Global Weather/Climate Modeling with NASA Supercomputing Technology

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Employment

- 2014/Aug - Present: *Associate Professor,* SDSU
- 2014/Aug - Present: *Visiting Associate Research Scientist*, ESSIC, University of Maryland, College Park (UMCP)
- 2012 - 2014: *Associate Research Scientist,* UMCP and NASA/GSFC
- 2006 - 2012: *Assistant Research Scientist*, UMCP and NASA/GSFC
- 1999 - 2006: *Senior Software Engineer* (Research Scientist), Science Application International Corporation (SAIC) and NASA/GSFC
- 1998 - 1999: Research Scientist, North Carolina State University (NCSU)
- 1995 - 1998: Research Assistant (part time), NCSU
- 1994 - 1995: Research Assistant, National Central University (NCU), Taiwan
- 1992 - 1994: Meteorological Officer (*Unix System Application Developer* and Administrator, military service), Weather Center of Weather Wing, Taiwan
- 1990-1992: Teaching and Research Assistant (part time), NCU, Taiwan

Outline

1. Introduction
2. Research Projects, Funds and Area of Interests
3. Supercomputing, Visualization, and Global Modeling
4. Predictability and Chaos (Butterfly effect)
5. Summary and Future Tasks

Research Projects and Funds

Selected Projects and Funds

- SDSU Startup Funds: $134,000, 09/2014-08/2016.
- NASA AIST CAMVis-MAP Project (PI: Shen), AIST11:

  $1,107K, 05/2012–08/2015,

  Integration of the NASA CAMVis and Multiscale Analysis Package (CAMVis-MAP) for Tropical Cyclone Climate Study.

  AIST: Advanced Information System Technology;

  HEC: High-Ending Computing

Pending Proposal

- NASA AIST Project (PI: Shen), AIST14 (submitted on July 10):

  $957.8K, 05/2015-04/2017

  Integration of Concurrent Ensemble Hierarchical Modeling and Fusion-Based Multivariate Data Visualization into the NASA CAMVis for Improving Climate Simulations

  (A joint proposal with 9 researchers)

Area of Interests and Research Highlights

1. High-Resolution Global Climate/Weather Modeling
2. High-end Computing and Large-scale Scientific computing
3. Numerical methods for linear and nonlinear data analysis
4. Nonlinear Dynamics (e.g., Chaos and Mountain Meteorology)

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 down-right fibrications 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 Hawai'i, Manoa. That gave them simulations that bore some resemblance to real weather maps but that ran 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 chirp 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 newest, 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 stepped 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, when, 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 Atmospheric 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

1040 — 25 AUGUST 2006 VOL 313 SCIENCE www.sciencemag.org — Published by AAAS

A central question to be addressed: ***"Is new science being produced or just really cool pictures?",*** which was raised by Mahlman and others who have reservations

(Above left to right) Dr. Bo-Wen Shen, Atmospheric Scientist; Jane Chevalier, Vice President for Science and Technology Strategy; Dr. Phil Silcock, Senior Signal Processing Analyst and 2006 Black Engineer of the Year

Science, August 2006

SAIC 2006 annual report

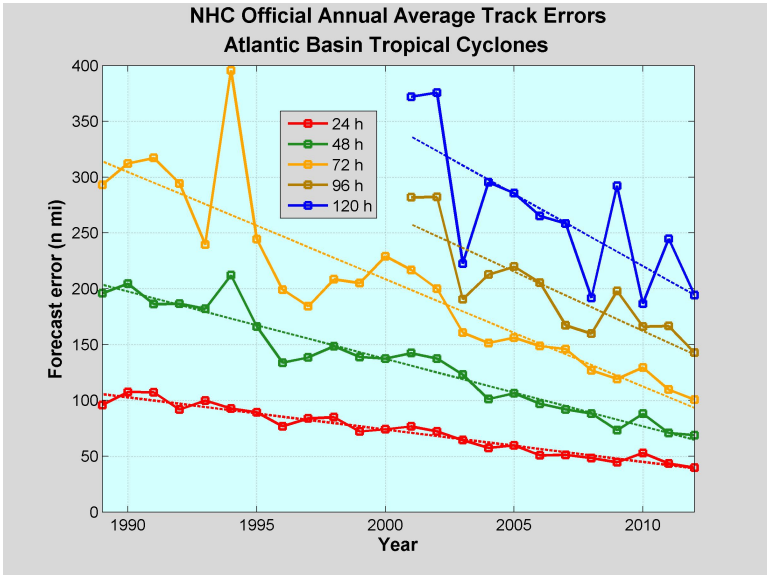
Publications and Professional Achievements
(since 2010)

1. Ten (Five) awards from UMCP, SAIC and NASA/GSFC Since 2001 (2006).
2. Research results featured by Dr. Jack Kaye (Associate Director at NASA/HQs) at the Interdepartmental Hurricane Conferences in 2012, 2013, and 2014.
3. Research results featured in a recent President's Corner article of UCAR Magazine by Dr. Rick Anthes, published on May 6, 2011. This article entitled *``Turning the Tables on Chaos: Is the atmosphere more predictable than we assume?"*
4. Research results featured in NASA News Stories (07/2010 and 11/2010).

   It was also translated in Chinese by Science and Technology Division, Taipei Economic and Cultural Representative Office in the United States (駐美國台北經濟文化代表處科技組).
5. Research results appeared in news medias, such as MSNBC, PhysOrg.com, National Geographic--Indonesia, ScienceDaily, EurekAlert, Yahoo News, TechNews Daily, Scientific Computing, HPCwire, Asian News International etc. (2010)
6. Research projects selected as one of top 4 demonstrations at NASA Booth for Supercomputing Conferences (SC) in 2004, 2008, 2009, and 2010.

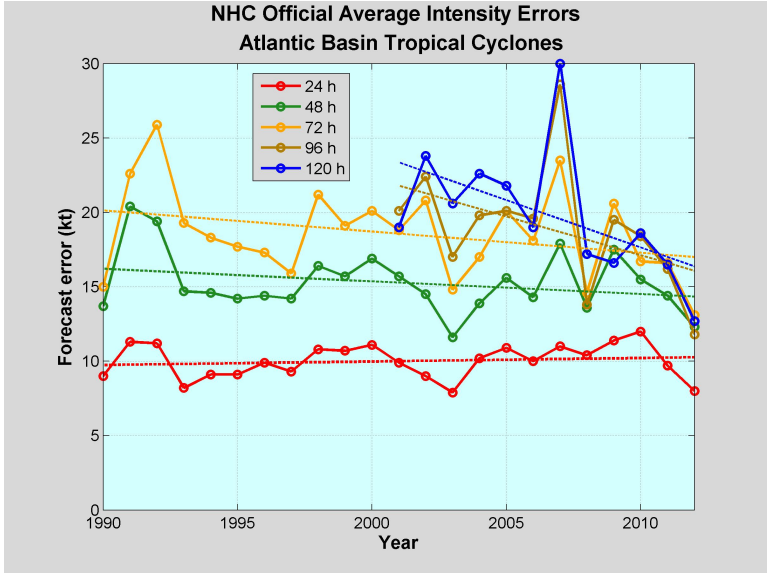
Progress of Hurricane Forecasts

Track Errors (1989-2012)



better

Intensity Errors (1990-2012)



During the past twenty years, track forecasts have been steadily improving (left panel), but Intensity forecasts have lagged behind until recently (e.g., 2012) (right panel).

``... the general problem of tropical cyclogenesis remains in large measure, one of the greatest mysteries of the tropical atmosphere." – Kerry Emanuel of MIT, *The Divine Wind (2005).*

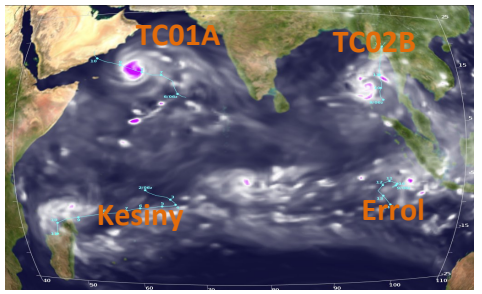
Supercomputing, Visualization, and Modeling

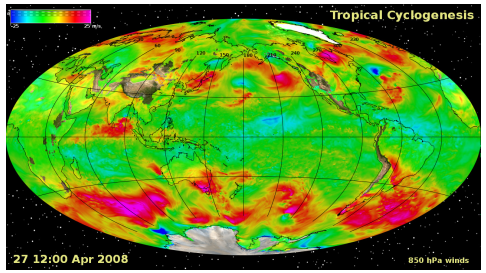
Objective of AIST11:

Develop a scalable, multiscale analysis tool, based on the Coupled Advanced multiscale Modeling and Visualization system (CAMVis), to improve extended-range tropical cyclone (TC) prediction and consequently TC climate projection by enabling:

- Understanding of the TC genesis processes, accompanying multiscale processes (both downscaling by large-scale events and upscaling by small-scale events), and their subsequent non-linear interactions
- Discovery of hidden predictive relationships between meteorological and climatological events.

This project targets the ACE, PATH, SMAP and 3D-Winds missions.





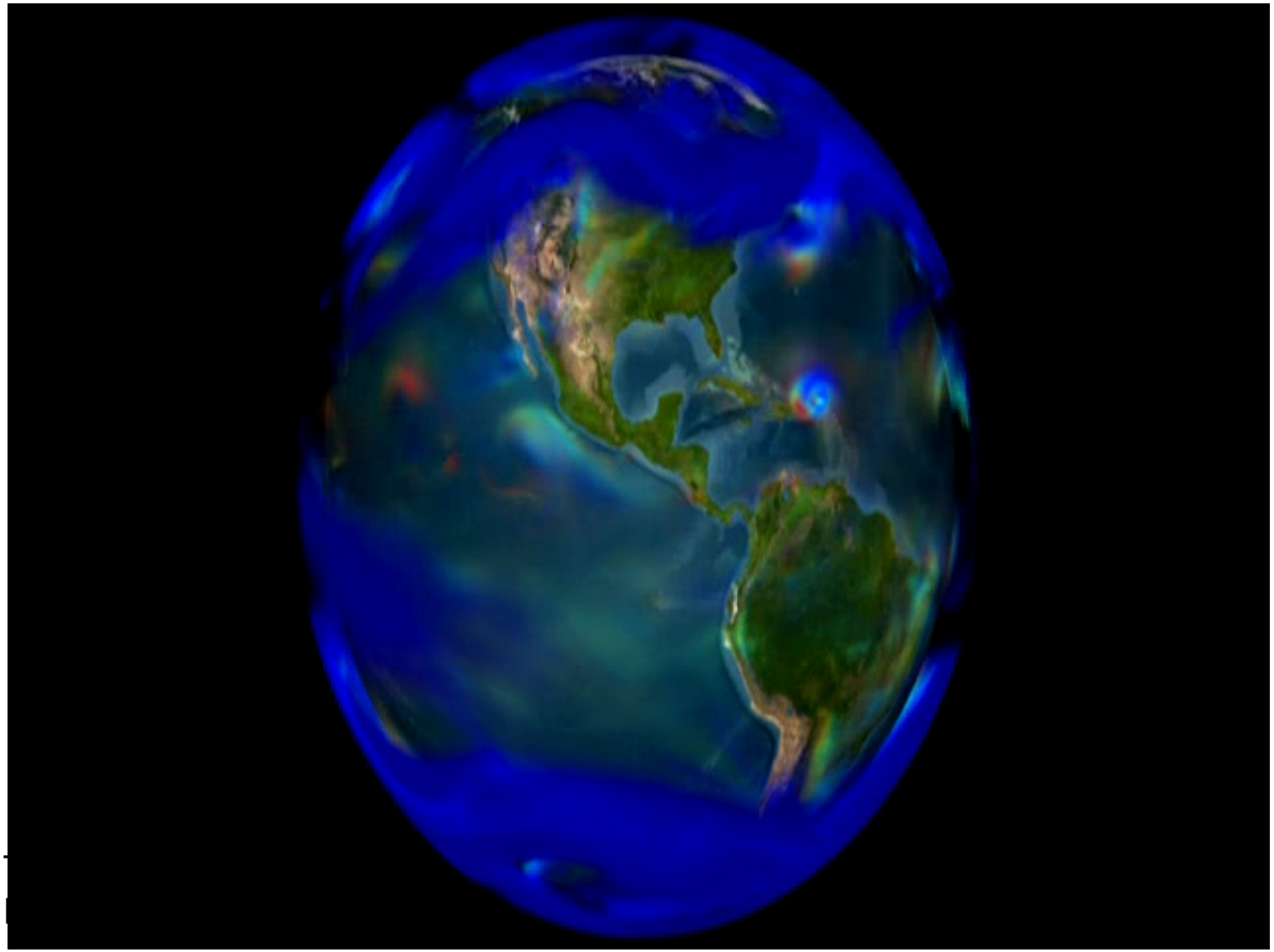
NASA Supercomputing and Visualization Systems

Pleiades Supercomputer (as June 2013)

- one of a few petascale supercomputers
- R_{max} of 1,240 teraflops (LINPACK); R_{peak} of 2,880 teraflops
- 162,496 cores in total; Intel Xeon processors, Nehalem, Westmere,Sandy Bridge, Ivy Bridge,
- 417 TB memory
- 3.1 PB disk space
- Largest InfiniBand network.

- Large-scale visualization system
  - 8x16 LCD tiled panel display
  - 245 million pixels
- 128 nodes
  - 1024 cores, 128 GPUs
- InfiniBand (IB) interconnect to Pleiades
  - 2D torus topology
  - High-bandwidth

Grid Cells vs. Grid Spacing



Visualizations of Sandy

Fallen Behind?

October 28, 2012, 8:17 PM ET

Why America Has Fallen Behind the World in Storm Forecasting

Article | Comments (22)

COMMENTARY By KERRY EMANUEL

Reuters

by Prof. Kerry Emanuel in the Wall Street Journal

SCIENTIFIC METHOD / SCIENCE & EXPLORATION

Why European forecasters saw Sandy's path first

US weather model is good, but lags behind the best.

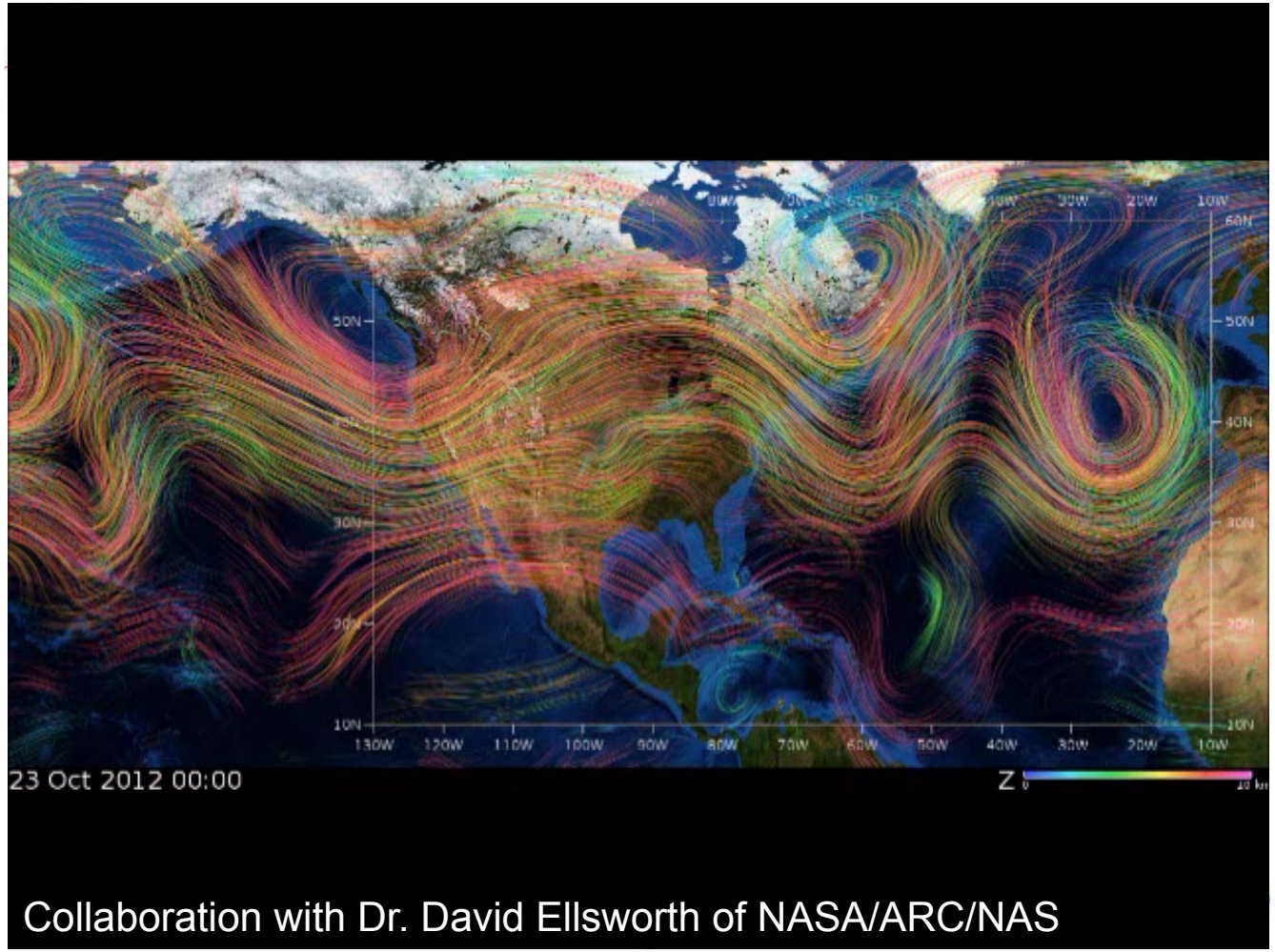
by Scott K. Johnson - Dec 26 2012, 1:30pm EST

EARTH SCIENCE | SCIENCE POLICY AND EDUCATION

Satellite image of Hurricane Sandy

Shen, B.-W., B. Nelson, W.-K. Tao, and Y.-L. Lin, 2013a: Advanced Visualizations of Scale Interactions of Tropical Cyclone Formation and Tropical Waves. *IEEE Computing in Science and Engineering*, vol. 15, no. 2, pp. 47-59, March-April 2013, doi:10.1109/MCSE.2012.64.

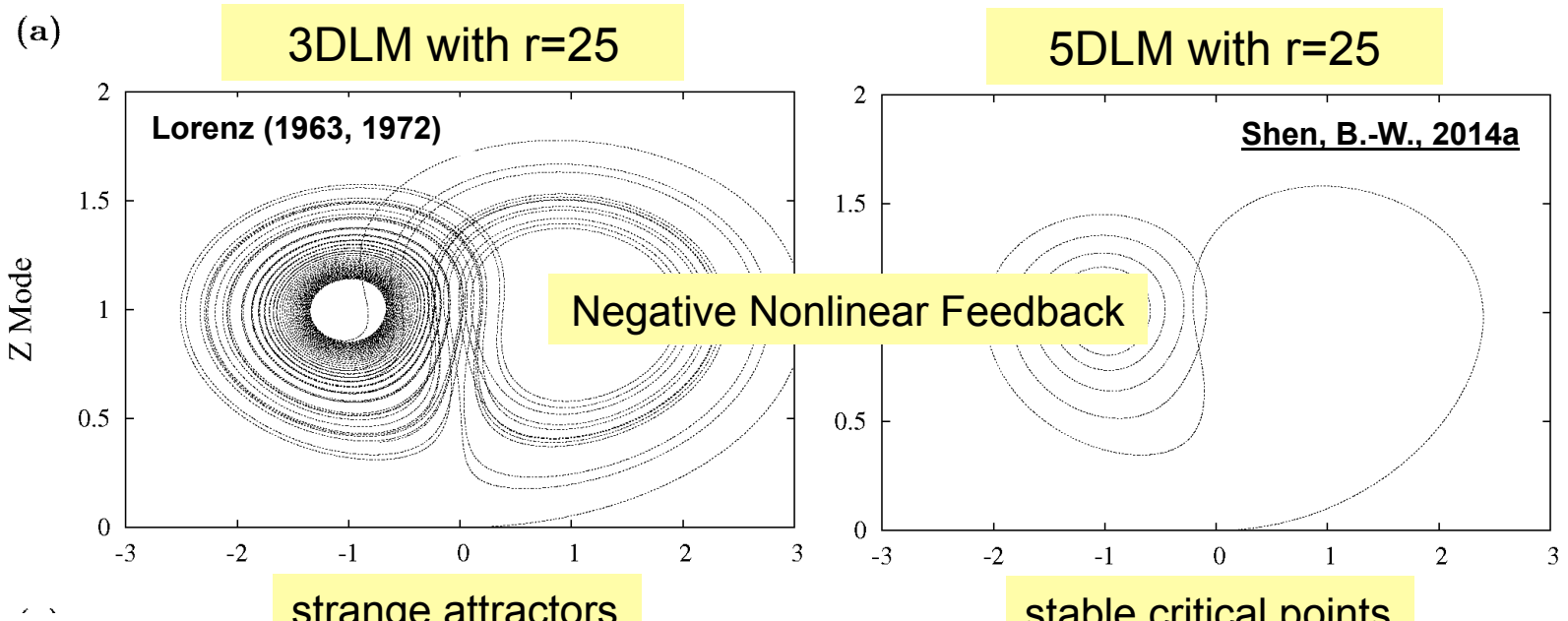
Visualizations of Sandy



Shen, B.-W., B. Nelson, W.-K. Tao, and Y.-L. Lin, 2013a: Advanced Visualizations of Scale Interactions of Tropical Cyclone Formation and Tropical Waves. *IEEE Computing in Science and Engineering*, vol. 15, no. 2, pp. 47-59, March-April 2013, doi:10.1109/MCSE.2012.64.

Chaos in the 3D and 5D Lorenz Models

1. Are the simulations of TC genesis consistent with Chaos theory?
2. Why can the high-resolution global model have skills?



Butterfly effect?

The studies by Lorenz (1963, 1972) laid the foundation for chaos theory, which was viewed as the third scientific revolution of the 20th century after relativity and quantum mechanics (e.g. Gleick, 1987; Anthes 2011).

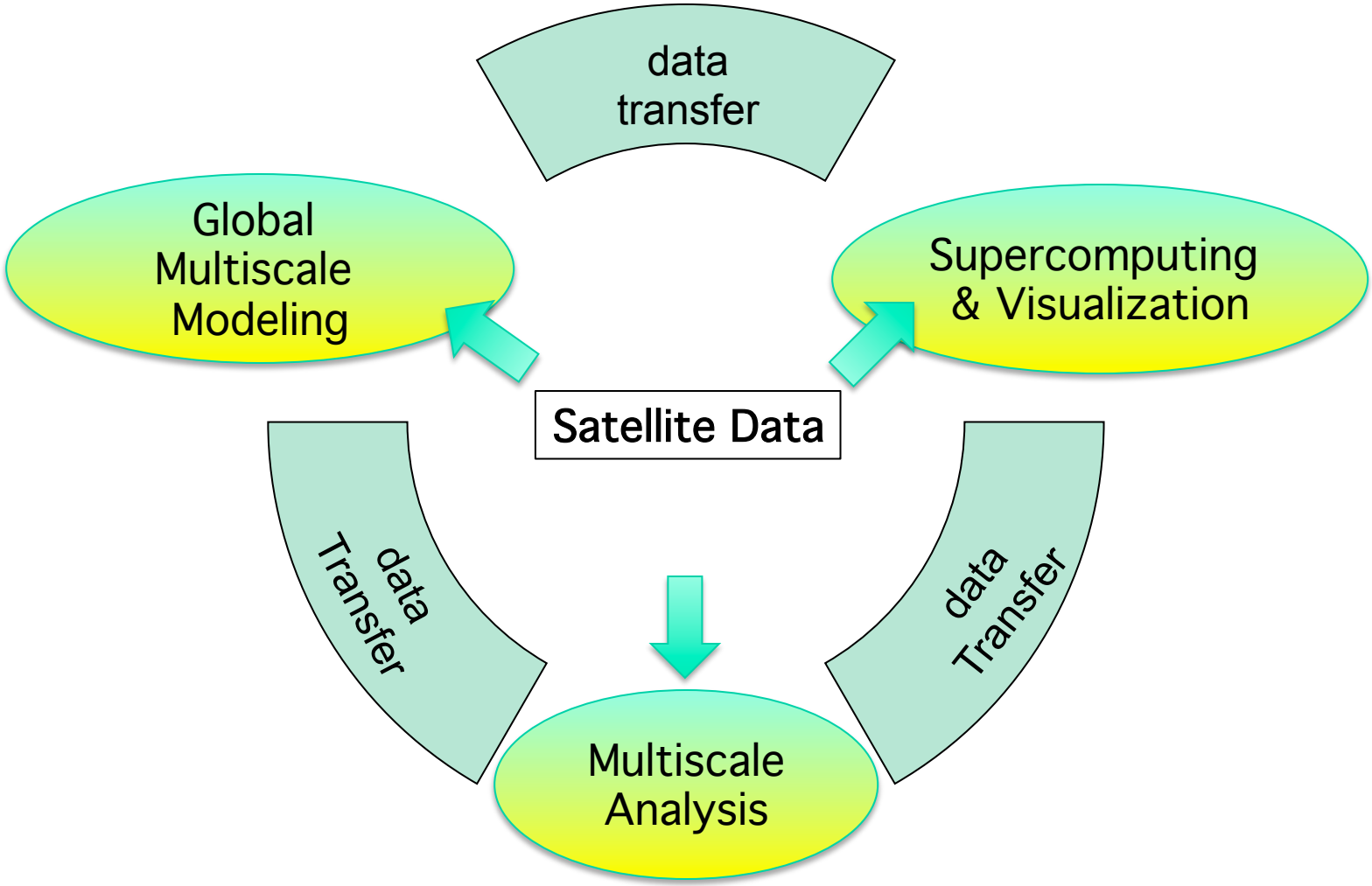
Reviewer's Comments

Evaluation/Assessment of the Technical Progress of the Project

This is an extremely ambitious project of high value to NASA and the nation. The team is making progress on all tasks and I don't see any stumbling blocks to achieving all the year 2 milestones. All aspects of the year two tasks were discussed.

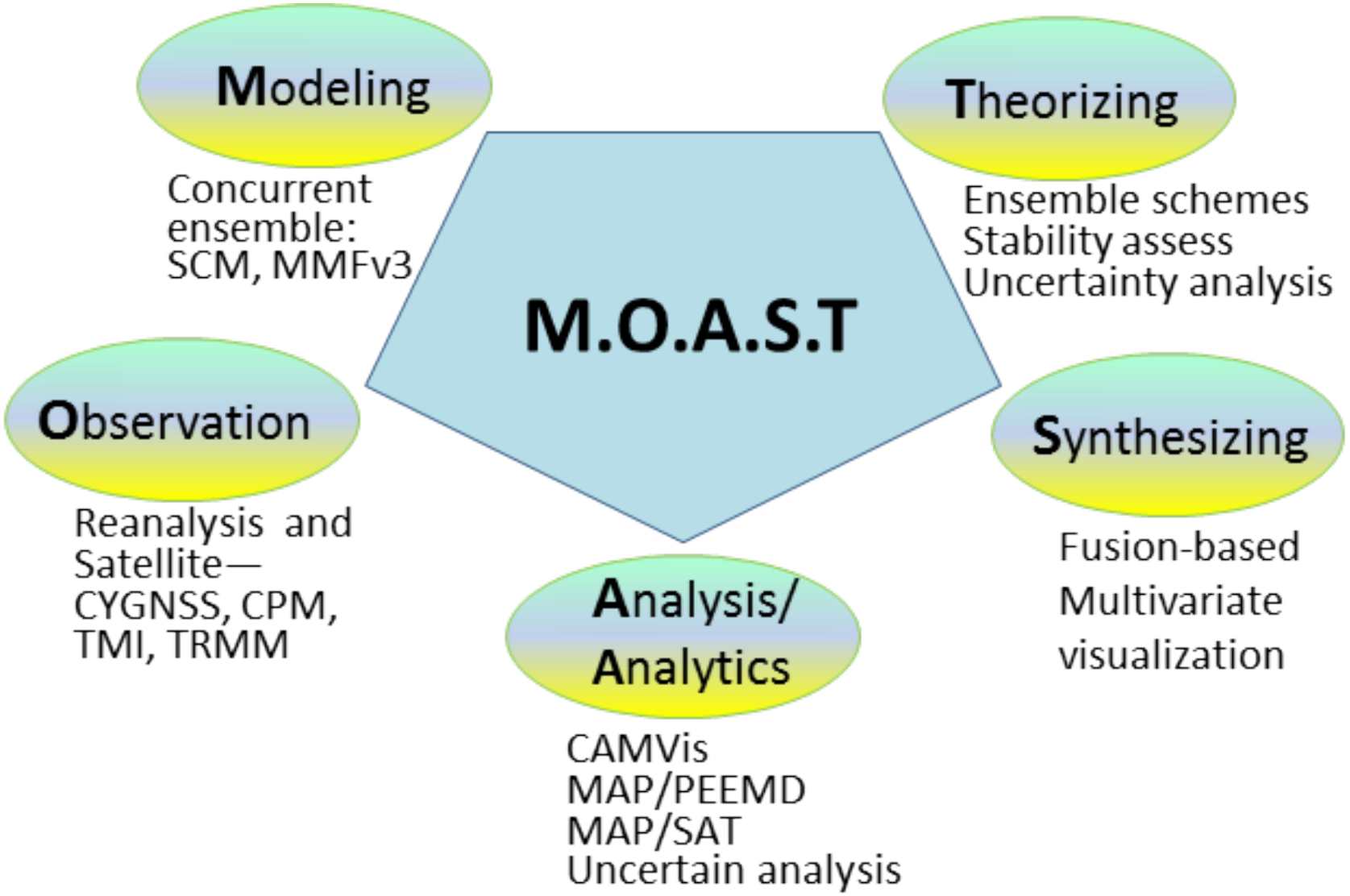
Now about your question. I believe that it can as whether the system is conservative or not, trajectories must still diverge for chaos to be present. The fact that this is true for finite times I found out from my two PhD students who are working on orbital stability of exoplanets. They confirmed your statement about Hamiltonian chaos.

AIST11 and AIST14 (pending)



Scalable Multiscale Analysis Package

AIST11 and AIST14 (pending)



Published Articles since 2010

Journal Articles:

1. **Shen, B.-W., 2014a:** Nonlinear Feedback in a Five-dimensional Lorenz Model. *J. of Atmos. Sci.* **71**, 1701–1723. doi: http://dx.doi.org/10.1175/JAS-D-13-0223.1
2. **Shen, B.-W.,** M. DeMaria, **J.-L. F. Li and S. Cheung, 2013c:** Genesis of Hurricane Sandy (2012) simulated with a global mesoscale model, *Geophys. Res. Lett., 40,* 4944–4950, *doi:*10.1002/grl.50934.
3. **Shen, B.-W.,** B. Nelson, **S. Cheung,** W.-K. Tao, **2013b:** Improving NASA's Multiscale Modeling Framework for Tropical Cyclone Climate Study. *IEEE Computing in Science and Engineering*, vol. 15, no 5, pp 56-67. Sep/Oct 2013.
4. **Shen, B.-W.,** B. Nelson, W.-K. Tao, and Y.-L. Lin, **2013a:** Advanced Visualizations of Scale Interactions of Tropical Cyclone Formation and Tropical Waves. *IEEE Computing in Science and Engineering*, vol. 15, no. 2, pp. 47-59, March-April 2013, doi: 10.1109/MCSE.2012.64.
5. **Shen, B.-W.,** W.-K. Tao, and Y.-L. Lin, and A. Laing, **2012:** Genesis of Twin Tropical Cyclones as Revealed by a Global Mesoscale Model: The Role of Mixed Rossby Gravity Waves. *J. Geophys. Res.* 117, D13114, doi:10.1029/2012JD017450. 28pp
6. **Shen, B.-W.,** W.-K. Tao, and B. Green, **2011:** Coupling Advanced Modeling and Visualization to Improve High-Impact Tropical Weather Prediction (CAMVis). *IEEE Computing in Science and Engineering (CiSE)*, vol. 13, no. 5, pp. 56-67, Sep./Oct. 2011, doi: 10.1109/MCSE.2010.141.
7. **Shen, B.-W.,** W.-K. Tao, and M.-L. Wu, **2010b:** African Easterly Waves in 30-day High resolution Global Simulations: A Case Study during the 2006 NAMMA Period. Geophys. Res. Lett., 37, L18803, doi:10.1029/2010GL044355.
8. **Shen, B.-W.,** W.-K. Tao, W. K. Lau, R. Atlas, **2010a:** Predicting Tropical Cyclogenesis with a Global Mesoscale Model: Hierarchical Multiscale Interactions During the Formation of Tropical Cyclone Nargis (2008) . J. Geophys. Res.,115, D14102, doi: 10.1029/2009JD013140.

Magazine Articles:

9. **Shen, B.-W., S. Cheung, J.-L. F. Li, and Y.-L. Wu, 2013e:** Analyzing Tropical Waves using the Parallel Ensemble Empirical Model Decomposition (PEEMD) Method: Preliminary Results with Hurricane Sandy (2012), NASA ESTO Showcase . IEEE Earthzine.
10. **Shen, B.-W., 2013f:** Simulations and Visualizations of Hurricane Sandy (2012) as Revealed by the NASA CAMVis. NASA ESTO Showcase. IEEE Earthzine. posted December 2, 2013.

Papers under review/preparation:

11. **Shen, B.-W., 2014b:** On the Nonlinear Feedback Loop and Energy Cycle of the Non-dissipative Lorenz Model. (accepted, NPGD)
12. **Shen, B.-W., 2014c:** Nonlinear Feedback in a Six-dimensional Lorenz Model. *Impact of an Additional Heating Term. (to be submitted)*