patterns and propagations of Madden-Julian Oscillation (MJO). The high-resolution fvGCM is able to reproduce realistically the observed patters and intensity as NCEP analysis. The fvMMF even with coarse-resolution (2x 2.5 degree) is also able to predict the large-scale MJO event, except its intensity is somewhat overestimated .