Recent Development of the NASA CAMVis for Tropical Cyclone Studies

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Coupling NASA Advanced Multi-Scale Modeling and Concurrent Visualization Systems for Improving Predictions of Tropical High-Impact Weather (CAMVis)

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  1.1 FTEs for Project CAMVis

Outline

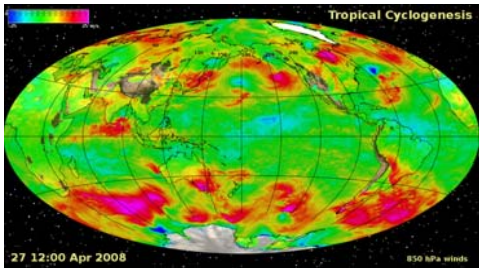
1. Introduction
2. NASA Supercomputing Technology
3. Technology Approach: Global Multiscale Modeling and Concurrent Visualization Systems
4. Scientific Demos: Predictions and Visualizations of Tropical Cyclone Formation and its Multiscale Interaction with Environmental Conditions
5. Conclusion and Future Tasks

Objectives

CAMVis weather prediction tool is being developed to achieve the following goals by seamlessly integrating NASA technologies (including advanced multiscale modeling visualizations and supercomputing):

- to inter-compare satellite observations (e.g., TRMM precipitation and QuikSCAT winds) and model simulations at fine resolution, aimed at improving understanding of consistency of satellite-derived fields;
- to improve the insightful understanding of the roles of atmospheric moist thermodynamic processes and cloud-radiation-aerosol interactions with high temporal and spatial-resolution 3D visualizations;
- to improve real-time prediction of high-impact tropical weather at different scales.

Project CAMVis has the potential for supporting the following NRC Decadal Survey Earth Science missions: ACE, XOVWM, PATH, SMAP, 3D-Winds.



Highlights of Decadal Survey Missions
(recommended by National Research Council)

- **Aerosol -Cloud-Ecosystems Mission (ACE, 2010-2013):** *to reduce uncertainty about climate forcing in aerosol-cloud interactions*
- **Extended Ocean Vector Winds Mission (XOVWM, 2013-2016):** *to further improve hurricane forecasts* and warnings *(suggested by previous studies with QuikSCAT winds)*
- **ICES at-II Mission (2010-2013):** *to address the contribution of changing terrestrial ice cover to global sea level; thus, to project the effects of sea-level change on growing populations and infrastructure along almost all coastal regions*
- **Precipitation and All-weather Temperature and Humidity (PATH) Mission (2016-2020):** *to provide early identification and reliable forecasting of the track and intensity of tropical cyclones with observations of three-dimensional atmospheric temperature and water vapor, as well as sea surface temperature and precipitation fields under all weather conditions*
- **Soil Moisture Active-Passive Mission (SMAP, 2010-2013):** *to improve flood forecasts and thus improve the capability to protect downstream resources through assimilation of satellite-derived soil moisture that is a key control on evaporation and transpiration at the land atmosphere boundary*
- **3D Tropospheric Winds from Space-based Lidar MISSION (3D-Winds, 2016-2020):** *to provide more accurate, more reliable, and longer-term weather forecasts, which are driven by fundamentally improved tropospheric wind observations from space.*

Project CAMVis information system has the potential for supporting the Decadal Survey Missions, as indicated with underlines. Examples are discussed with QuikSCAT winds and TRMM precipitations in the following.

Scenarios in Decadal Survey

- **Extreme Event Warnings** (near-term goal): Discovering predictive relationships between meteorological and climatological events and less obvious precursor conditions from massive data sets → multiscale interactions; modulations and feedbacks between large/long-term scale and small/short-term scale flows

- **Climate Prediction** (long-term goal): Robust estimates of primary climate forcings for improved climate forecasts, including local predictions of the effects of climate change. Data fusion will enhance exploitation of the complementary Earth Science data products to improve climate model predictions.

Courtesy of the Advanced Data Processing Group,
ESTO AIST PI Workshop Feb 8-11, 2010, Cocoa Beach, FL

Expectations from the Earth Science Community: Challenges with high-resolution GCMs

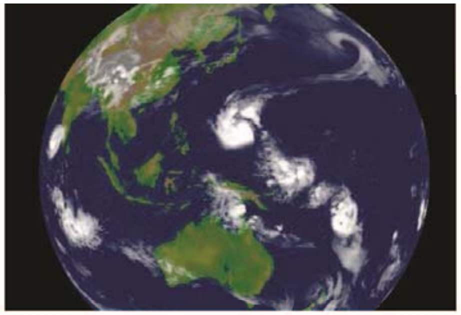
- In August 2006, Bo-Wen Shen was featured in Science magazine for the 5-day predictions of Katrina with a high-resolution global model on the NASA Columbia supercomputer. Two other studies by Japanese were also featured in the article. In the last paragraph, the following question was raised: ***"Is new science being produced or just really cool pictures?"***
- In 2011, Richard Anthes of UCAR featured our hurricane simulations prominently in his talk and paper. Then, he raised a visioning question: ***"Beating predictability theory – long-range forecasts of severe weather by 2025?"***

Demons and Butterflies

Beating predictability theory--long-range forecasts of severe weather by 2025?

Talk to be presented at Harry Otten Symposium on Past and Future of Meteorology Wageningen, Netherlands 13 May 2011

Science, August, 2006, p1040



Sharper still. Typhoon Suda (*center*) looks almost real in this 3.5-kilometer simulation.

METEOROLOGY

Sharpening Up Models for a Better View of the Atmosphere

The exponential rise of computing power and the 2002 arrival of the great Earth Simulator computer have driven atmospheric models to extremes

Machines simulating Earth's atmosphere are producing ever-more-detailed pictures of weather and climate, thanks to ever-increasing computer power. And that new detail is now beginning to let researchers shed some of the approximations and downright fabrications they once needed to get anything useful out of their models. The new view of the atmosphere "looks very, very different" from that of less detailed model simulations, says modeler Jerry D. Mahlman of the National Center for Atmospheric Research in Boulder, Colorado. "It's a very important thing to do."

Supercomputers now run at once-undreamed-of speeds many tens of teraflops (tens of trillions of floating point operations per second). In weather forecasting models, part of this exponentially improving computing power has always gone into increasing model resolution. Modelers do that by moving the isolated points at which atmospheric properties are calculated the model's grid points closer together. It's like a pointillist painter going from big splotches of color to smaller and smaller dabs that show greater and greater detail. Global weather-forecasting models are down to grid-point spacing of a few tens of kilometers in the horizontal. Climate modelers, in contrast, have favored a spacing of about 200 kilometers, says modeler Kevin Hamilton of the University of Hawaii, Manoa. That gave them simulations that bore some resemblance to real weather maps but that run for not just a week but centuries.

Then, in 2002, Japanese researchers turned on the 40-teraflops Earth Simulator. "The Japanese had two advantages," says Hamilton. "They were willing to invest an enormous amount of money, on the order of a billion [U.S.] dollars." And they had some very clever engineers figuring out how to build a unique, hybrid supercomputer that efficiently combines the conventional approach of simultaneously running large numbers of cheap processors with processors specially designed to accelerate atmospheric model calculations.

Spurred by the Earth Simulator, climate and meteorology researchers in Japan and around the world are pushing the resolution of their global models to new extremes. In a *Geophysical Research Letters* paper published 14 July, modeler Bo-Wen Shen of NASA's Goddard Space Flight Center in Greenbelt, Maryland, and colleagues report how they simulated 5 days in the life of Hurricane Katrina on NASA's newer, 61-teraflops Columbia supercomputer at the Ames Research Center in Mountain View, California. Global models have generally failed to produce intense tropical storms, but when the resolution was dropped from 20 kilometers to 10 kilometers, the simulated Katrina intensified to about the same extremely low central pressure as the real Katrina. It had winds nearly as strong spiraling around a suitably compact eye.

Shen and his colleagues then turned off the model's convective parameterization, the part of the model that tells it how, where, and when buoyant air will rise in puffy clouds and thunderheads. Even without that guidance, the simulated storm bore the same strong resemblance to the real thing. Apparently, the higher-resolution model was producing realistic convection which powers tropical cyclones all by itself from the smaller details of hurricane workings, without being told what to do.

In another high-resolution tropical cyclone study, reported last April, modeler Kazuyoshi Oouchi of the Earth Simulator Center in Yokohama, Japan, and colleagues simulated 10 years of global tropical cyclone activity both under present conditions and under warmer, greenhouse conditions. On the Earth Simulator, they ran a 20-kilometer-resolution model. Under present conditions, the model produced a reasonable rendition of the number, strength, and geographic distribution of storms. Under greenhouse warmth, the number of tropical cyclones around the world actually decreased 30%, but the number of more intense storms increased substantially. That supports upward trends in storm intensity recently reported from analyses of observations (*Science*, 5 May, p. 676).

Global simulations have driven resolution to even smaller scales. Modeler Hiroaki Miura and colleagues at the Frontier Research Center for Global Change in Yokohama, Japan, have been running a model called NICAM Nonhydrostatic Icosahedral Atmosphere Model on the Earth Simulator at resolutions of 7 and 3.5 kilometers. That is nearly fine enough to resolve individual clouds. When run without convective parameterization, the 7-kilometer-resolution version of NICAM showed signs of being less sensitive than a lower-resolution model to rising greenhouse gases.

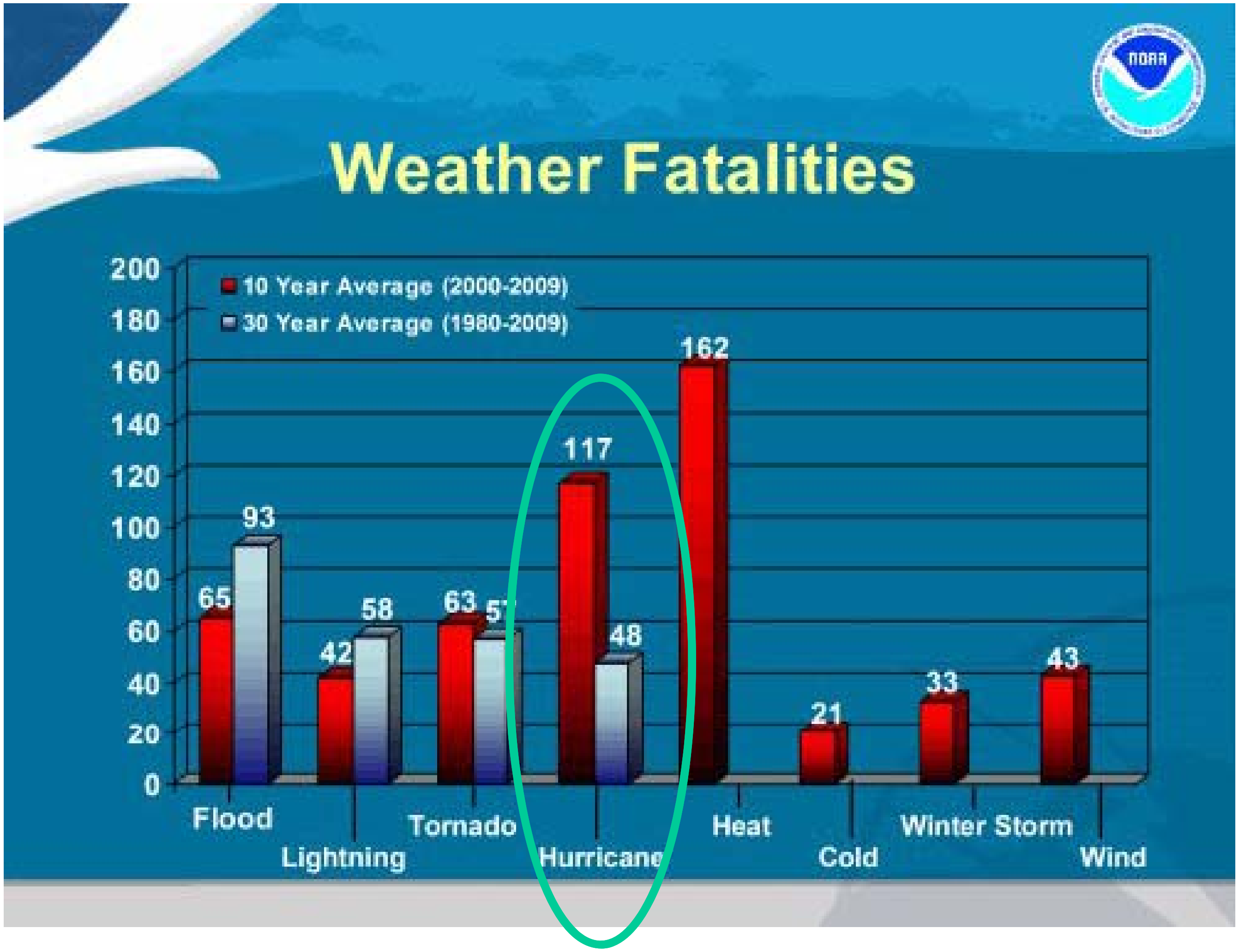
The new high-resolution work is producing intriguing hypotheses, says Mahlman. But he and others still have reservations. "Is new science being produced or just really cool pictures?" he asks. With computing resources growing exponentially and staffing not, he says, computer power might overwhelm the available brainpower. All the more reason to remember that a model no matter how super is only a model.

–RICHARD A. KERR

CREDIT: H. MIURA/FRONTIER RESEARCH CENTER FOR GLOBAL CHANGE, JAMSTEC

Published by AAAS

The U.S. Natural Hazard Statistics



http://www.weather.gov/os/hazstats.shtml

Scientific Goals

Accurate predictions of tropical cyclone(TC) activity at a large lead time can save lives and reduce economic costs.

To improve our understanding of mesoscale predictability for tropical cyclones (TCs) with the aim of extending the lead time of TC prediction and studying TC climate, experiments in recent papers (Shen et al., 2010a,b,c; 2011) were performed to address the following questions:

- to what extent can large-scale flows determine the timing and location of TC genesis; Predictive relationship; zoomed-out view
- if and how realistically can a high-resolution global model depict those processes. Process studies; zoomed-in view

The CAMVis is developed to show:

(1) downscaling (zoomed-in) processes ----- reductionism

(2) scale interaction (zoomed-out) processes ----- Integrative view/thinking

with (1) simulated structures of TCs, and (2) nonlinear multiscale interaction of TCs with environmental flows such as tropical easterly waves.

NASA Supercomputing and Visualization Systems

Pleiades Supercomputer (ranked 3rd in late 2008; 6th in June, 2010; 11th in late 2010; 7th in June, 2011)

- R_{max} of 1,088 teraflops (LINPACK); R_{peak} of 1,315 teraflops
- 111,104 cores in total; Xeon 5472 (Harpertown), Xeon 5570 (Nehalem), Xeon 5670 (Westmere)
- 185 TB memory
- 3.1 PB disk space
- Largest InfiniBand network: 11,648 nodes; Partial 11D hypercube; Direct visualization cluster connections

- Supercomputer-scale visualization system
  - 8x16 LCD tiled panel display
  - 245 million pixels
- 128 nodes
  - Dual-socket quad-core Opterons
  - 1024 cores, 128 GPUs
- InfiniBand (IB) interconnect to Pleiades
  - 2D torus topology, 32 links to Pleiades
  - 9x2 switches
  - High-bandwidth concurrent visualization

The First Numerical Weather Prediction on ENIAC

- Von Neumann recognized weather forecasting, a problem of both great practical significance and intrinsic scientific interest, as an ideal problem for an automatic computer.
- The invention of the first electronic general-purpose computer **ENIAC** (Electronic Numerical Integrator And Computer) in mid-1940s enabled Charney, Fjortoft, and vov Neumann fulfill the dream of Richardson's (1922) on numerical weather prediction (NWP). Four 24-hour forecasts were made, and each 24 hour integration took about 24 hours of computation.

Reference:

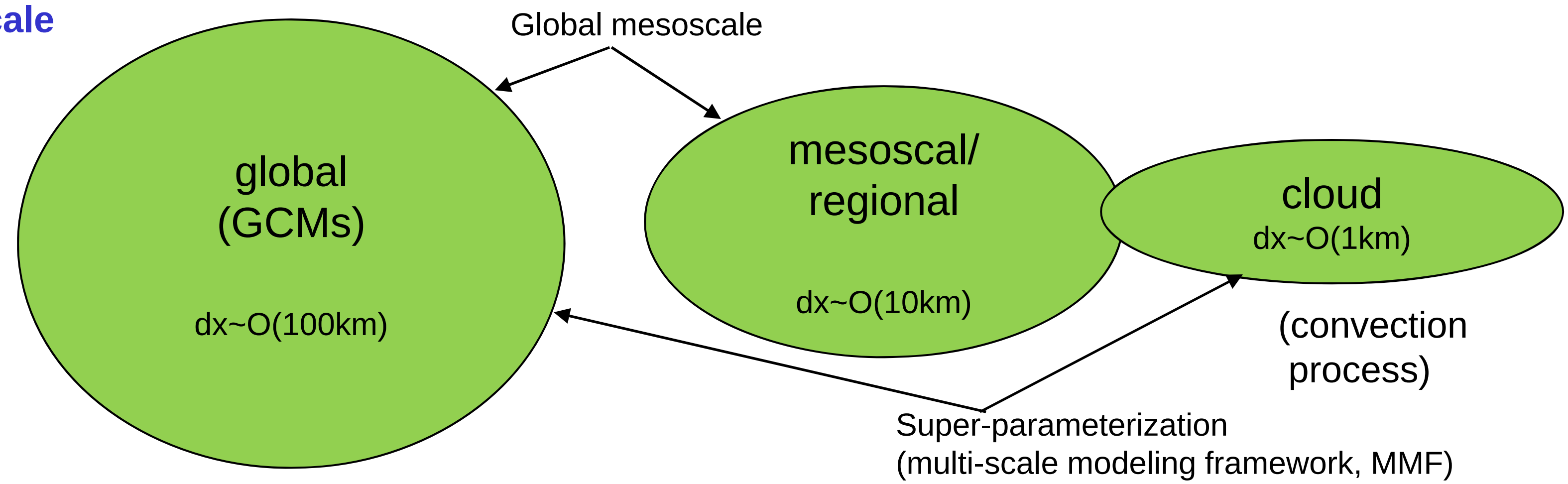
- Charney, J. G., R. Fjortoft, and J. von Neumann, 1950: Numerical Integration of the Barotropic Vorticity Equation. *Tellus*, 2, 237-254.

- "*Even though the advancement of NWP also depends heavily on the arrival of the modern observing system and the complexities of the lately numerical models, the subsequent improvements of NWP have been paced primarily by advances in computer technology,"* by F. G. Shuman, *Weather and Forecasting*, **4**, 286-296, 1989.
- In 1994, the NOAA/NCEP was running its GCM at one degree resolution on its C90 supercomputer which has 16 CPUs with a peak performance of 15.3 GFlops. In contrast, three CPUs on Altix (at a speed of 1.5 GHz) could provide a comparable aggregate performance of 18 GFlops, and therefore one 512-CPU Altix node provide computational power 170 times larger than C90.

Multiscale Modeling Approach

To improve the prediction of TC's formation, movement and intensification, we need to improve the model to accurately simulate interactions across a wide range of scales, from the large-scale environment (deterministic), to mesoscale flows, down to convective-scale motions (stochastic).

model scale



physical processes

MJO

Tropical Easterly Waves

vortex merger/ axisymmetrization

CISK/WISHE

scale interaction

modulation (initial conditions, initialization)

vortex dynamics

feedback (cps, surface/boundary layer)

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;

Similarity

Is an individual (a cloud) the source of stability (predictability)?

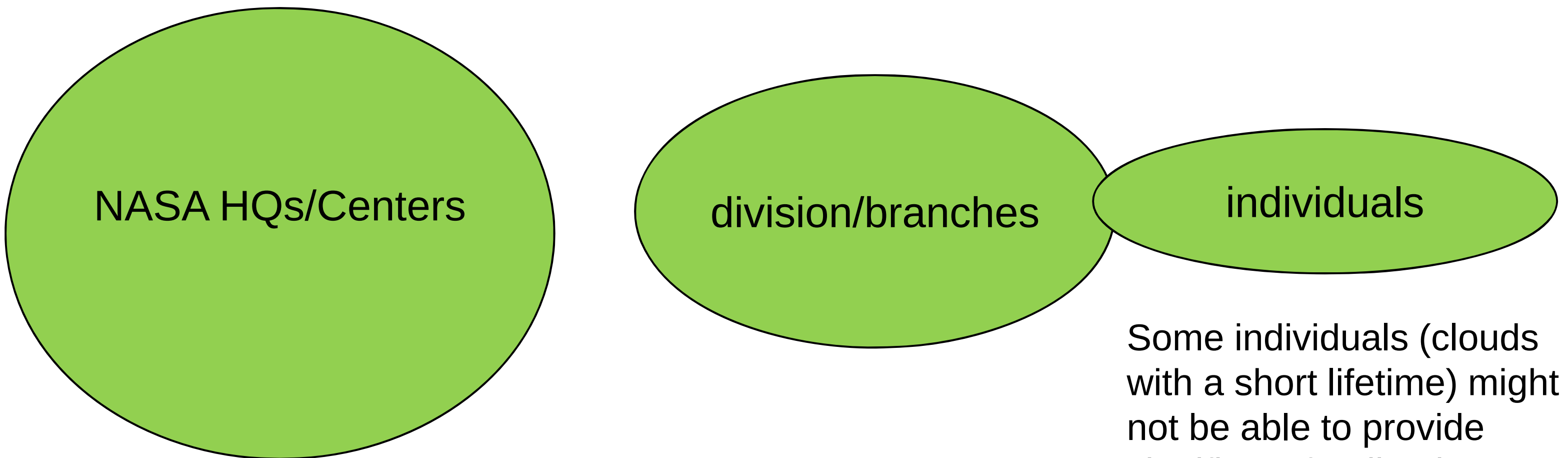
Top down →

e.g., funds

← **Bottom up**

e.g., papers, reports etc

Scale



Some individuals (clouds with a short lifetime) might not be able to provide significant feedbacks.

Forcing / Power scale

Large — Downscaling processes →

← Upscaling processes — Small

Scale interaction

control/modulation → aggregated feedbacks

expecting responses at a short time scale ← providing feedbacks at a long time scale

Multiscale Modeling Approach

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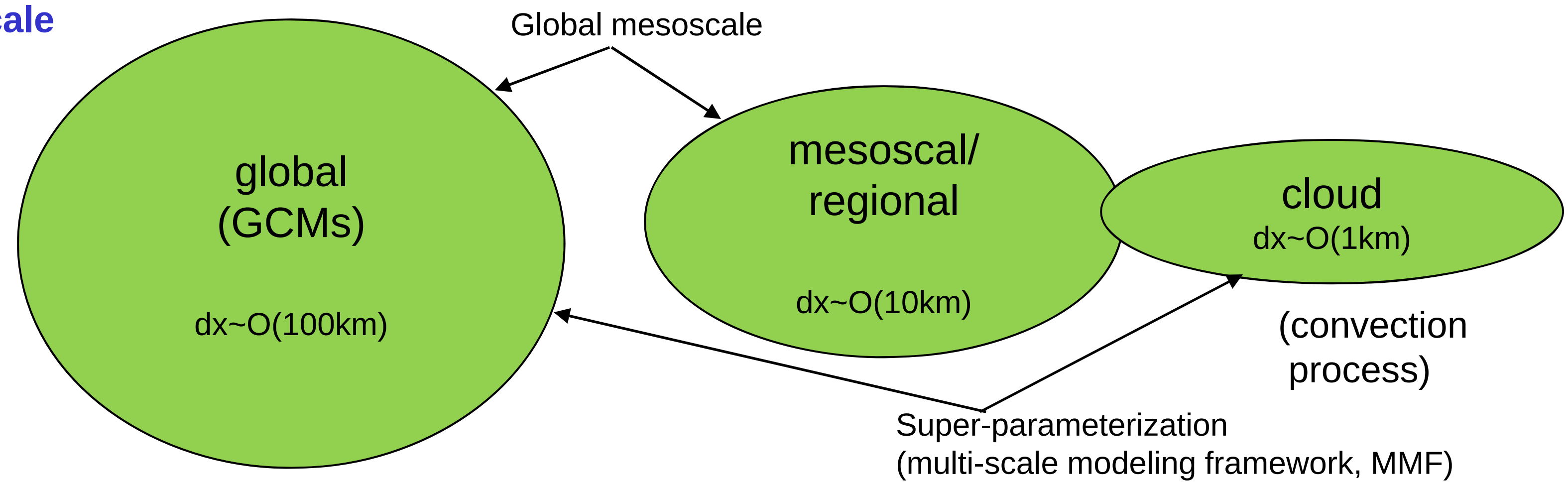
model scale



physical processes: MJO | Tropical Easterly Waves | vortex merger/ axisymmetrization | CISK/WISHE

scale interaction: modulation (initial conditions, initialization) → vortex dynamics → feedback (cps, surface/boundary layer)

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;

Challenges

- Satellite Data Challenges:
  - o) Massive data storage
  - o) Display/visualizations (~TB)
- Modeling Challenges:
  - o) Explicit representation of (the effects of) convective-scale motions
  - o) Verification of model simulations at high spatial and temporal resolutions
  - o) Understanding and representation of multiscale interactions
- Computational Challenges:
  - o) Real-time requirements with supercomputing
  - o) Efficient data I/O (at runtime) and data access (via massive storage systems)
  - o) Parallel computing and parallel I/O with new processors (e.g., *multi-cores*)
  - o) Processing and visualizations of massive data volumes with large-scale multiple-panel display system

The cloud parameterization problem is ``deadlocked'' in the sense that our rate of progress is unacceptably slow during the past 40 years (Randall et al.,2003)

Satellite, Numerical Models, and Supercomputing Technology

Concurrent Visualization: Why and How?

1. Large time-varying simulations generate more data than can be saved
   – Problem gets worse as processing power increases
   – Models increase spatial and temporal-resolution
2. Saving data to mass storage consumes a significant portion of runtime
3. Only a small fraction of timesteps are typically saved and important dynamics may be missed

process huge data efficiently

1. Extract data directly from running simulation for asynchronous processing
   - Add instrumentation to the simulation code, usually quite minimal
2. Simultaneously produce a series of visualizations
   - Many fields;
   - Multiple views
3. Generate and store images, movies, and “extracts”
4. Send visualizations of current simulation state almost anywhere, including web
   - Images of current state kept up-to-date in web browser
   - Stream progressively growing movies to remote systems
5. Use hyperwall-2 for parallel rendering and asynchronous I/O

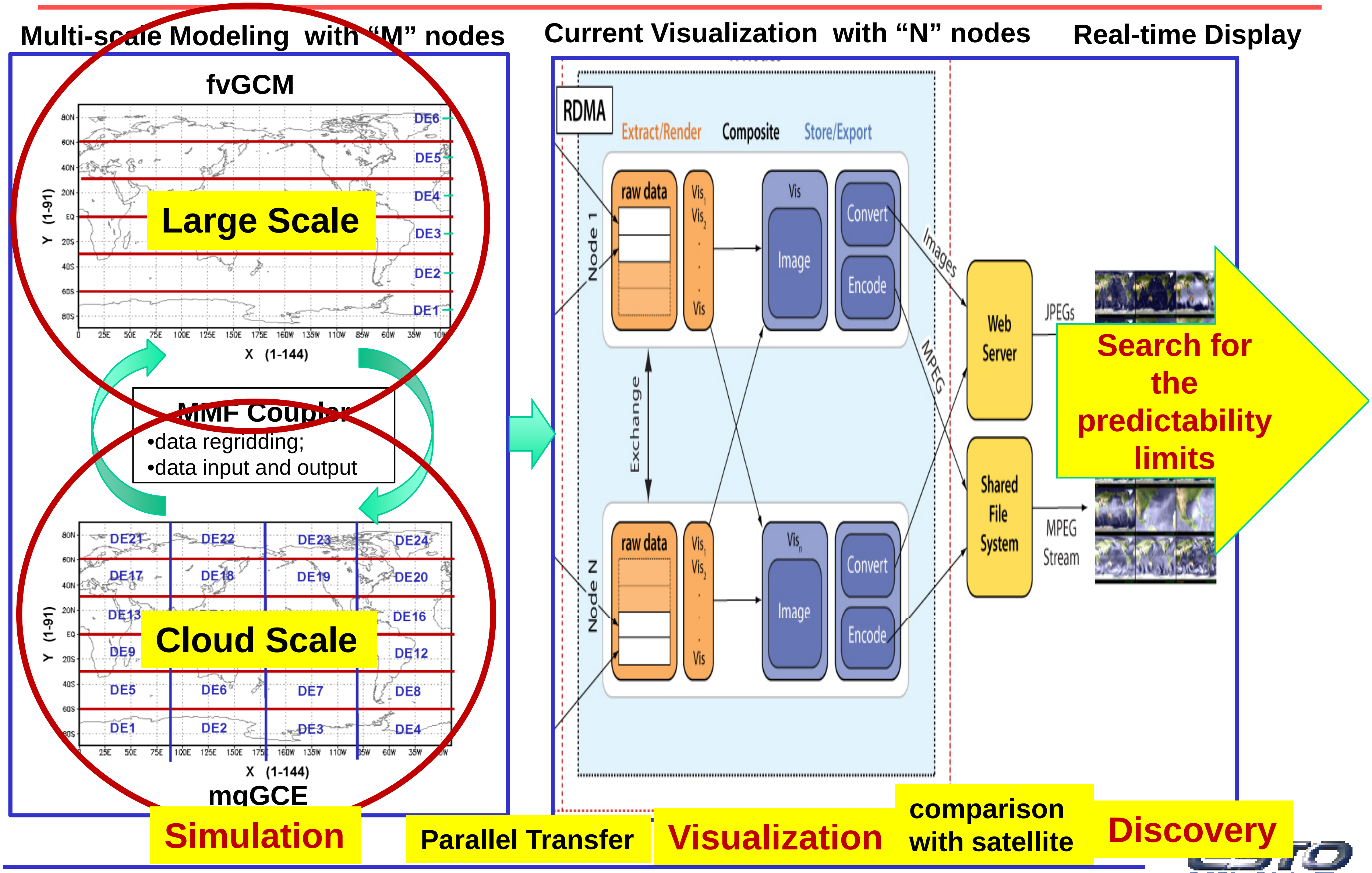
generate visualizations while model is still running

Concurrent Visualization: Benefits

- Higher temporal resolution than post-processing
  - Avoids disk space and write speed limits
  - Output typically 10-1000x greater than standard I/O
- See current state of simulation as its running
  - Application monitoring or steering
  - Detect serious job failures that might otherwise cause waste of system resources
- Minimal impact to application
  - Data are offloaded to vis cluster for concurrent processing
- Reveals features not otherwise observable
  - Has consistently revealed previously unknown dynamics

Architecture of the CAMVis v1.0

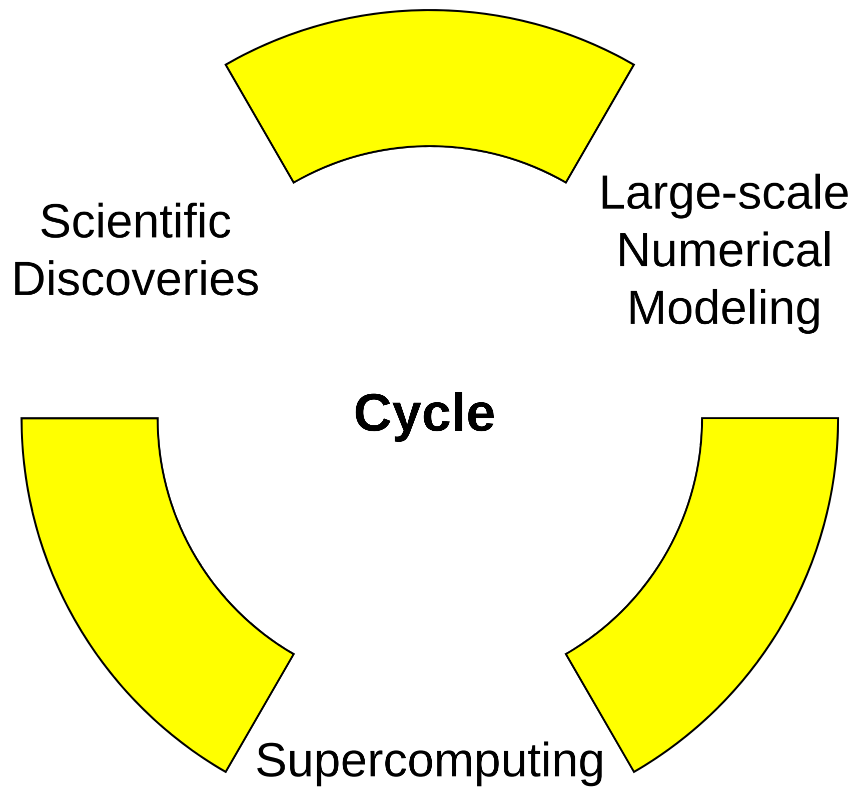
(the Coupled Advanced Multiscale modeling and concurrent Visualization systems)



A Science-Driven Approach

Goals:

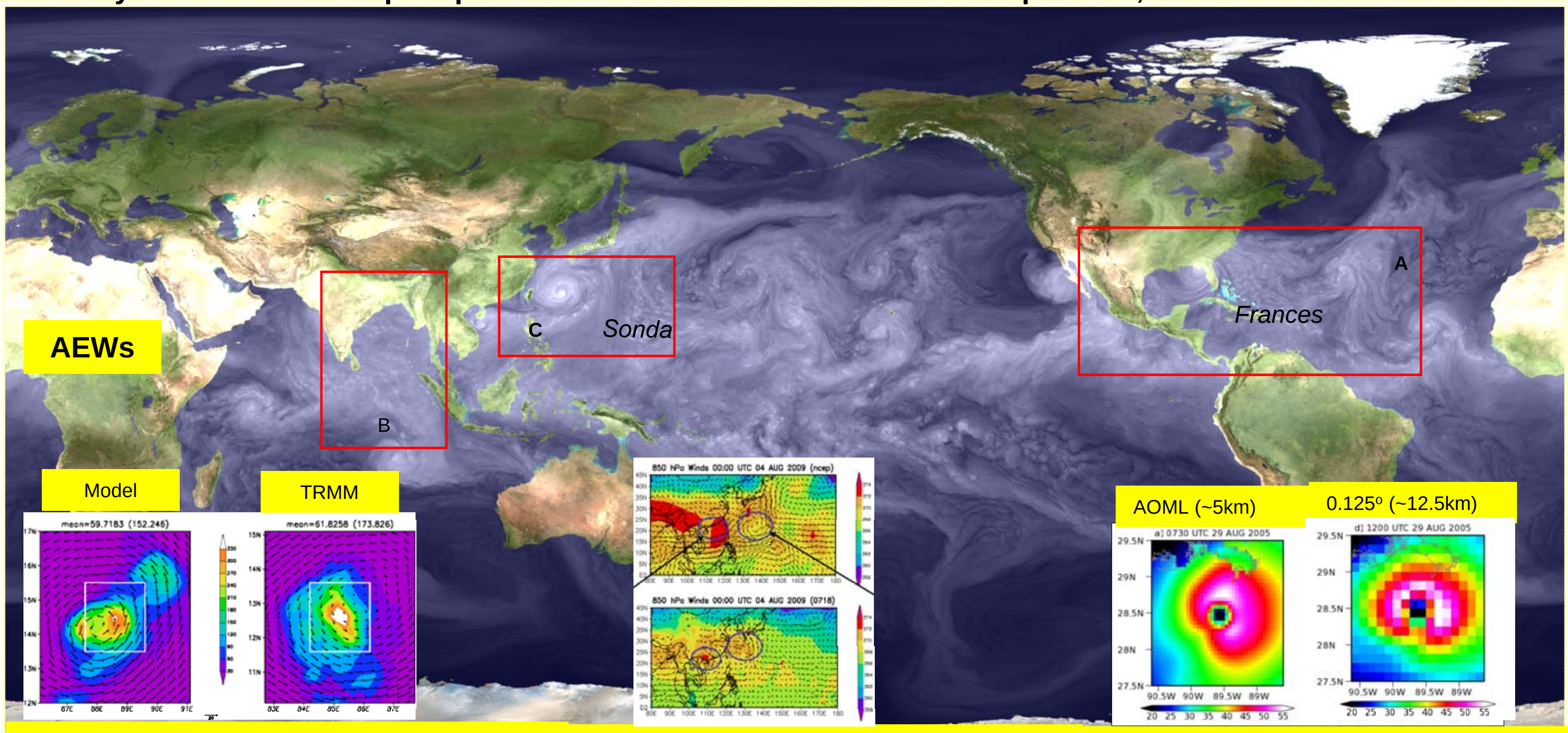
- **to explore** the power of supercomputing technology (e.g., supercomputers and visualization systems) on the advancement of global weather and hurricane modeling;
- **to discover** how hurricanes form, intensify, and move with advanced numerical models;
- **to understand** the underlining mechanisms (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

Predicting High-impact Tropical Cyclones with the NASA CAMVis

5-day forecasts of total precipitable water initialized at 0000 UTC 1 September, 2004 with the 1/12º fvGCM



B:Tropical Cyclone Nargis (2008)

C: Typhoon Morakot (2009)

A: Hurricane Katrina (2005)

- **Cat 4, MSLP of 962 hPa**
- **Deadliest named cyclone in the North Indian Ocean Basin**
- **damage ~ $10 billion; fatalities ~ 134,000**

- **Cat 2, MSLP of 954 hPa**
- **Record-breaking rainfall of 2327mm (accumulated)**
- **damage ~ $6.2 billion; fatalities ~ 789**

- **Cat 5, MSLP of 902 hPa**
- **The sixth-strongest Atlantic hurricane ever recorded.**
- **The third-strongest landfalling U.S. hurricane ever recorded.**
- **The costliest Atlantic hurricane in history! ($75 billion)**

Hierarchical Multiscale interactions of Nargis (2008)

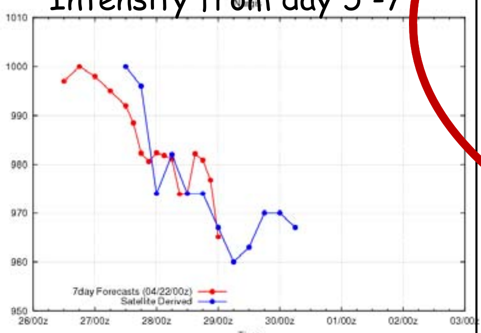
which devastated Burma in May 2008, causing tremendous damage (~$10 billion) and numerous fatalities (~130,000 deaths),

7-day global multiscale simulations suggest the following favorite factors for the formation and initial intensification of tropical cyclone Nargis:

Large Scale

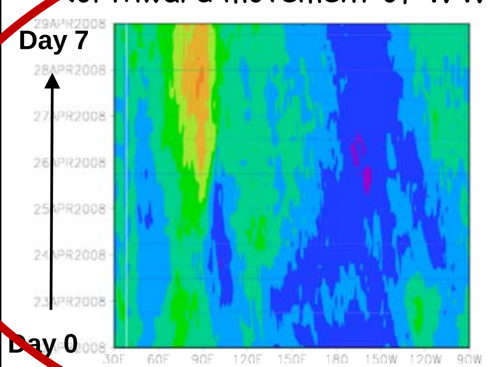
Hierarchical Multiscale Interaction

Intensity from day 5 -7



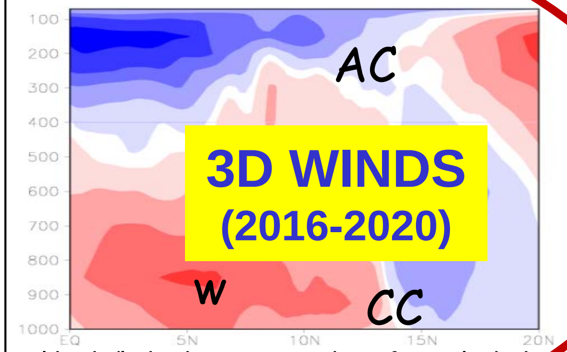
Time evolution of simulated min SLP (red) from day 5 to day 7, as compared to the satellite observation (blue).

Northward movement of WWB



Time/longitude diagram of zonal winds averaged over latitude 5ºN to 10ºN. West Wind Belt/Burst (WWB) is indicated by orange area. (No... shown as the ab... averaged latitude 5S to the equator.)

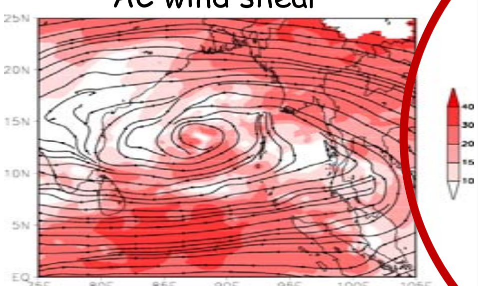
Enhanced Monsoonal circulation



3D WINDS (2016-2020)

Altitude/latitude cross section of zonal winds averaged over longitude 80ºE-90ºE. Westerly and early winds are shown in red and blue. Weak vertical wind shear is indicated by the "vertical orientation of the white line". Middle- and low-level ... d at 132h simulation.

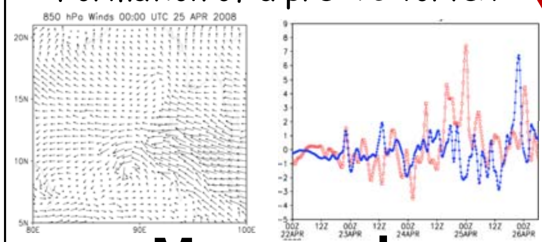
AC wind shear



126h simulation of vertical wind shear between 850- and 200-hap, showing anti-cyclonic wind shear and good upper-level outflow.

Mesoscale

Formation of a pre-TC vortex

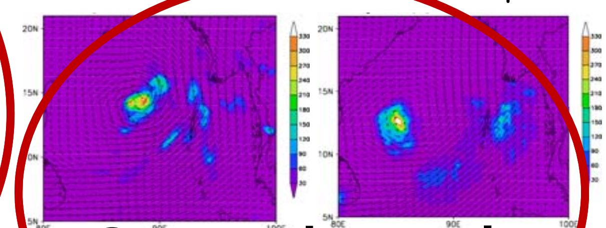


72h simulation of 850-hpa winds (left) and time evolution of low-level convergence (right), showing ... vortex associat... convergence

QuikSCAT

Convective scale

Vortex circulation and precip

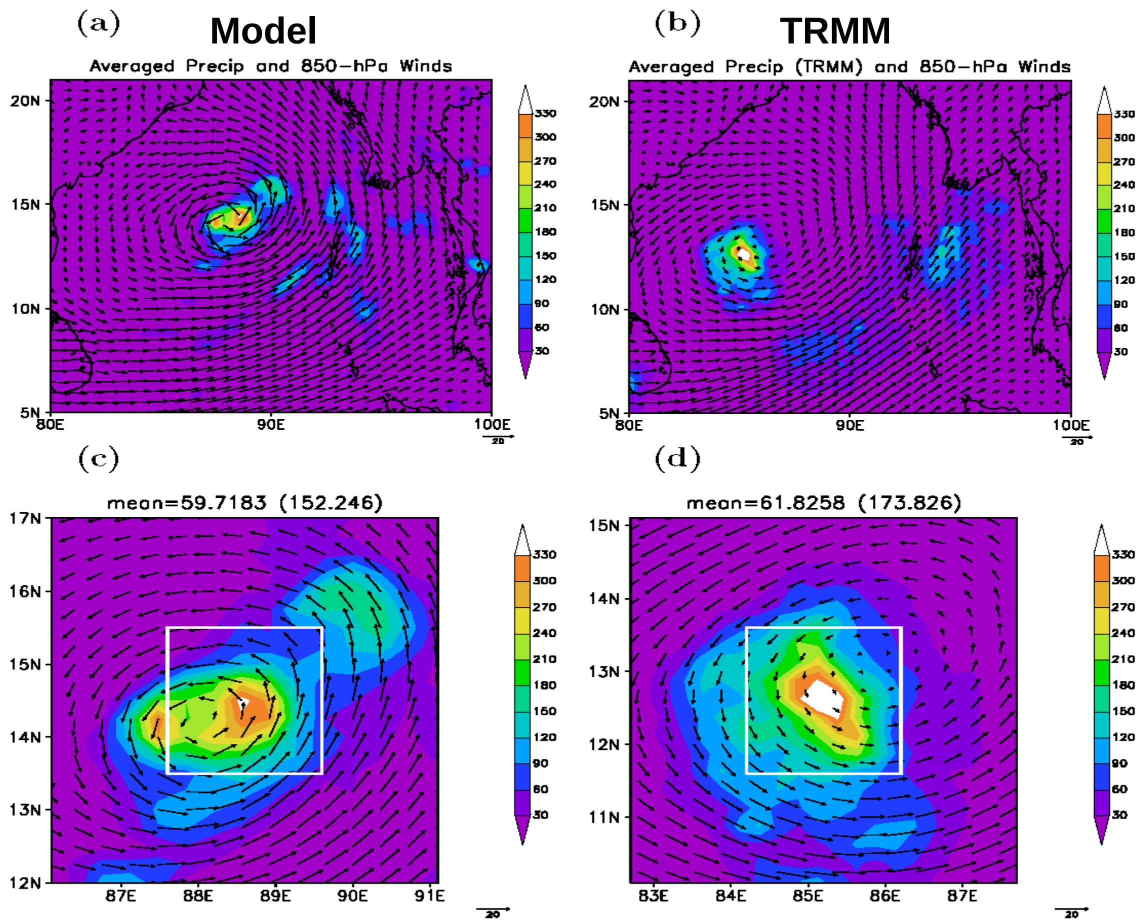


Averaged precip and 850-hPa winds from day 5 to day 7 (left) and averaged NASA TRMM precip and NCEP Rea... (right)

TRMM

Averaged precipitation and wind vectors for Nargis

$5^o x 5^o$

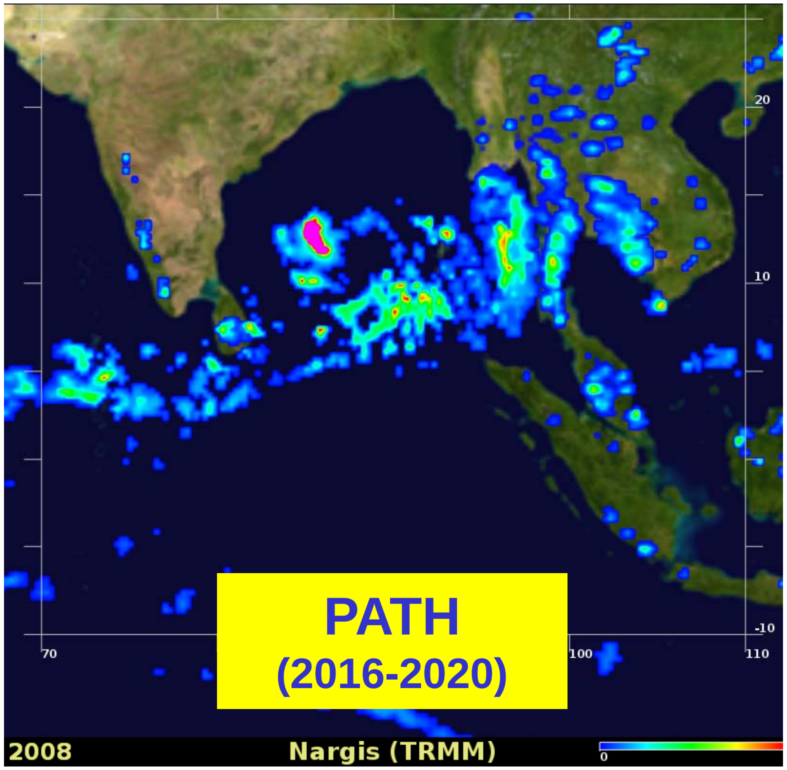


The domain-averaged precipitation in the 5^o (2^o) box is 59.7 (152.2) mm/day for the model and 61.8 (173.8) mm/day for TRMM. **This indicates an underestimate of 3.4% (12.4%) in the 5^o (2^o) average precipitation** by the model with a larger discrepancy for 2^o average precipitation. This indicates the difficulty in automatically selecting a sample domain size, because an accurate assessment of the simulated precipitation associated with the vortex, including its location and scale, is important for quantitative comparison.

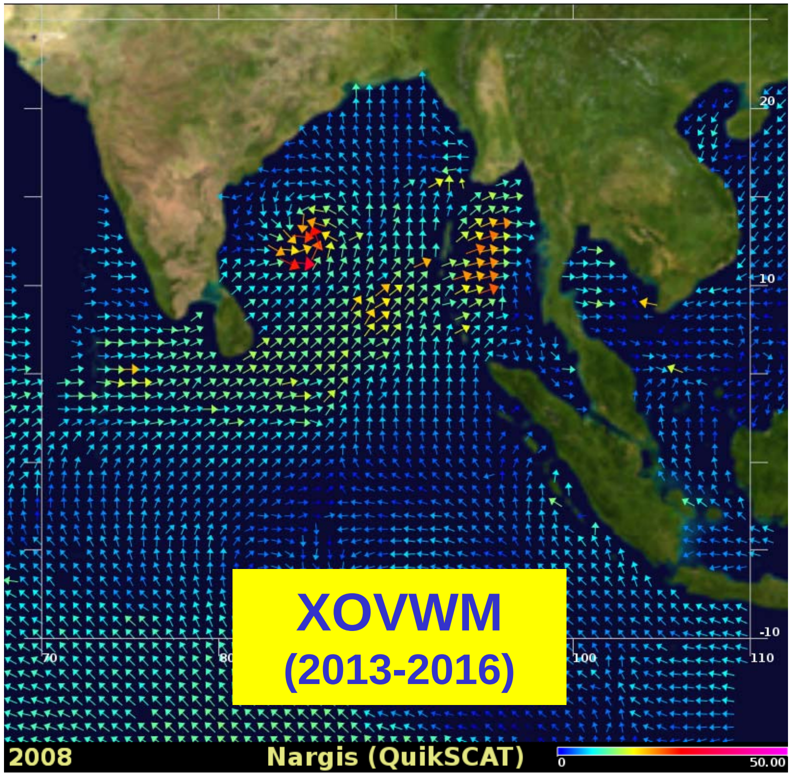
Averaged precipitation and wind vectors. (a) The 2-day average precipitation (shaded) and 850-hPa winds (vectors) from 0000 UTC April 27 (day 5) to 29 (day 7) and (b) NASA TRMM precipitation and NCEP analysis winds. (c, d) The same fields as Figures 10a and 10b, respectively, in a 5^o box, centered at the maximum of precipitation near the vortex center.

“Fusion” of TRMM and QuikSCAT Data into CAMVis

1500 UTC April 27 2008



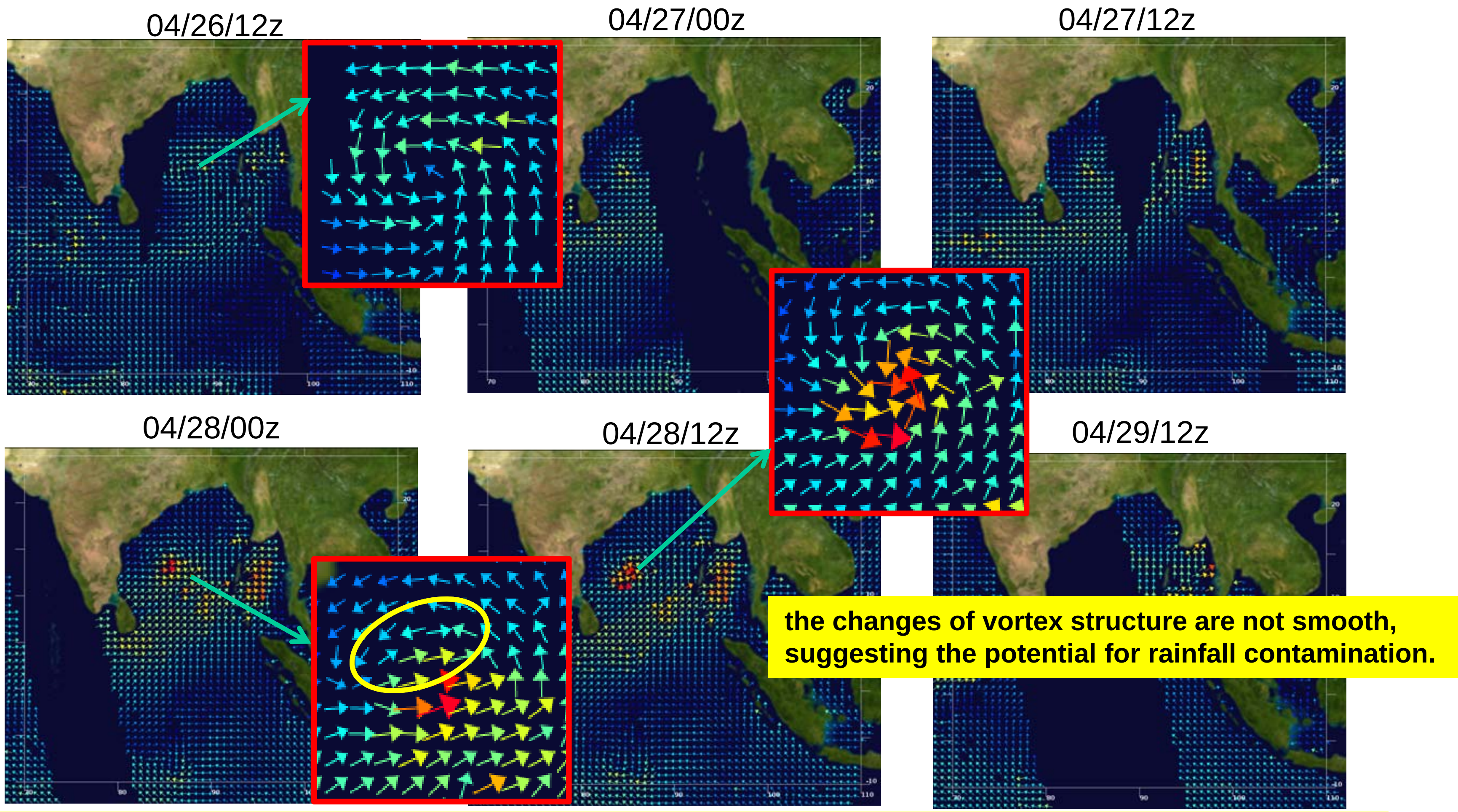
1200 UTC April 28 2008



Initial implementation of a visualization module into the CAMVis information system, including data convert and vector plotter for TRMM satellite-derived precipitation (left panel) and QuikSCAT winds (right panel), respectively. These figures show the TC Nargis (2008).

Shen, B.-W., W.-K. Tao, and B. Green, 2010c: Coupling NASA Advanced Multi-Scale Modeling and Concurrent Visualization Systems for Improving Predictions of Tropical High-Impact Weather (CAMVis). Computing in Science and Engineering, 23 Nov. 2010. IEEE computer Society Digital Library. IEEE Computer Society, http://doi.ieeecomputersociety.org/10.1109/MCSE.2010.141 (impact factor 0.973)

QuikSCAT Winds for Nargis (2008)



Data continuity (or consistency) is important for tracing a TC movement or identifying its formation. This above figure with QuikSCAT winds for Nargis (2008) is inter-compared with high-resolution model simulations, aimed at understanding the data consistent accuracy in the representation of mesoscale vortex circulation and thus improving formation prediction.

Nargis (2008) and an Equatorial Rossby Wave

Very severe cyclonic storm Nargis devastated Burma (Myanmar) in May 2008, caused tremendous damage (~$10 billion) and numerous fatalities (~130,000 deaths), and became one of the 10 deadliest tropical cyclones (TCs) of all time. To increase the warning time in order to save lives and reduce economic damage, it is important to extend the lead time in the prediction of TCs like Nargis. Seven-day high-resolution global simulations with real data show that the initial formation and intensity variations of TC Nargis can be realistically predicted up to 5 days in advance (bottom). Preliminary analysis (slide 7) suggests that improved representations of the following environmental conditions and their hierarchical multiscale interactions were the key to achieving this lead time: (1) a westerly wind burst and equatorial trough, (2) an enhanced monsoon circulation with a zero wind shear line, (3) good upper-level outflow with anti-cyclonic wind shear between 200 and 850 hPa, and (4) low-level moisture convergence.

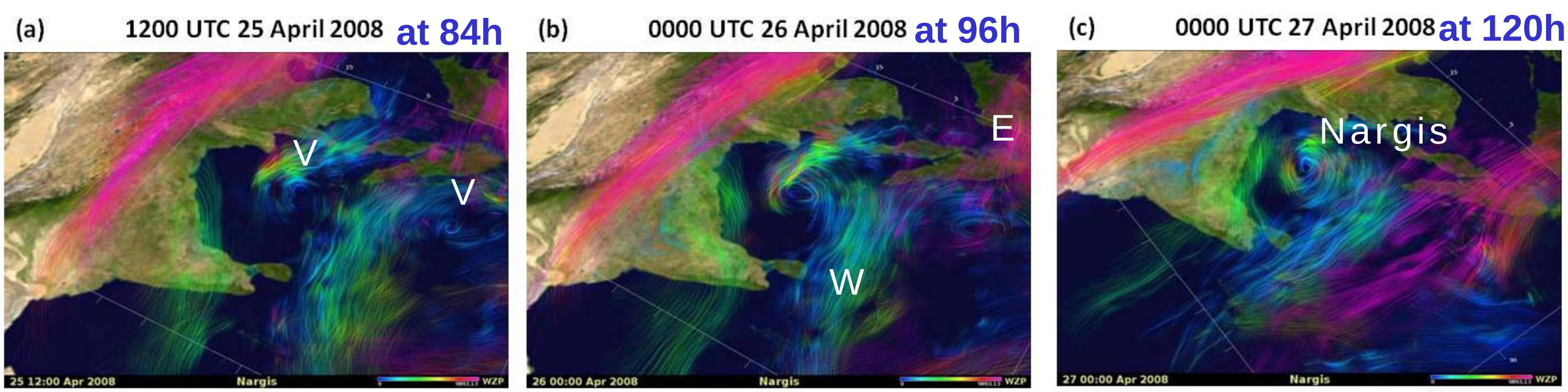


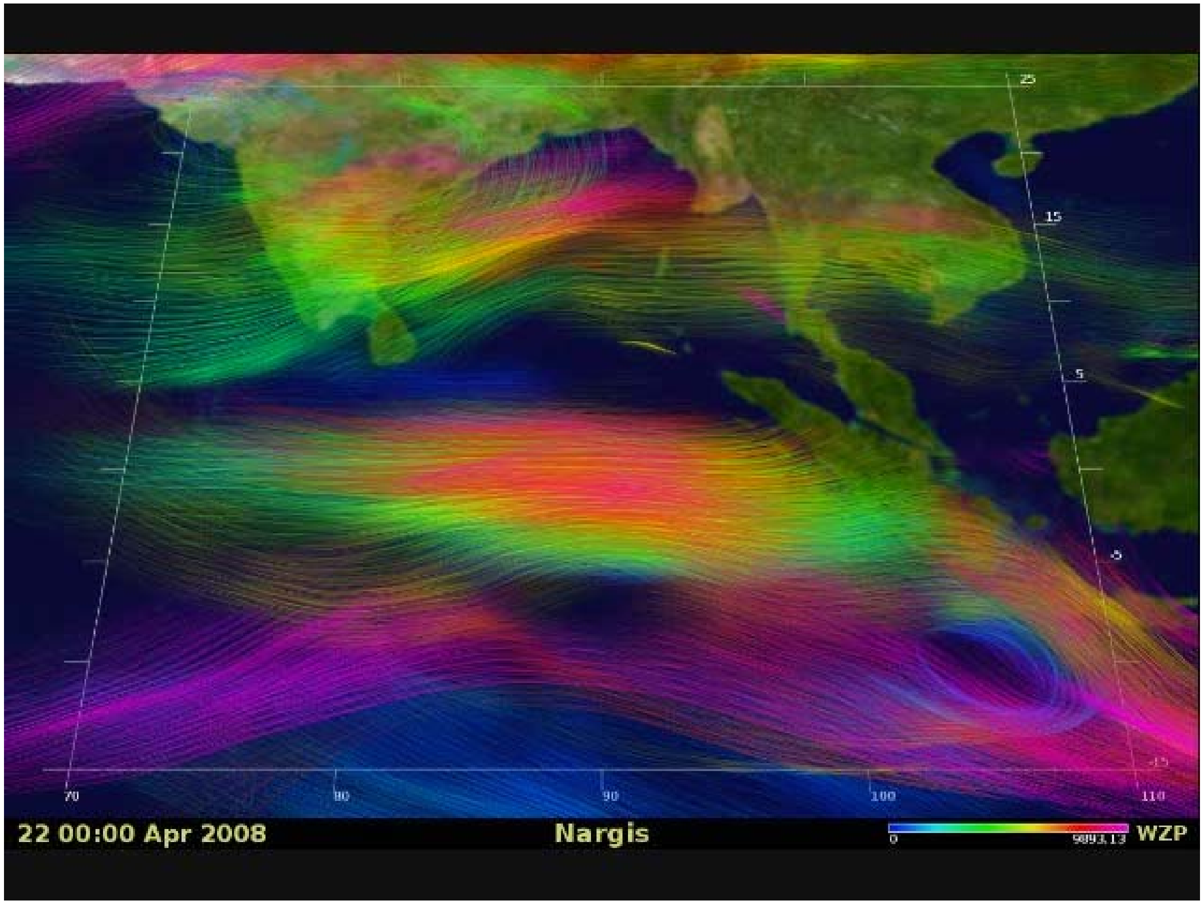
Figure: Realistic 7-day simulations of the formation and initial intensification of TC Nargis (2008) initialized at 0000 UTC April 22, 2008, showing streamlines at different levels. Low-level winds are in blue and upper-level winds in red: (a) formation of a pair of low-level mesoscale vortices (labeled in ‘V’) at 84h simulation, which are associated with an equatorial Rossby wave; (b) intensification of the northern vortex (to the left); (c) formation of TC Nargis associated with the enhancement of the northern vortex. 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).

7-day Forecast of Genesis of Cyclone Nargis (2008)
00 UTC 22 Apr-00UTC 29 Apr

An Integrative view with advanced global modeling, supercomputing, and visualization technologies

- Upper-level winds in red
- Low-level winds in blue

fusion of satellite data; the search for predictive index

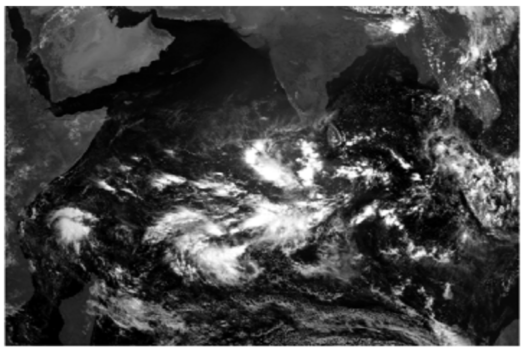


Bo-Wen Shen et al., JGR, **115, D14102, doi:10.1029/2009JD013140, 2010**

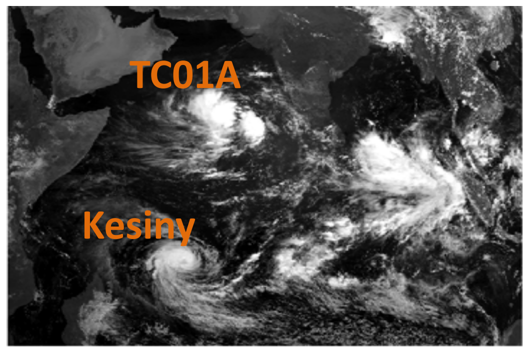
Twin Tropical Cyclones and an MJO in May 2002

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. Multiscale Interactions between a mixed Rossby gravity wave and the twin TC are shown in slide 9.

0630 UTC 1 May 2002



0000 UTC 6 May 2002



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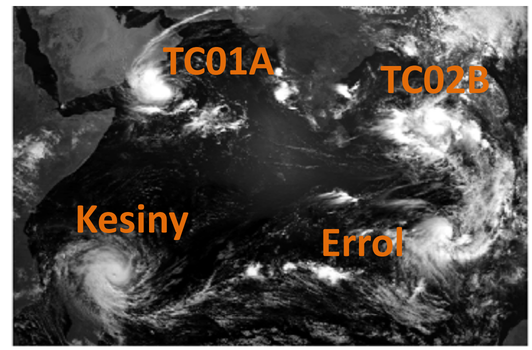


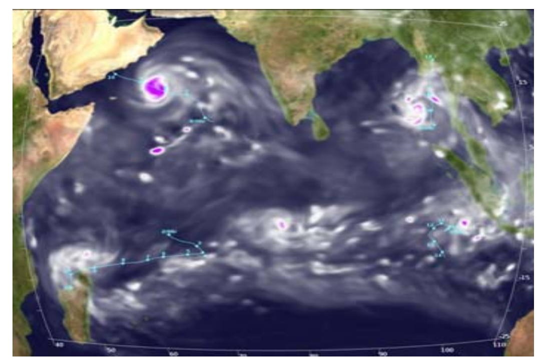


Figure: Predictions regarding the formation of twin tropical cyclones in the Indian Ocean: (a) MJO-organized convection over the Indian Ocean at 0630 UTC 1 May 2002. When the MJO moved eastward, two pairs of twin TCs appeared sequentially on 6 May (b) and 9 May (c), including TC 01A, Kesiny, TC 02B and Errol. Two TCs (01A and 02B) with anti-clockwise circulation appeared in the Northern Hemisphere, while the other 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., 2010c and 2011 for details).

Shen, B.-W., W.-K. Tao, et al. 2011: Forecasting Tropical Cyclogenesis with a Global Mesoscale Model: Preliminary Results for Twin Tropical Cyclones in May 2002. (to be submitted)

Brief Summary

Scenarios	Current Progress and Challenges	CAMVis Current Capabilities (as of February, 2011)
Real-time global multiscale modeling of hurricane or tropical cyclones (TCs)	limited scalability and significant I/O overheads	a revised parallelism for improving scalability (up to 364 CPUs with a speedup of 12 as compared to an earlier version); implementation of concurrent visualization to significantly reduce I/O overheads and thus enable high temporal-resolution (~7-15 minutes) global simulations
TC track forecast	steadily improving with a lead time of up to 96 hours during the past 20 years; as of 2008 and 2009, the 120h track errors of about 200 and 290 knots (~370 and 537 km) in Atlantic basin, respectively; still very challenging in other basins	remarkable 5-day forecasts of intense hurricanes in 2004 and 2005. e.g., a 5-day Katrina track error of 320 km with timing and location errors of 6h and 30km at landfall, respectively; a 7-day track error of 250km for the Nargis; thirteen 5-day forecasts of Hurricane Ivan (2004), giving an average error of about 280km at 120h predictions.
TC intensity forecast	progress being slow during the past twenty years, mainly because of the nature of multiscale interactions in TC dynamics	realistic 5-day intensity forecasts in limited number of cases (e.g., Ivan, 2004; six Katrina forecasts of the center pressure with errors of only ±12 hPa
TC formation forecast	experimental with a lead time of 48 hours at some operational centers (no official forecasts for the location and subsequent path)	realistic formation forecasts for twin TC (2002) 3~5 days in advance; for Nargis (2008) 5 days in advance; for hurricane Helene (2006) 22 days in advance
AEW forecast	"experimental" at some sites	realistic predictions of formation for multiple AEWs in two 30-day runs in 2004 and 2006, respectively

Why Predictable?

Anthes, R., 2011:"Turning the Tables on Chaos: Is the atmosphere more predictable than we assume?

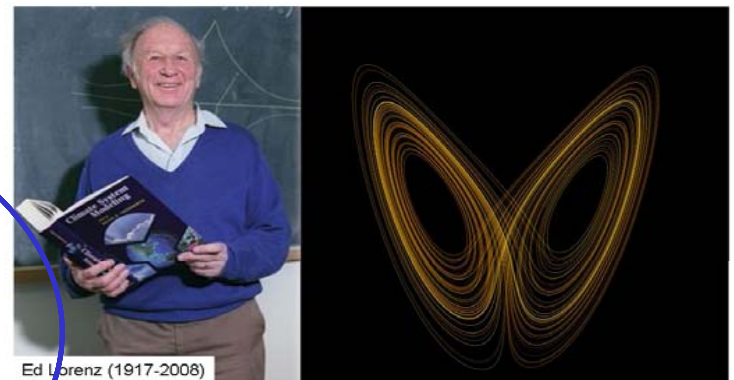
Anthes (2011, UCAR Magazine) discussed predictability, the foundation of predictions, as follows:

- Gottfried Leibniz (1646-1716), Pierre-Simon Laplace (1749-1827) and others: the future is predictable -- deterministic predictability
- Lorenz (1917-2008): perfect deterministic forecasts of weather were impossible --- "chaos theory", which is one of the three great scientific revolutions of the 20th century.
- In the early 1960s, J. Charney, C. Leith, Y. Mintz, and J. Smagorinsky suggested that the limit to useful deterministic predictions of large scale (synoptic) atmospheric motion was about two weeks. --- practical predictability
- Conducting simulations with his high-resolution regional model in 1980s, Anthes hypothesized that mesoscale features might be predictable one to three days in advance if synoptic-scale features could be accurately modeled. --- mesoscale predictability
- He illustrated recent amazing mesoscale predictions:

    1. Morris Weisman et al. (2011) describe a successful forecast of a mesoscale vortex with a derecho, a

       extended mesoscale predictability
    2. Shen et al. (2010a) reported a successful 7-day prediction of TC Nargis formation in the Indian Ocean;
    3. Shen et al. (2011) reported a successful 10-day prediction of twin TC formation and movement in the Indian Ocean;
    4. Shen et al. (2010b) reported a successful 4-week prediction for the initiation of multiple AEWs and formation of Hurricane Helene in the Atlantic.

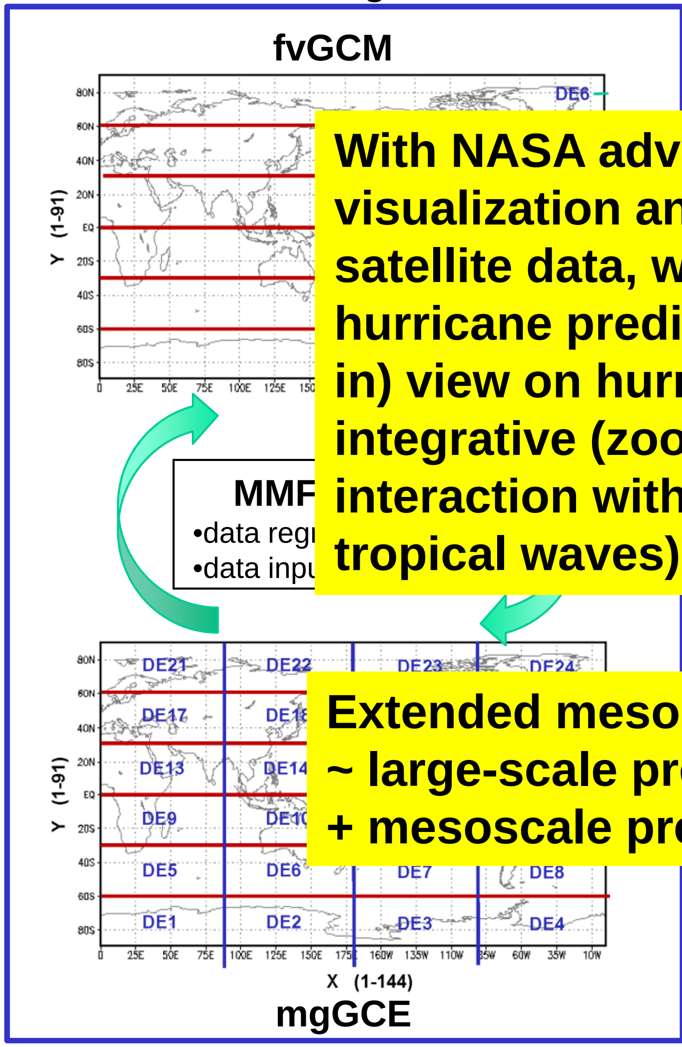
Does the flap of a butterfly's wing in Brazil set off a tornado in Texas?

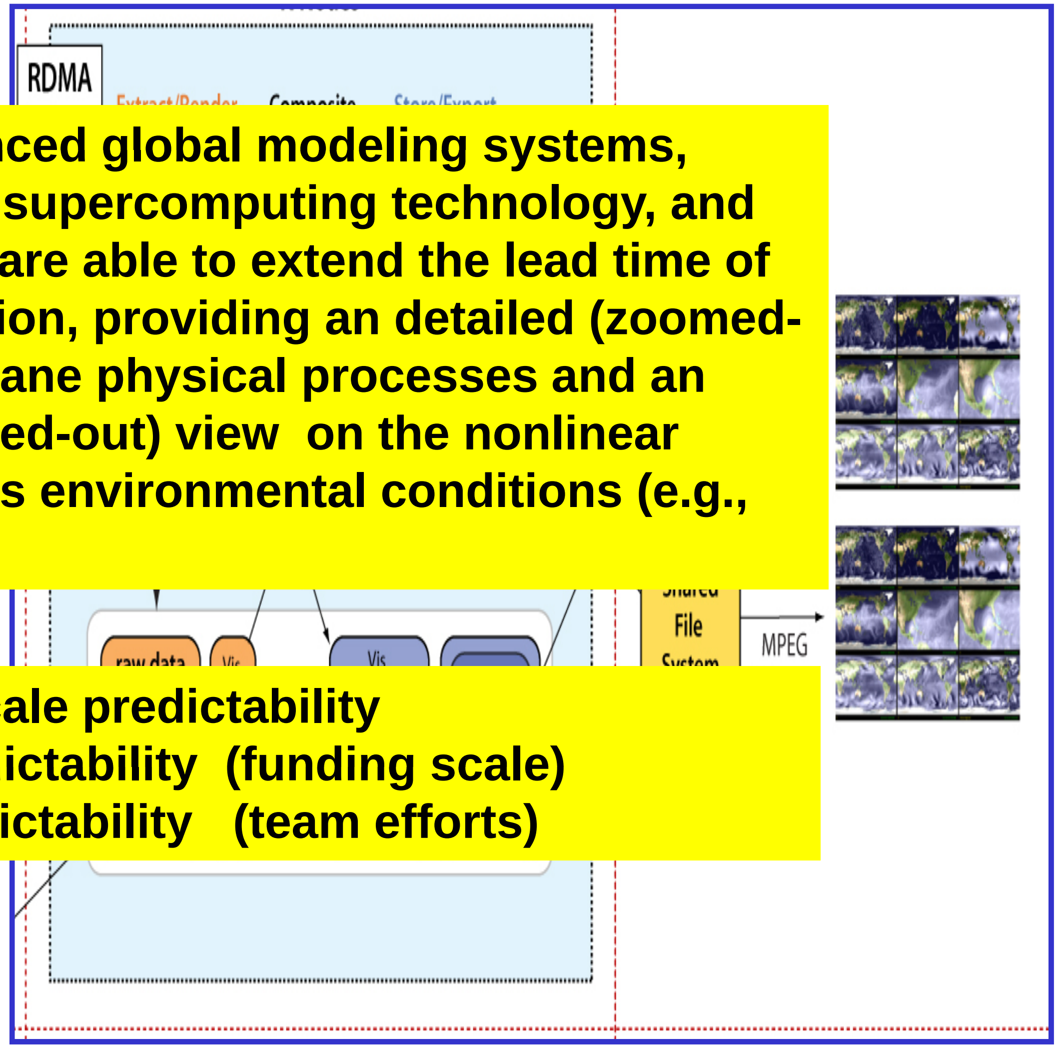


An African wave forming to the lee of the Ethiopian Highlands might well portend a hurricane threatening the Texas coast two weeks later—butterflies or no butterflies

Concluding Remarks

Multi-scale Modeling with "M" nodes | Current Visualization with "N" nodes | Real-time Display





With NASA advanced global modeling systems, visualization and supercomputing technology, and satellite data, we are able to extend the lead time of hurricane prediction, providing an detailed (zoomed-in) view on hurricane physical processes and an integrative (zoomed-out) view on the nonlinear interaction with its environmental conditions (e.g., tropical waves).

Extended mesoscale predictability
~ large-scale predictability (funding scale)
+ mesoscale predictability (team efforts)

Simulation | Extraction | Visualization | MPEG generation