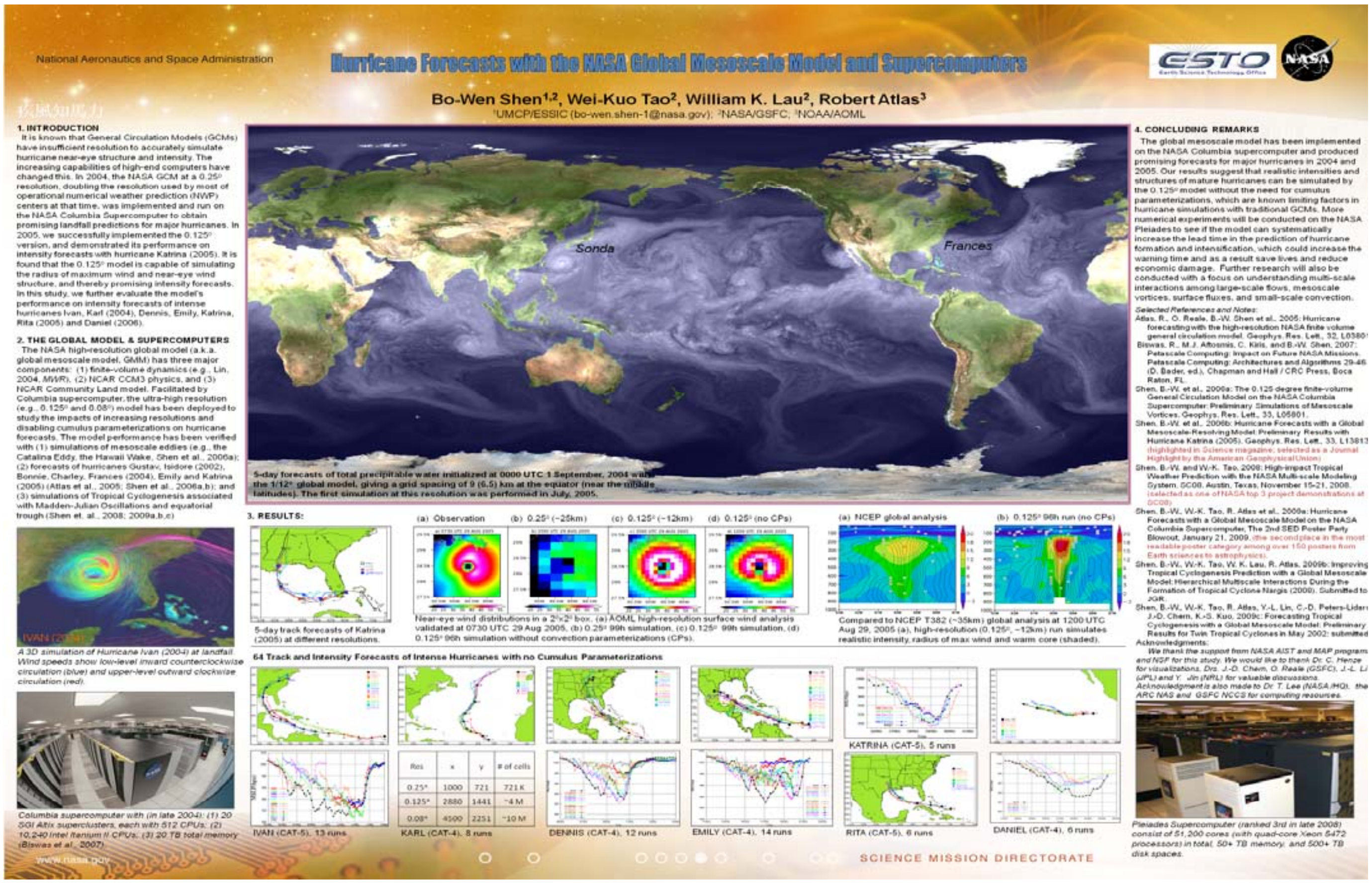
Global Mesoscale Modeling with NASA Supercomputing Technology: Hierarchical Multi-scale Interactions during the Formation of Nargis (2008)

Bo-Wen Shen[1,2]

[1]UMCP/ESSIC; [2]NASA/GSFC



bio

Employment/Experiences:

- 2006 - Present: Research Scientist, ESSIC, University of Maryland
- 1999 - 2006: Research Scientist, Sr. Software Engineer, SAIC
- 1998 - 1999: PostDoc, NCSU
- 1995 - 1998: PhD student, Research/Teaching Assistant, NCSU
- 1994 - 1995: Research Assistant, NCU, Taiwan
- 1992 - 1994: Meteorological Officer (Unix System Application Developer and Administrator, military service), Weather Center of Weather Wing, Taiwan
- 1990, 1992, NCU

Thesis and Dissertation :

(theoretical and modeling studies with a focus on comparisons among different scale weather systems from non-hydrostatic, hydrostatic, ageostrophic, to quasi-geostrophic mountain waves.)

- Shen, B.- W., 1992: *A Linear Theory for a Three-Dimensional Flow over an Isolated Mountain*, Master Thesis, National Central University, Taiwan, (in Chinese) p. 85
- Shen, B.-W., 1998: *Inertia Critical Layers and Their Impacts on Nongeostrophic Baroclinic Instability.* North Carolina State University. 10/1998. p255.

Advisor: Prof. Yuh-Lang Lin ←the lead author of the microphysics scheme (Lin et al., 1983)

GODDARD SPACE FLIGHT CENTER

Office of the Director
Director – R. Strain
Deputy Director – A. Obenschain
Deputy Director for Science & Technology – L. Leshin
Associate Director – N. Abell
100

NASA Office of Inspector General
190

Equal Opportunity Programs Office
L. Simmons
120

Office of Public Affairs
M. Hess
130

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R. Stephens
140

NASA Independent Verification & Validation Program Office
D. Caffall
180

Office of Human Capital Management
Director – V. Brade
Deputy – D. Parsons
110

Office of Chief Financial Officer
Director – C. Ejiasa
Deputy – J. Baker
150

Management Operations
Director – T. Paprocki
Deputy – R. Rubilotta
200

Safety & Mission Assurance
Director – M. Watkins
Deputy – Vacant
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Director – G. Morrow
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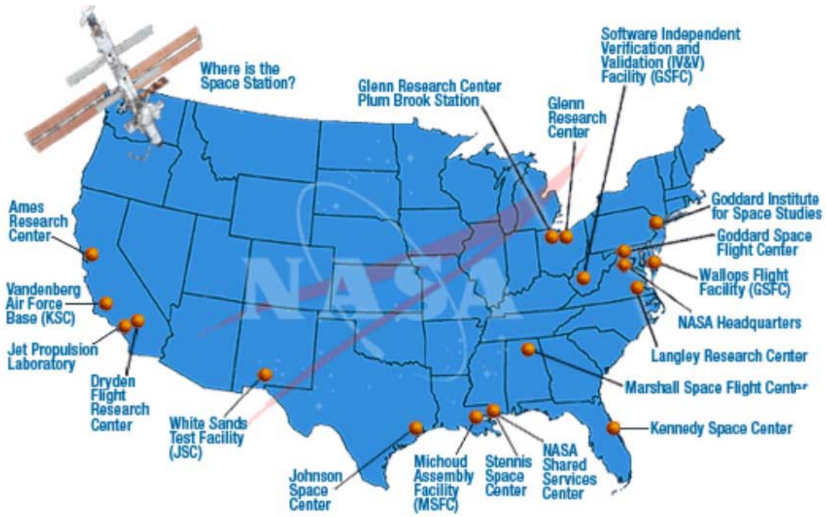
600

Information Technology & Communications
Director – L. Cureton
Deputy – M. Walther
700

Suborbital & Special Orbital Projects
Director – J. Campbell
Deputy – C. Purdy
800

NASA Workforce Map



http://nasapeople.nasa.gov/workforce/

- NASA HQ - Headquarters, Washington, DC
- ARC - Ames Research Center, Mountain View, California
- DFRC - Dryden Flight Research Center, Edwards AFB, California
- LaRC - Langley Research Center, Hampton, Virginia
- GRC - Glenn Research Center, Cleveland, Ohio
- GSFC - Goddard Space Flight Center, Greenbelt, Maryland
- IV&V (GSFC) - Independent Verification and Validation Facility, Fairmont, West Virginia
- WFF (GSFC) - Wallops Flight Facility, Wallops Island,Virginia
- JPL - Jet Propulsion Laboratory, Pasadena, California
- JSC - Johnson Space Center, Houston, Texas
- KSC - Kennedy Space Center, Merritt Island, Florida
- MSFC - Marshall Space Flight Center, Huntsville, Alabama
- NSSC - NASA Shared Services Center, Bay St. Louis, Mississippi
- SSC - Stennis Space Center, Bay St. Louis, Mississippi
- WSTF - White Sands Test Facility, Las Cruces, New Mexico

CS: CIVIL SERVICE　　CTR: CONTRACTOR

NASA Full-time Equivalent Employment
CS: 18,600 CTR: 43,500

NASA HQ	
CS	1,300
CTR	650

ARC	
CS	1,280
CTR	1,100

DFRC	
CS	490
CTR	460

LaRC	
CS	1,960
CTR	1,500

GRC	
CS	1,700
CTR	1,400

GSFC	
CS	3,020
CTR	4,200

IV&V (GSFC)	
CS	40
CTR	100

WFF (GSFC)	
CS	240
CTR	466

JPL	
Cal Tech	5,200
CTR	240

JSC	
CS	3,160
CTR	12,100

KSC	
CS	2,080
CTR	13,300

MSFC	
CS	2,550
CTR	5,500

SSC	
CS	280
CTR	1,380

NSSC
50
150

WSTF
55
520

- The civil service data does not include student employment.
- Contractor data is approximate and from the 2006 FAIR inventory.
- JPL employees are not civil service; they work for Cal Tech.
- Data is as of June 2006

Team Work

BEIJING (AP) - The U.S. has failed to advance out of the first round of both the men's and women's 400-meter relays at the Olympics, dropping the baton in each race.

Collaborators (since 2005)

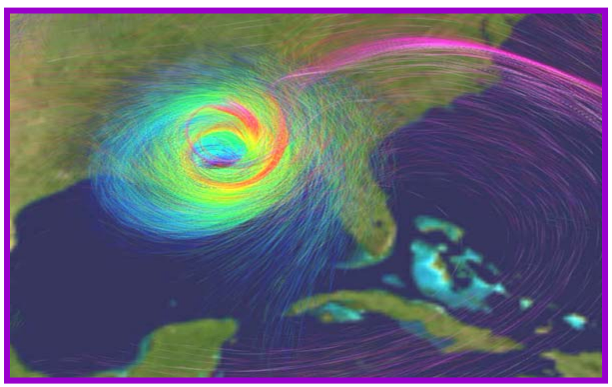
NASA/GSFC: Wei-Kuo Tao (lead), William K.-M. Lau, Jiun-Dar Chern, Christa Peters-Lidard, Oreste Reale, Kuo-Sen Kuo (GSFC), Tsengdar Lee (HQ)

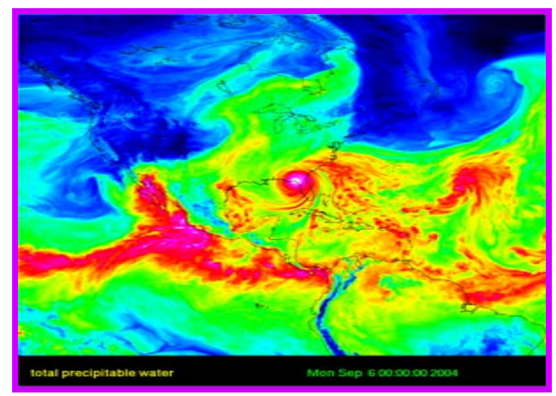
NASA/ARC: Bryan Green, Chris Henze, Piyush Mehrotra, Samson Cheung, Henry Jin, Johnny Chang,

NASA/JPL: Jui-lin (Frank) Li, Peggy Li;

NOAA: Robert Atlas (AOML), Shian-Jiann Lin (GFDL)

Acknowledgements: Drs. A. Busalacchi (ESSIC), Jin Yi (NRL), Dr. Jenny Wu (GSFC), Drs. C. Schulbach, R. Ciotti, C. Niggley, S. Chang, W. Thigpen, B. Hood A. Lazanoff, K. Freeman, J. Taft, control-room (NASA/ARC) and P. Webster (NASA/GSFC),





High-resolution Global Modeling at AGU 2010 WPGM

http://www.agu.org/meetings/wp10

- Meeting place: Taipei, Taiwan
- Meeting time: 22-25 June 2010
- Deadline: 25 Feb 2010 for abstract submissions
- Session title: "High-resolution Global and Regional Modeling and Simulations of High-impact Weather and Climate"

- Conveners: Bo-Wen Shen of UMCP/ESSIC and NASA/GSFC,
  Shian-Jiann Lin of NOAA/GFDL,
  Jin-Luen Lee of NOAA/ESRL,
  Masaki Satoh of CCSR at U. of Tokyo

Outline

Introduction

Global Mesoscale Modeling with NASA Supercomputing Technology

Simulations of High-impact Tropical Weather

- 5-day track/intensity forecasts of Katrina (2005) and Ivan (2004)
- 10-day genesis forecasts of Twin TCs (2002)
- Multiscale interactions during the formation of Nargis (2008)
- 15/30-day simulations of Madden-Julian Oscillations in 2002/2006
- Five AEWs and genesis of Hurricane Helene (2006) in 30-day runs

Global Mesoscale Model as a New Research Tool

Summary and Conclusions

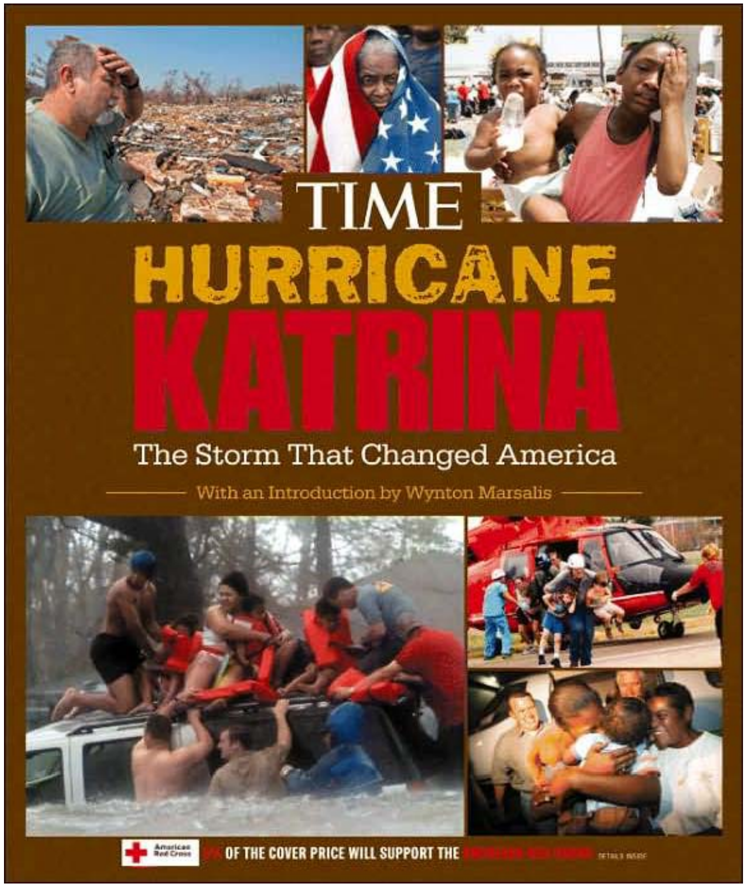
Hurricanes: high-impact weather

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 a degression at 04/27/03Z by the IMD; as TC01B at 04/27/12Z by the JTWC
- Very intense, with a MSLP of 962 hPa and peak winds of 135 mph (~CAT 4)
- High Impact: damage ~ $10 billion; fatalities ~ 134,000
- Affected areas: Myanmar (Burma), Bangladesh, India, Srilanka

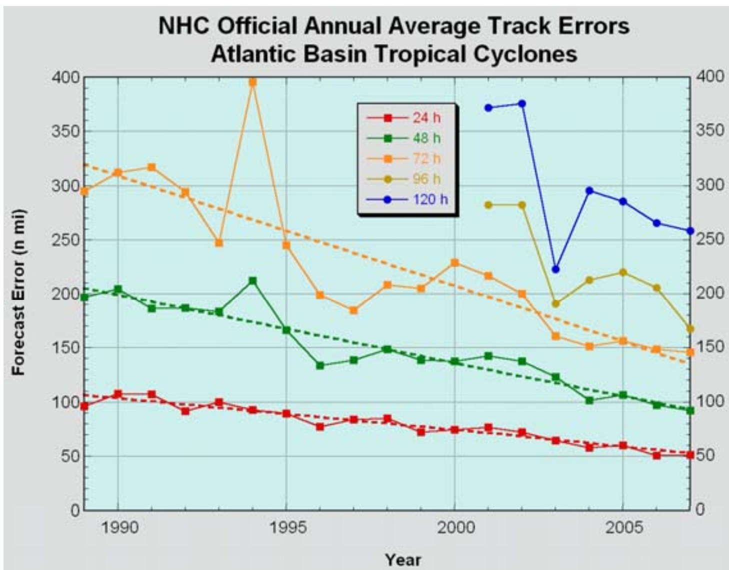


Progress of Hurricane Forecasts
(by National Hurricane Center)

http://www.nhc.noaa.gov/verification/figs/OFCL_ATL_int_error_trend.gif

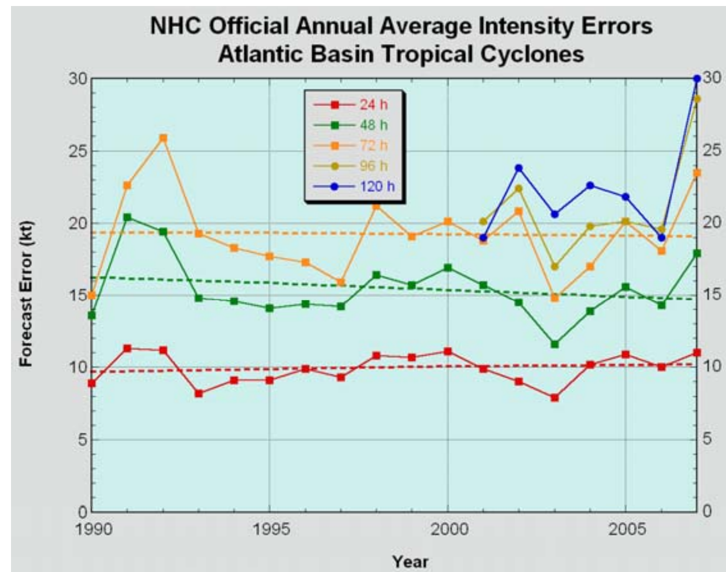
Track Errors

better



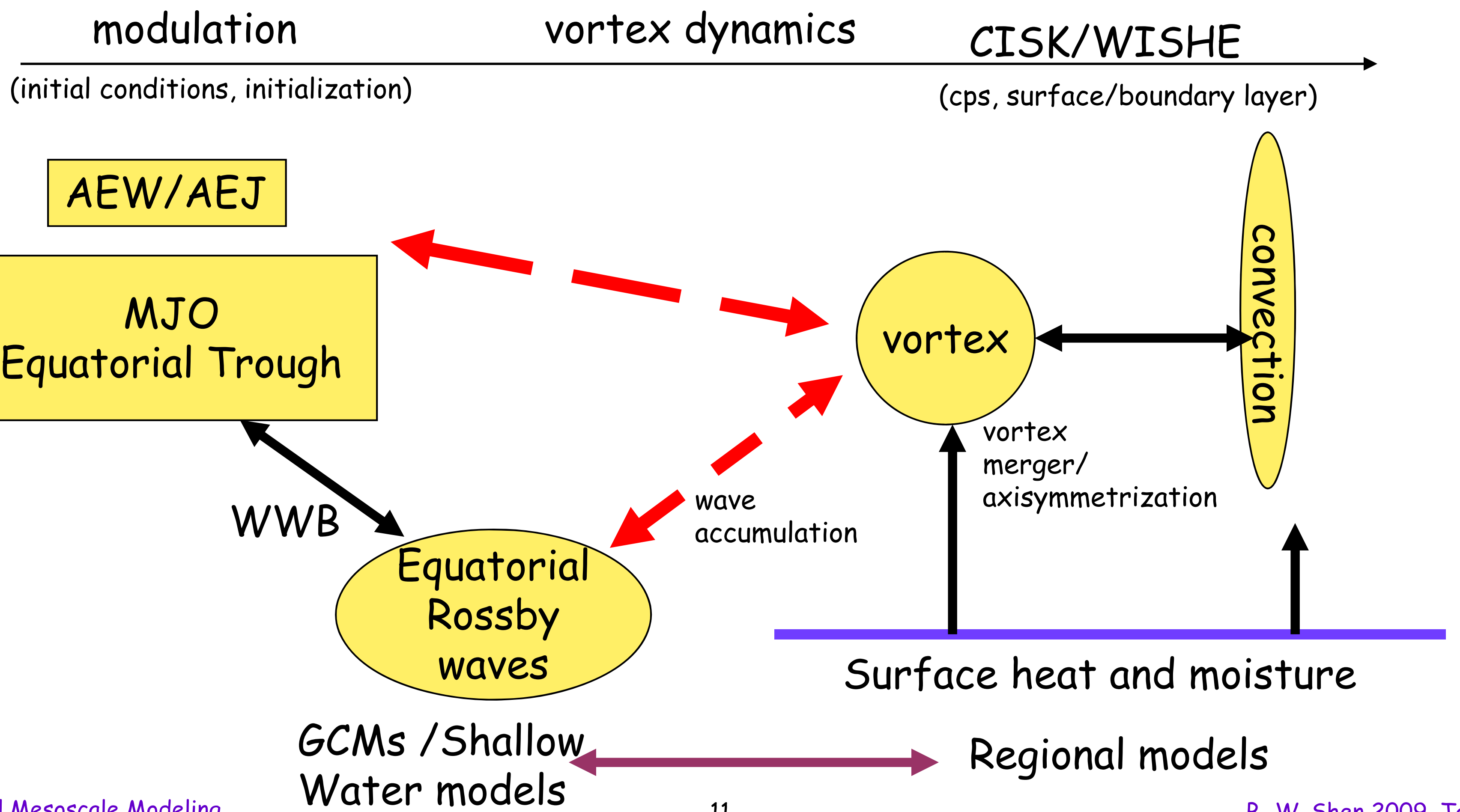
Track forecasts have been steadily improving.

Intensity Errors



Intensity forecasts have lagged behind.

Multiscale Interaction During TC Genesis



Hierarchical Multiscale Interactions

Meaning:

- multiscale but "asymmetric" , e.g., large scale vs. small scale (e.g., organization vs. individuals)
- dependence of predictability at different scales ("P" may not be totally independent)
- (potential) existence of control-feedback-response relationship (at different stages) that can be simulated with numerical models (e.g., Q-E for CPs?)
- a different range of "involved" scales at a different stage of a (TC) lifecycle

Implications:

- From a modeling perspective, clarifications of the following terms might be helpful to understand the hierarchical (two-way) multiscale interactions.
  1. **lifetime of the large-scale flow (forcing duration)**: the period that the large-scale flow could act as a forcing, (e.g., barotropic or baroclinic instatilbity);
  2. **lifetime of the small scale flow**;
  3. **response time:** the time for small scale flow to respond and adjust (e.g., time for the initiation of convection); how quickly a small-scale flow can respond in reality and in "models".
  4. **feedback duration:** the period that small scale flow can provide feedbacks to large-scale flows (which should be less than its lifetime)

     how long it will take for small-scale flows to have significant impact on the large-scale flow
- For two-way scale interactions, accurate representation of "forcing" and its "control", and simulations of "response" and its "feedback" are equally important!

Modeling at Different Scales

HQ

Center/Division

Individuals

Global
(GCMs)

mesoscal/
regional

cloud

(convection
process)

Scale or detail matters?

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Cumulus Parameterizations

- Cumulus parameterization (CP) is to ``emulate'' the statistic effects of unresolved convection in the latent heat release → Cooperative interaction between a vortex and convection. → CP is weak to simulate the life cycle of the convection.

- The CP was an important technical factor in the reduction of a multiscale interaction problem to a mathematically tractable form. (Ooyama, 1982)
  → Scale interactions are kind of limited.

- CP has a long history in hurricane modeling: Anthes (2003) states "*the late 1950s and early 1060s saw the beginning of serious attempts to model TCs...... The observational studies of Riehl and Malkus showed that the cumulus clouds were essential components of hurricane energetics and so...... CP so dominated the research in the 1950s and 1960s that many people simply referred to the topic as "parameterization".*

- CP was used to stabilize numerical integrations by Kasahara, who (2000) stated "*The origin of CP is traced as a necessary means to perform stable time integrations of the PE model with moist physical processes*", which is different from usual.

Issues with CPs

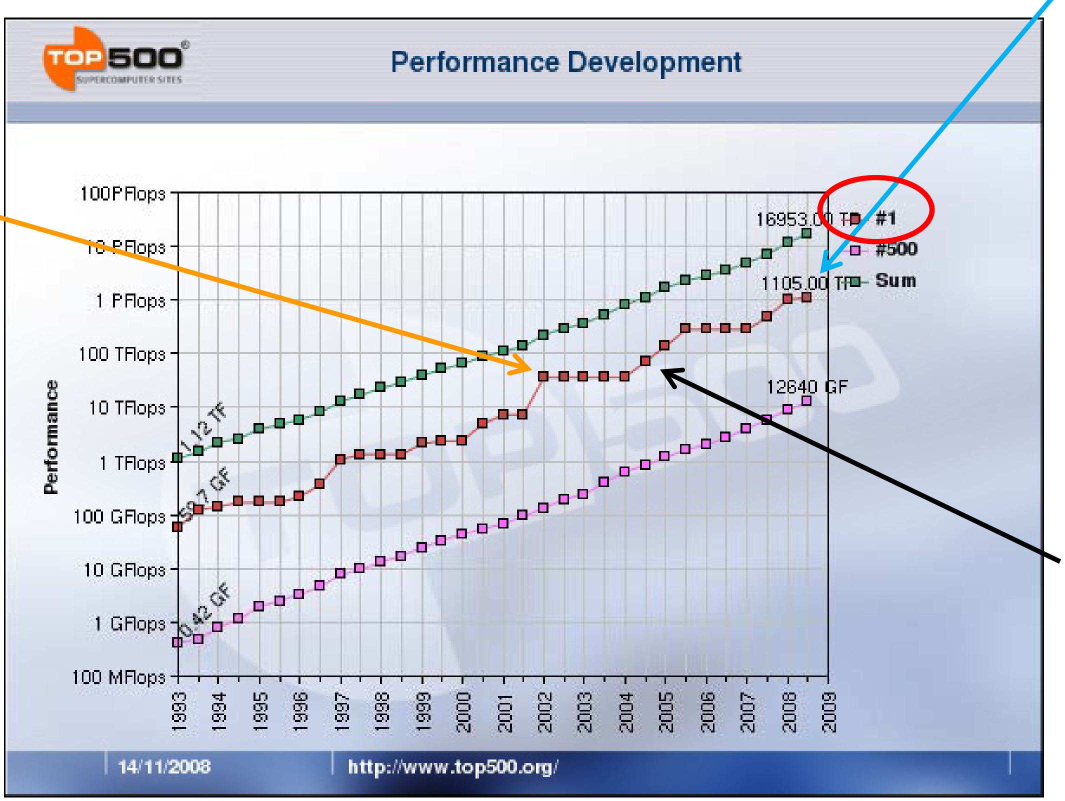
- The cloud parameterization problem is ``deadlocked'' in the sense that our rate of progress is unacceptably slow (Randall et al.,2003)
- In spite of the accumulated experience over the past decades, however, cumulus parameterization is still a very young subject (Arakawa, 2004).
- The performance of parameterization scheme can be better understood if one is not bound by their authors' justifications (Arakawa, 2004).

- CP has problems for grid spacing between 3 and 25km (e.g., Molinari and Dedek, 1992); CP is not good for studying TC genesis!

Supercomputers @Top 500.org

November, 2008

Japan Earth Simulator (06/2002)



1: Roadrunner
2: Jugar
3: NASA Pleiades
(11/2008)

1: IBM/DOE BG/L Beta
2: NASA Columbia
3: Japan ES
(11/2004)

NASA Major Supercomputers

Columbia Supercomputer (ranked 2nd in late 2004)

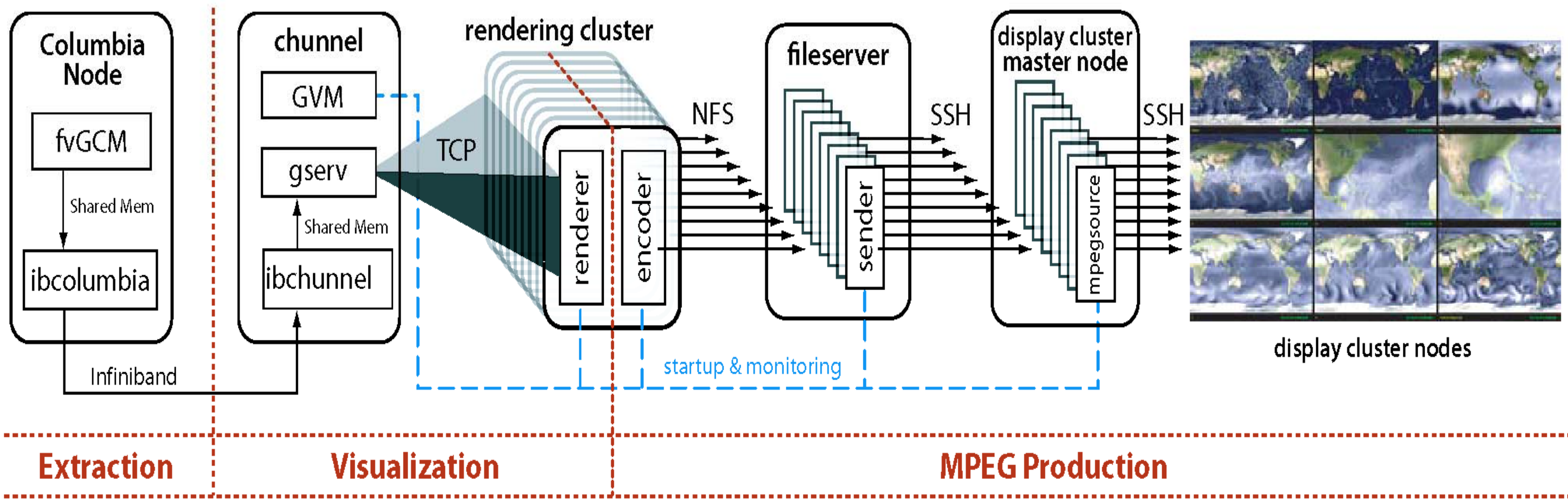
- **Based on SGI® NUMAflex™ architecture** 20 SGI® Altix™ 3700 superclusters, each with 512 processors Global shared memory across 512 processors
- **10,240 Intel Itanium® 2 CPUs**; Current processor speed: 1.5 gigahertz; Current cache: 6 megabytes
- **20 terabytes total memory;** 1 terabyte of memory 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) processors, speed - 3GHz; Cache - 12MB per processor•**
- **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**

Concurrent Visualization System (CVs)

Ellsworth, Green, Henze et al., 2006
AIST Porject: CAMVis, PI B.-W. Shen, 2009-2012



The NASA ARC Concurrent Visualization System. Rounded rectangles indicate systems, and rectangles indicate processes. The whole system (from left to right panels) consists of a computing node ("Columbia node"), a 16-CPU middle-layer system ("Chunnel"), 50 dual-CPU rending cluster, and the hyperwall-1. These systems are used for data extraction, data handling, data visualization and MPEG image production, and visualization display.

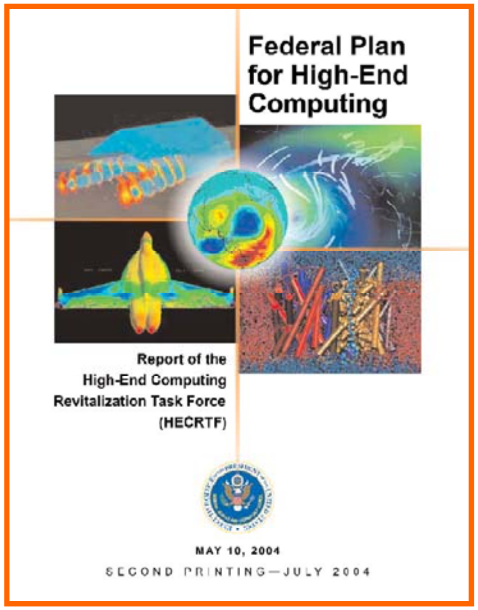
128-panel Hyperwall

The Hyperwall-II is made of 128 LCD monitors, arranged in an 8-by-16 matrix. Collectively, they will generate 245 million pixels

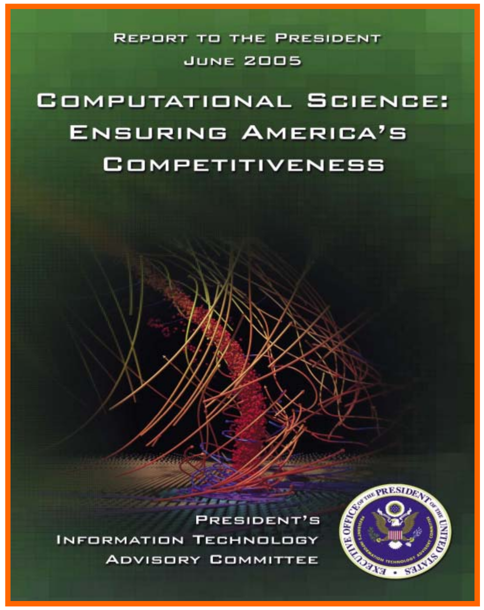
Shen, B.-W., W.-K. Tao, G. Bryan, C. Henze, P. Mehrotra, J.-L. F. Li, 2009: High-impact Tropical Weather Prediction with the NASA Coupled Advanced multi-scale Modeling and concurrent Visualization Systems (CAMVis). Supercomputing conference 2009, Portland, Oregon, November 14-20, 2009. **(accepted to be demonstrated on a 42" LCD display)**

Computational Science

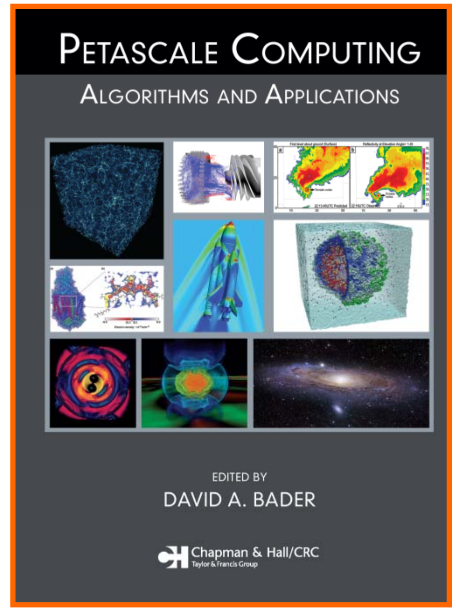
July, 2004



June, 2005

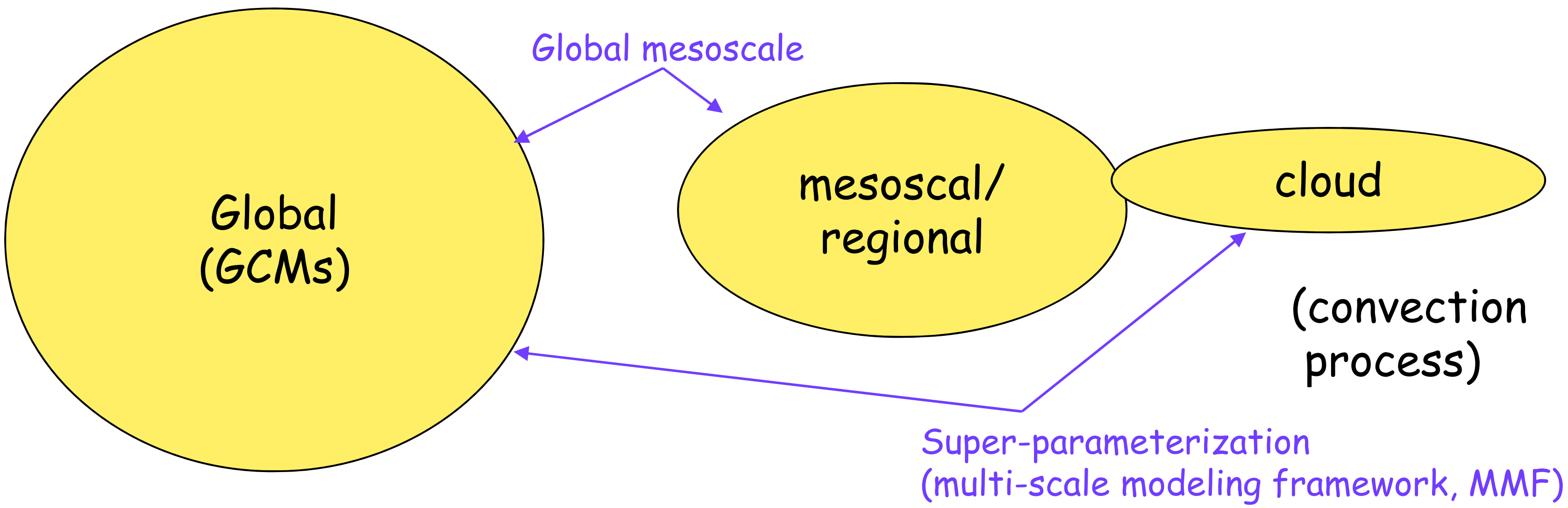


Dec., 2007



- ``*researchers of the most challenging scientific applications must know the hardware details intimately in order to extract sufficient percentage of the machine's potential performance to render their problem tractable in a reasonable time*.''
- **Computational Science** (CS) is defined as an inter-disciplinary filed with the goals of understanding and solving complex problems using high-end computing facilities
- CS is identified as one of the most important filed of the 21st century to contribute to the scientific, economic, social and national security goals of USA ***by the President's Information Technology Advisory Committee (PITAC).***
- Biswas, R., M. J. Aftosmis, C. Kiris, and B.-W. Shen, 2007: Petascale Computing: Impact on Future NASA Missions. Petascale Computing: Architectures and Algorithms (D. Bader, ed.), Chapman and Hall / CRC Press.

Modeling at Different Scales



- To understand if effects/impacts of (resolved) "convection" on the system scale of the MJO/TC/AEW are better simulated with either one of these approaches than the traditional approach where cumulus parameterizations (CPs) are applied.

The Global Mesoscale Model

1. Model Dynamics and Physics:

   - The finite-volume dynamical core (Lin 2004);
   - The NCAR physical parameterizations, and NCEP SAS as an alternative cumulus parameterization scheme
   - The NCAR land surface model (CLM2, Dai et al. 2003)

2. Computational design, scalability and performance (suitable for running on clusters or multi-core systems)

Physics Parameterizations

- Moist physics:
  - -Deep convections: Zhang and McFarlane (1995);
    Pan and Wu (1995, aka **NCEP/SAS**)
  - -Shallow convection: Hack (1994)
  - -large-scale condensation (Sundqvist 1988)
  - -rain evaporation
- Boundary Layer
  - - first order closure scheme
  - - local and non-local transport (Holtslag and Boville 1992)
- Surface Exchange
  - - Bryan et al. (1996)

Pan, H.-L., and W.-S. Wu, 1995: Implementing a mass flux convection parameterization package for the NMC medium-range forecast model. NMC office note, No. 409, 40pp. [Available from NCEP].

Resolutions vs. Model Grid Cells

Resolution	x	y	Grid cells	Date
1^{o} (~110km)	288	181	52 K	2000
0.5^{o} (~55km)	576	361	208 K	2002
0.25^{o} (~28km)	1000	721	721 K	2004
0.125^{o} (~14km)	2880	1441	4.15 M	2005
0.08^{o} (~9km)	4500	2251	10.13 M	2005
MMF (2D CRM)	144x64	91	839 K	2006

Goals

Goals:

to explore the power of supercomputers on the advancement of global weather and hurricane modeling;

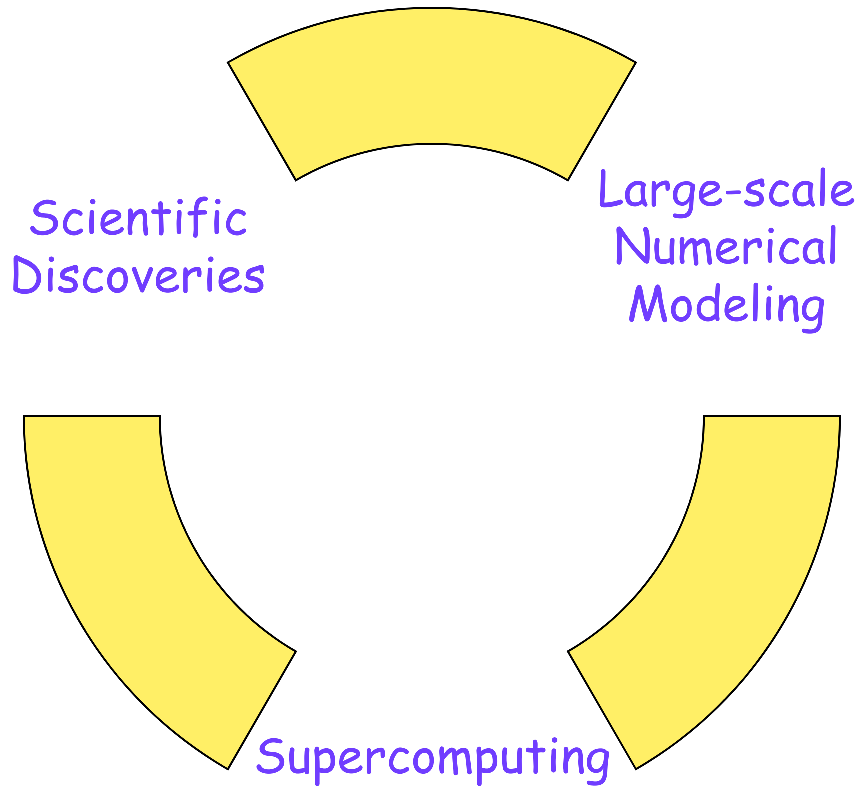
to discover the "potential" predictability of hurricanes with advanced models (how hurricanes form, intensify, and move)

to understand the underlining mechanisms (e.g., hierarchical multiscale interaction)

to extend the lead-time of hurricane predictions

Reducing time to solution by "cooperative interactions"!

(not competing for the same resources!)



Scientific Visualizations with the NASA CAMVis

- A central question to be addressed: ***"Is new science being produced** (with high-resolution modeling)* ***or just really cool pictures?",*** which was raised by Mahlman and others who have reservations ***(Science, p1040, 2006 August)***.
- The high-resolution global modeling work on the NASA Columbia supercomputer (e.g., Shen et al., 2006) was featured in the same article.
- Computational Science (CS) is defined as an inter-disciplinary filed with the **goals of understanding and solving complex problems** using high-end computing facilities
- The next-generation visualizations should help provide **the insights of the complicated physical processes** in these complex problems (e.g., hurricane prediction) and thus improve our understanding of these processes at different scales and their interactions.

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

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

1040 25 AUGUST 2006 VOL 313 SCIENCE www.sciencemag.org

Published by AAAS

Modeling Approach

This work is to illustrate the "potential predictability" of high-impact tropical weather with a global meososcale model, which has shown the potential of simulating more realistic hierarchical multiscale interactions (control/response/feedbacks relationship).
To achieve our goals of improving our understanding of and confidence in model's performance in hurricane short-term and climate simulations, we have done the following:

- Given an initial mesoscale vortex (TC), we verify model's performance in predicting its movement and intensification;
- Given a large-scale flow (e.g., MJO and/or AEWs), we investigate if modulations of TC activities (e.g., formation) can be simulated realistically;
- By performing extended-range (15-30day) simulations, we test if our modeling approach could extend the predictions of an MJO or AEWs.

- To understand if and how the lead time of "mesoscale" hurricane prediction can be extended by a global mesoscale model

Model's predictive ability != Predictability (of a weather system)

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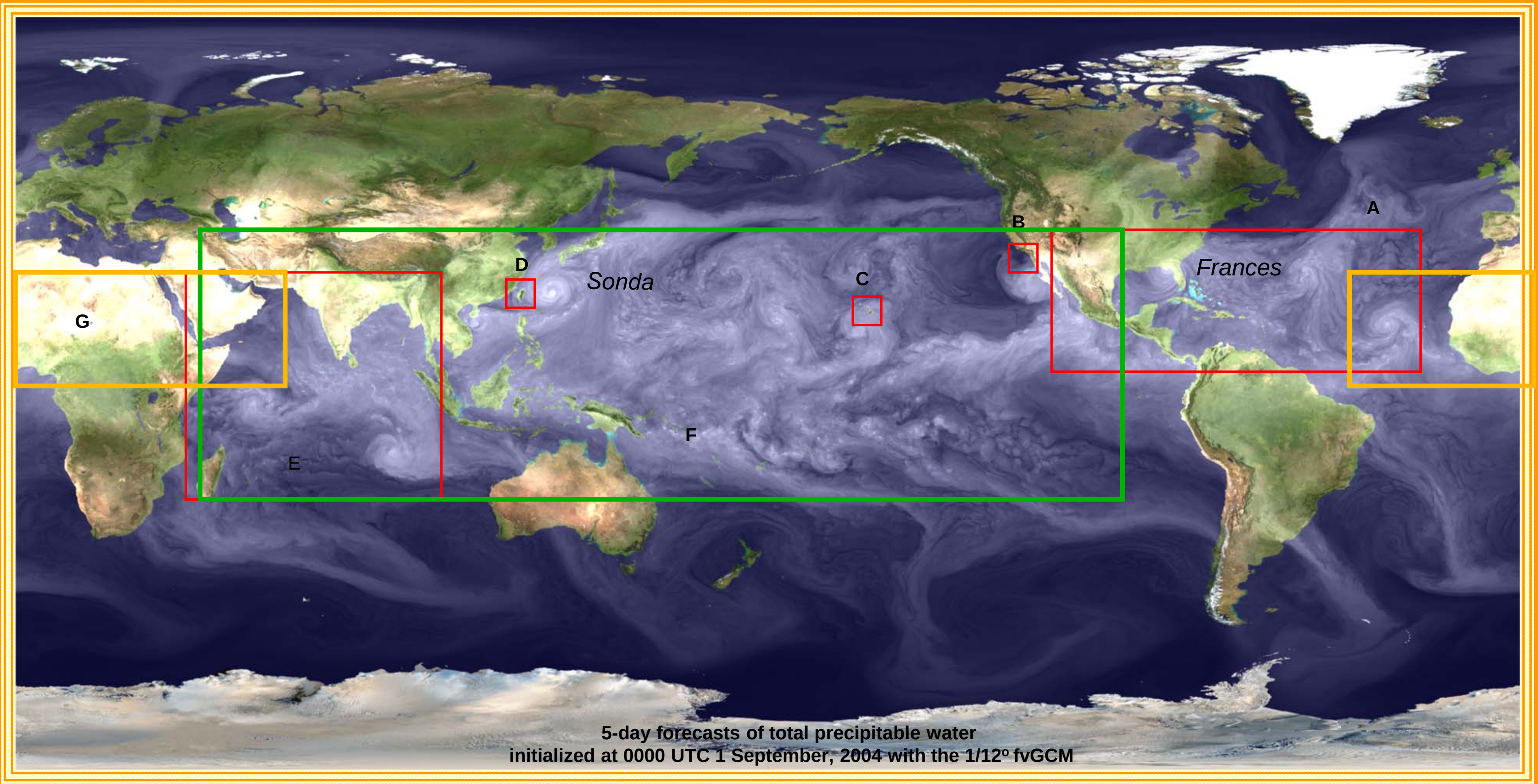
Global Mesoscale Model as a New Research Tool

Summary and Conclusions

Global Mesoscale Modeling on the NASA Columbia Supercomputer



F: Madden-Julian Oscillation (MJO)

G: African Easterly Wave (AEW)

D: Asian Mei-Yu Front

E: Twin Tropical Cyclones

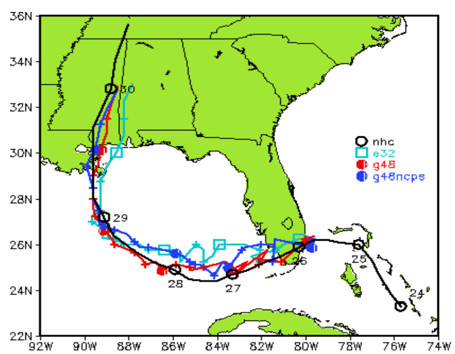
A: Atlantic Hurricanes

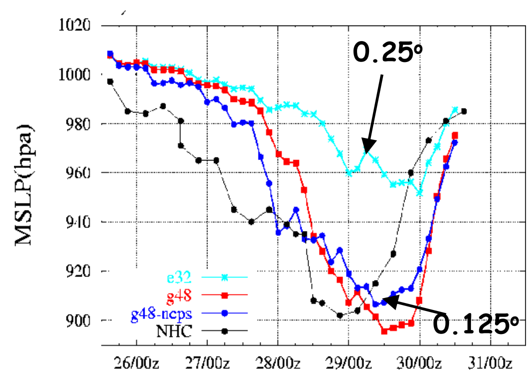
B: Catalina Eddy

C: Hawaiian Lee Wakes

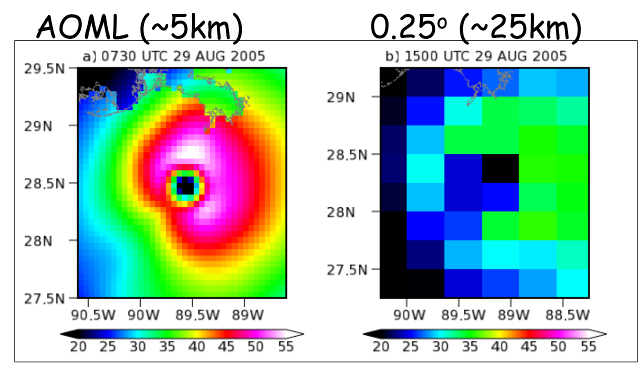
Forecasts of Katrina's Track, Intensity, Structures (Shen et al., 2006b)

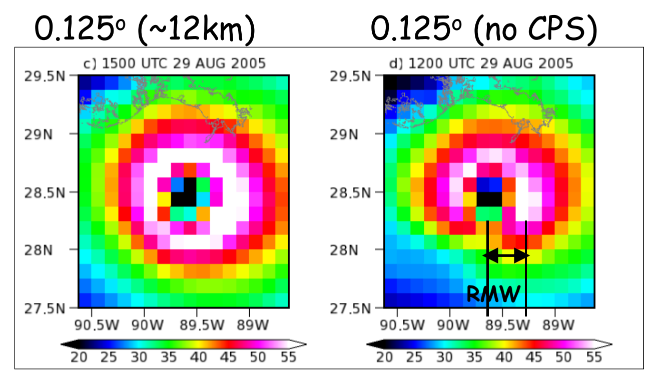
Selected as Journal Highlight by American Geophysical Union
Featured in *Science* magazine (August, 2006)
Featured in the 2006 Annual report of SAIC (Science Application International Corp.)

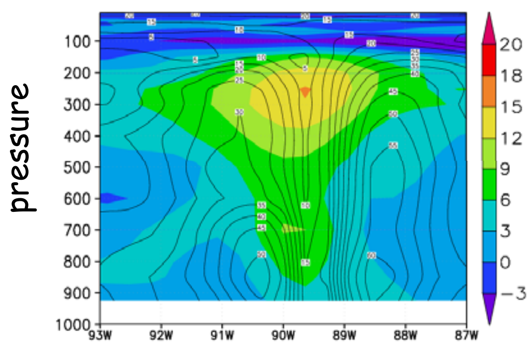




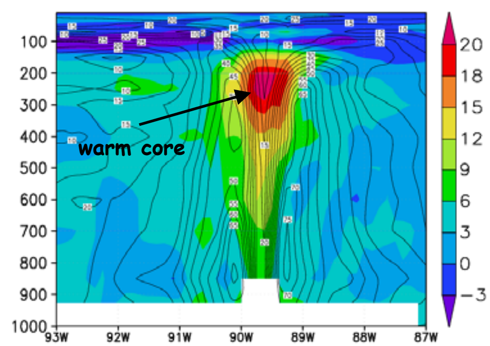
Landfall errors: e32 (1/4°): 50km, g48(1/8°): 14km, g48ncps (1/8° w/o CPs): 30km







GFS Analysis (~35km) valid at 08/29/12z



96 h Simulations with no CPS

Near-eye Wind Distributions in a 2°x2° box from 96h simulations, validated at 08/29/12z.

High-resolution runs simulate realistic intensity, radius of max wind (RMW) and warm core.

Outline

Introduction

Global Mesoscale Modeling with NASA Supercomputing Technology

Simulations of High-impact Tropical Weather
- 5-day track/intensity forecasts of Katrina (2005) and Ivan (2004)
- 10-day genesis forecasts of Twin TCs (2002)
- Multiscale interactions during the formation of Nargis (2008)
- 15/30-day simulations of Madden-Julian Oscillations in 2002/2006
- Five AEWs and genesis of Hurricane Helene (2006) in 30-day runs

Global Mesoscale Model as a New Research Tool

Summary and Conclusions

MJO and TC Genesis

• The MJO, also referred to as the 30-60 day or 40-50 day oscillation, turns out to be the main intra-annual fluctuation that explains weather variations in the tropics. The MJO affects the entire tropical troposphere but is most evident in the Indian and western Pacific Oceans.

•The modulation of TC activity by the MJO in different regions was documented by Liebmann et al. (1994), Maloney and Hartmann (2000).

• Twin TCs, straddling the equator at low latitudes, occasionally may occur in the Indian Ocean and West Pacific Ocean (e.g., Lander 1990).

MJO Dynamics

Current understanding (including theory and hypotheses) indicates that

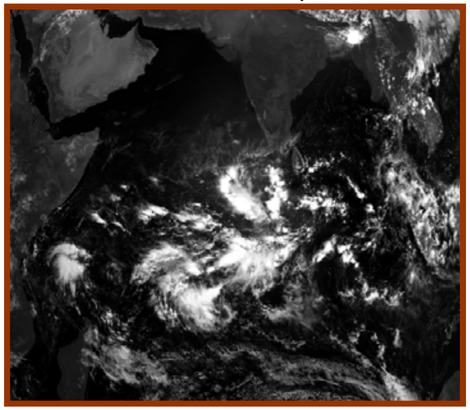
(1) moisture convergence (e.g., Lau and Peng 1987; Wang 1988),
(2) surface heat and moisture fluxes (e.g., Emanuel 1987; Neelin *et al.* 1987),
(3) cloud-radiation feedback (e.g., Hu and Randall 1994, 1995),
(4) convection-water vapor feedback (e.g., Woolnough *et al.* 2000; Tompkins 2001), and
(5) "discharge-recharge" associated with moist static energy build-up and release (e.g., Blade and Hartmann 1993)

are important for the MJO's initiation, intensification, and propagation (see a review by Zhang 2005).

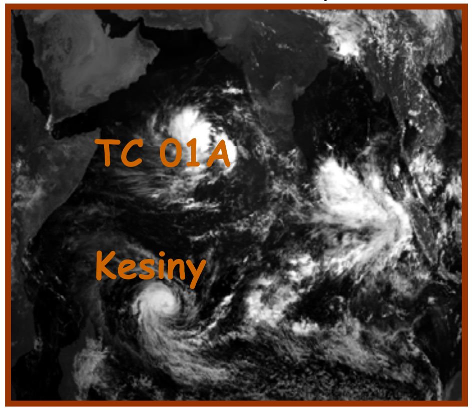
TCs associated with an MJO in May 2002

(see also Moncrieff et al., 2007; Shen et al. 2009, in revision)

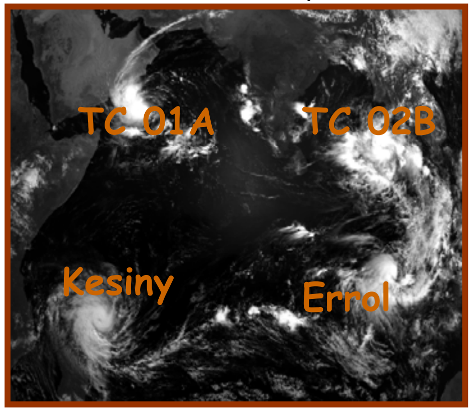
0630 UTC 1 May 2002



0630 UTC 6 May 2002



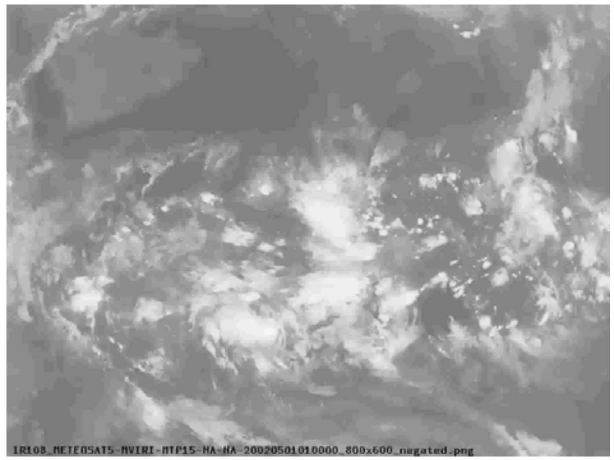
0630 UTC 9 May 2002



Two pairs of twin TCs appeared sequentially after an Madden- Julian Oscillation (MJO) propagated eastward through these areas.

Six TCs appearing in May 2002 include:

- **Kesiny** (3-11) and **TC 01A** (6-10, May)
- **Errol** (9-14) and **TC 02B** (9-12 May)
- Supertyphoon **Hagibis** (15-21 May)
- Hurricane **Alma** (25 May – 1 June)



Formation of 6 TCs in four 10-day Simulations

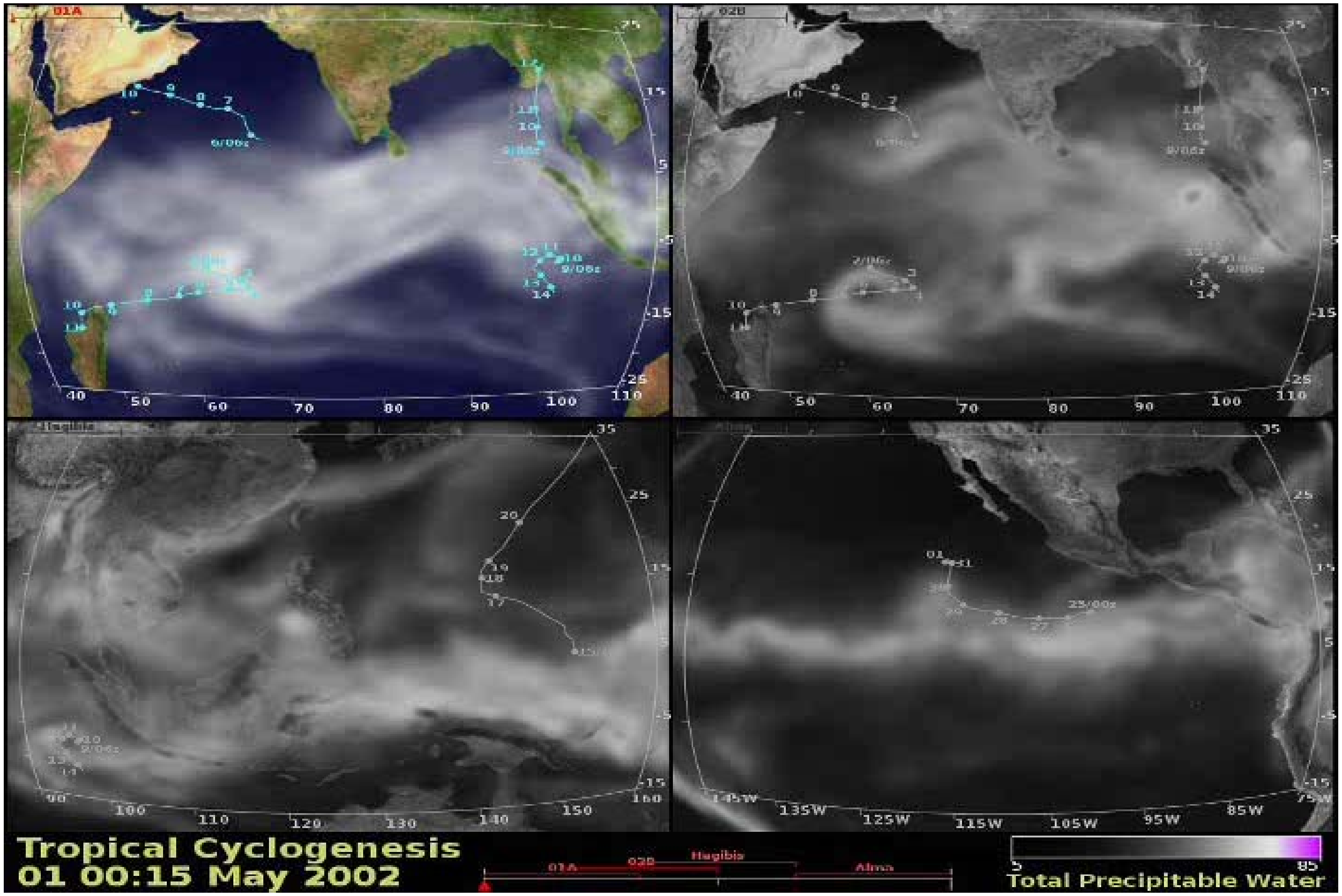
Init at 05/01/00z

Init at 05/06/00z

Init at 05/11/00z

Init at 05/22/00z

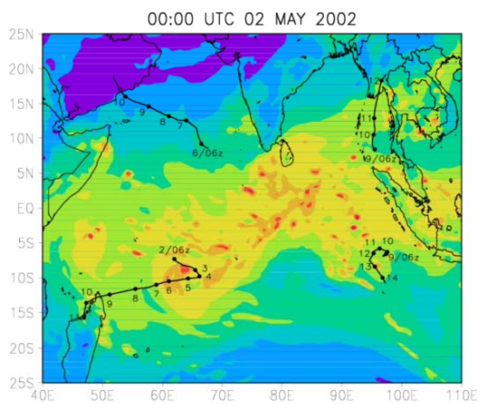
Best tracks indicated by blue lines:



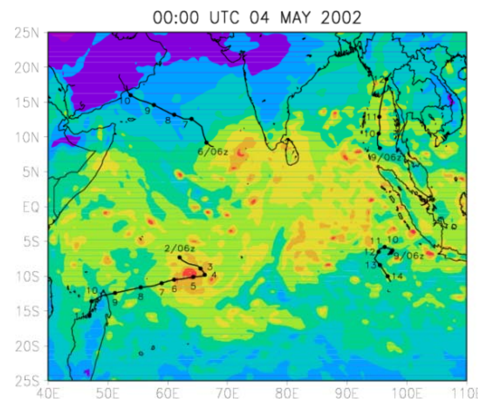
Genesis of Twin TC Kesiny and 01A

init at 2002/05/01/00z

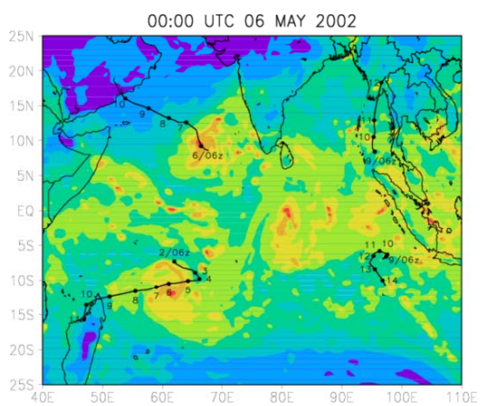
24 h



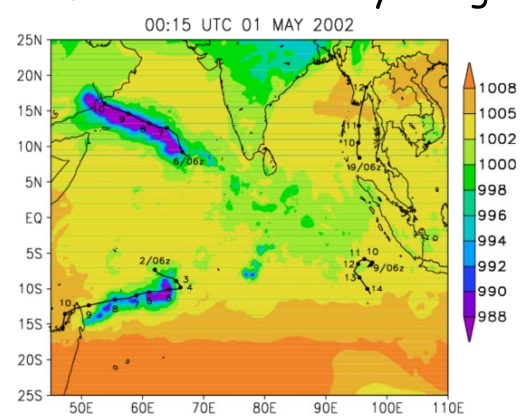
72 h



120 h



min SLP over the 10-day integration

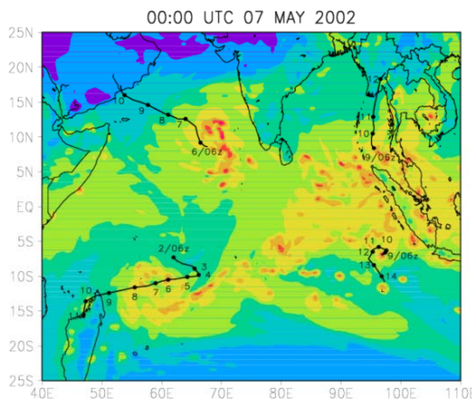


Best tracks are plotted in black.

Genesis of Twin TC Errol and 02B
Movement of Twin TC Kesiny and 01A

init at 2002/05/06/00z

24 h



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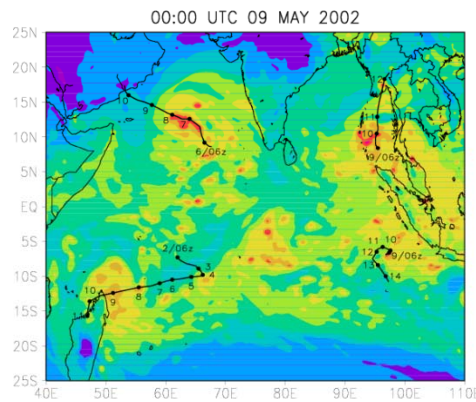
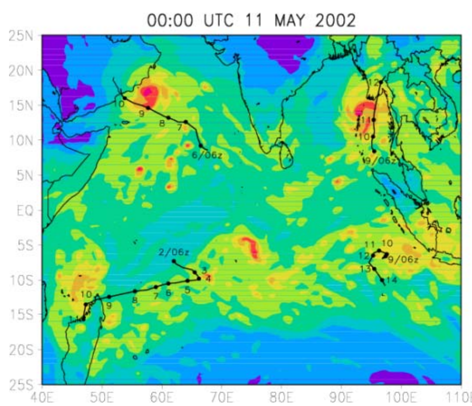
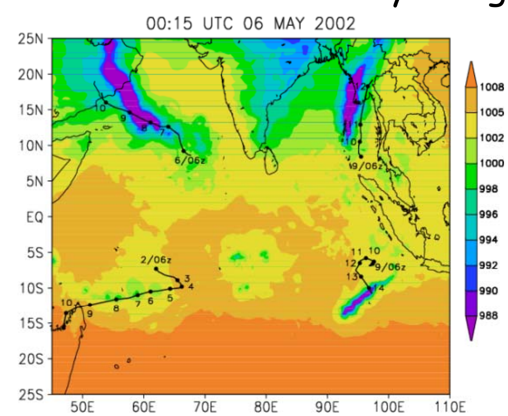


120 h



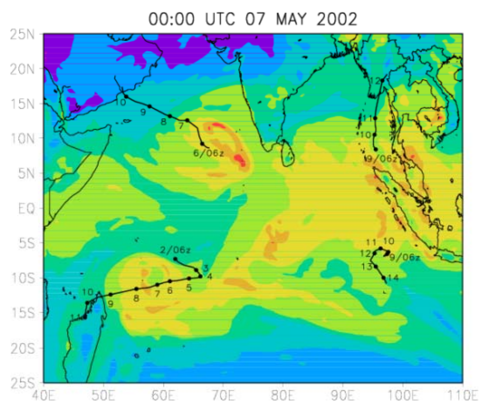
min SLP over the 10-day integration



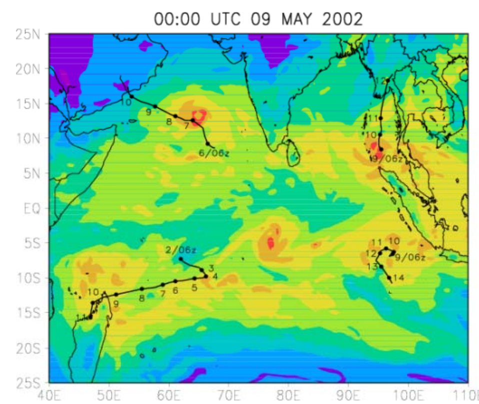
Exp-A run with ZF95 and Hack Schemes

init at 2002/05/06/00z

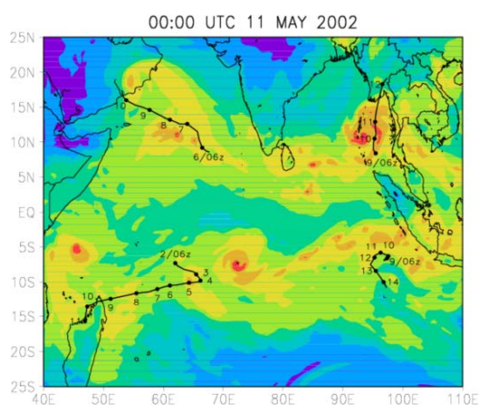
24 h



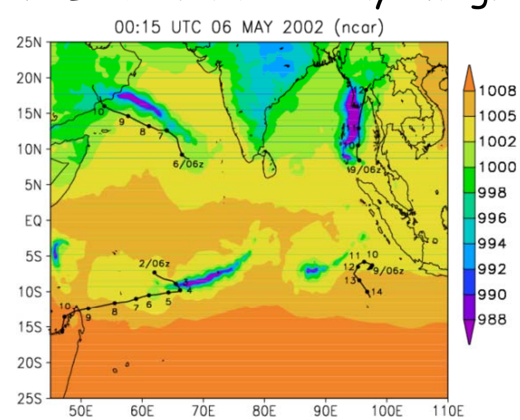
72 h



120 h



min SLP over the 10-day integration

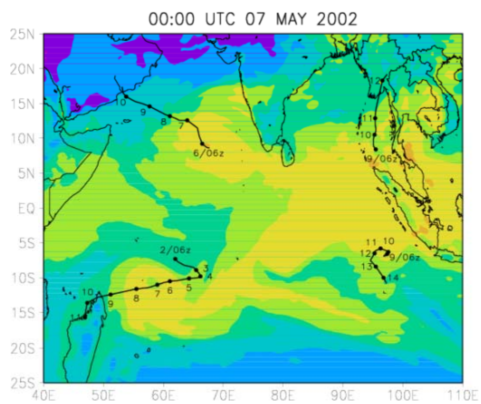


EXP-A: with Zhang and McFarlane (1995) and Hack (1994) schemes for deep and shallow-and-midlevel convection, respectively.

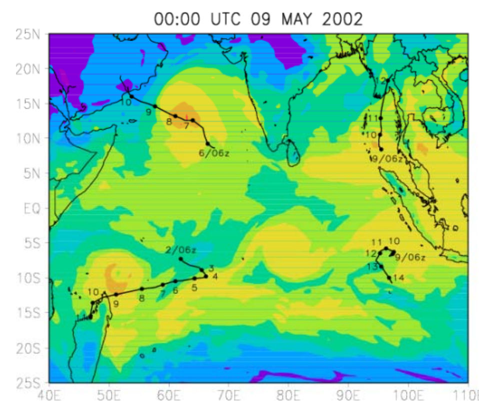
Exp-B run with NCEP SAS Scheme

init at 2002/05/06/00z

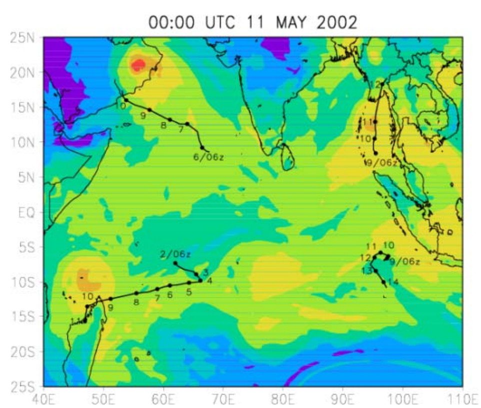
24 h



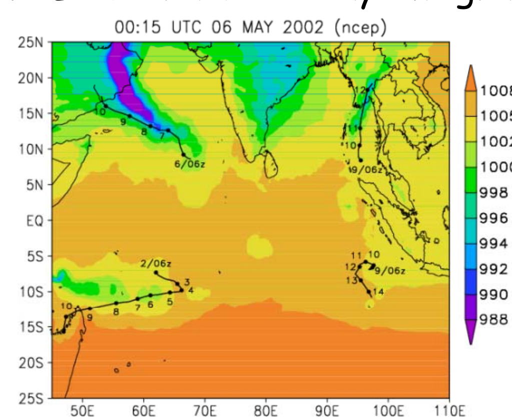
72 h



120 h



min SLP over the 10-day integration

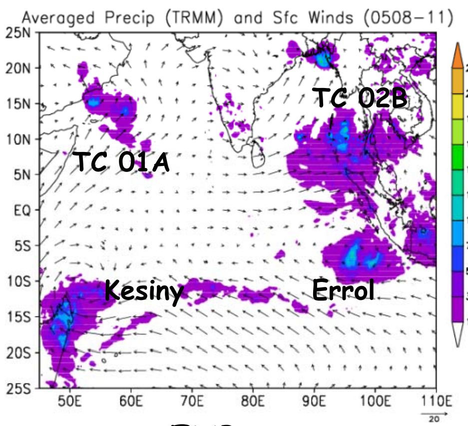


EXP-B: with NCEP SAS (simplified Arakawa and Schubert) scheme (Pan and Wu 1995)

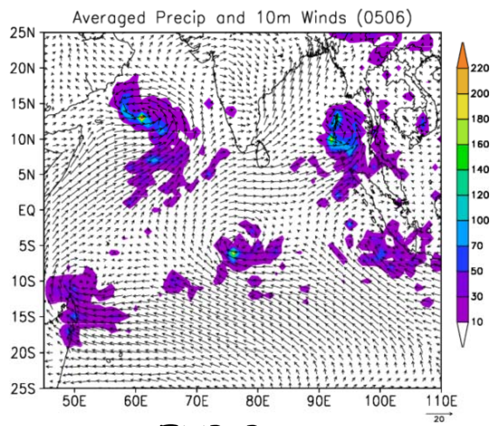
Forecasts of Twin TCs:

Averaged precipitation over May 8 – 11, 2002

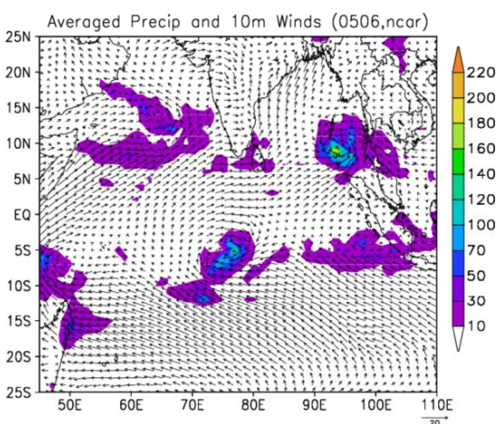
NASA TRMM



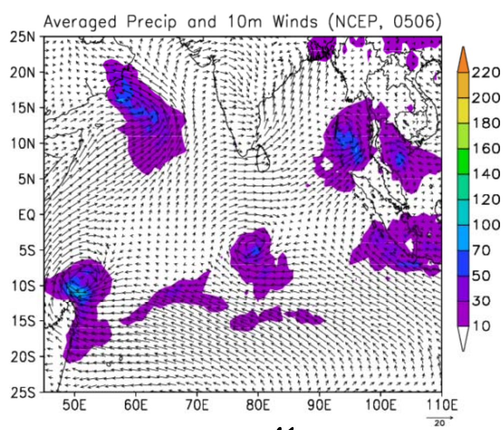
CNTL (no CPs)



EXP-A



EXP-B



All of three runs (CNTL, EXP-A and EXP-B) are initialized at 0000 UTC May 6, 2002 with different moist physical processes.

CNTL: No CPs

EXP-A: with Zhang and McFarlane (1995) and Hack (1994) schemes for deep and shallow-and-midlevel convection, respectively.

EXP-B: with NCEP SAS (simplified Arakawa and Schubert) scheme (Pan and Wu 1995)

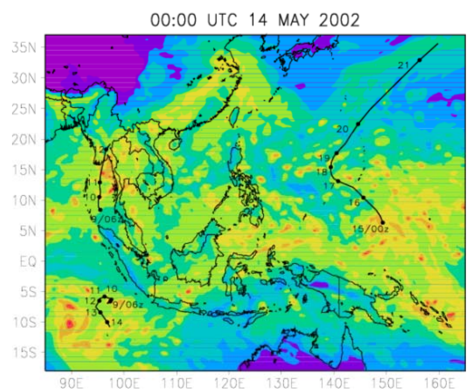
(i) The false-alarm event appears in all of three runs, suggesting missing physical processes in the model or imperfect ICs?

(ii) Can column-based physics (CPs) simulate spatial distribution of precipitation better?

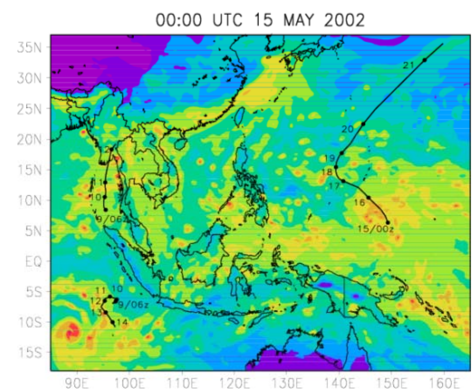
Genesis of Supertyphoon Hagibis (2002)

init at 2002/05/011/00z

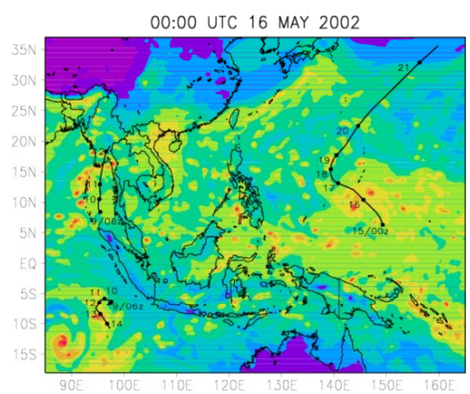
72 h



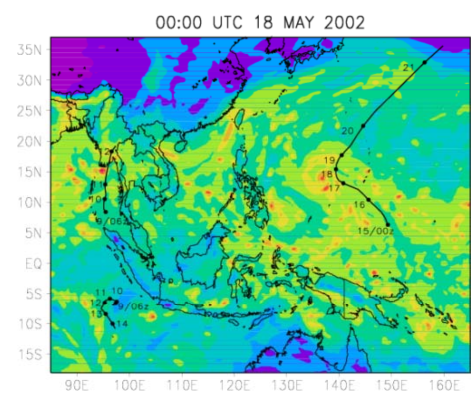
96 h



120 h



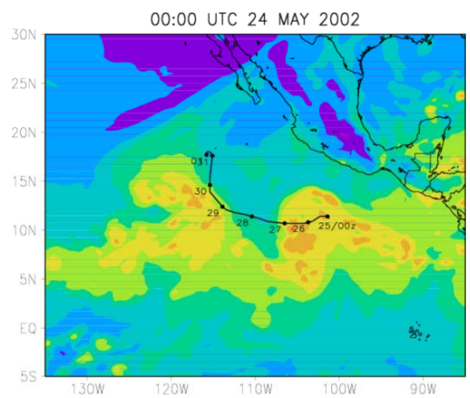
168 h



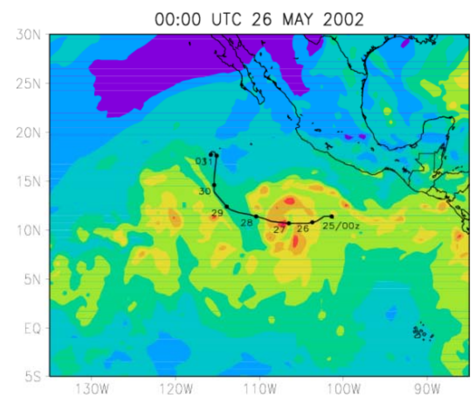
Genesis of Hurricane Alma (2002)

init at 2002/05/22/00z

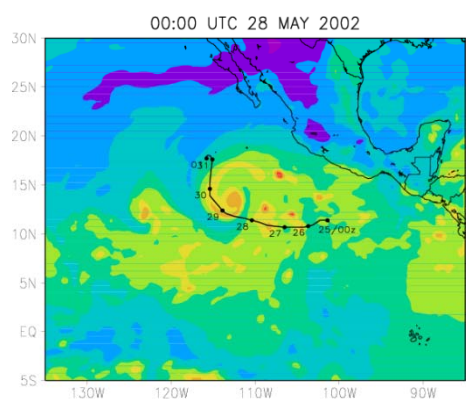
48 h



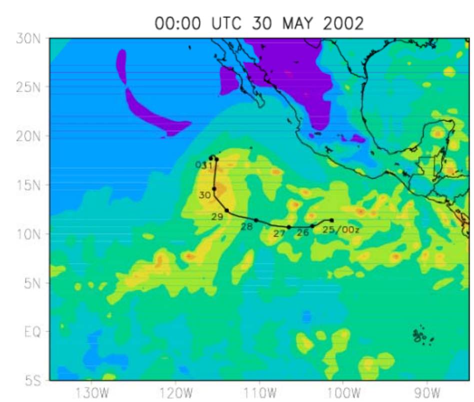
96 h



144 h



192 h



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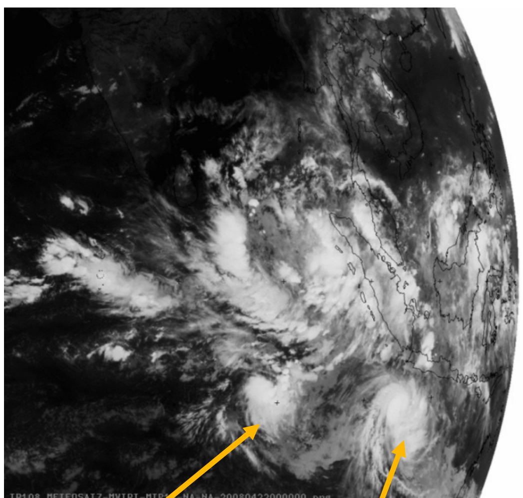
Very Severe Tropical Storm Nargis (2008)

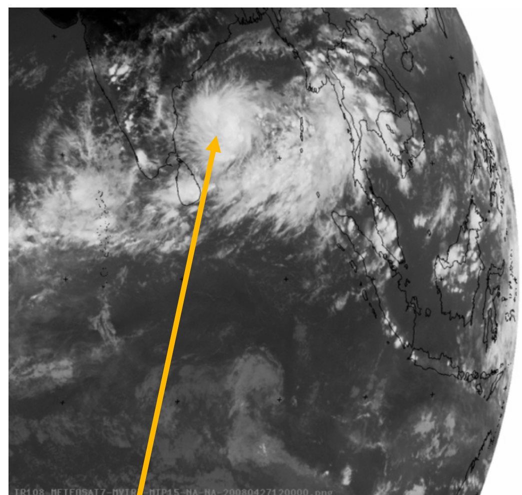
00Z Apr 22



Durga
(22-24 Apr)

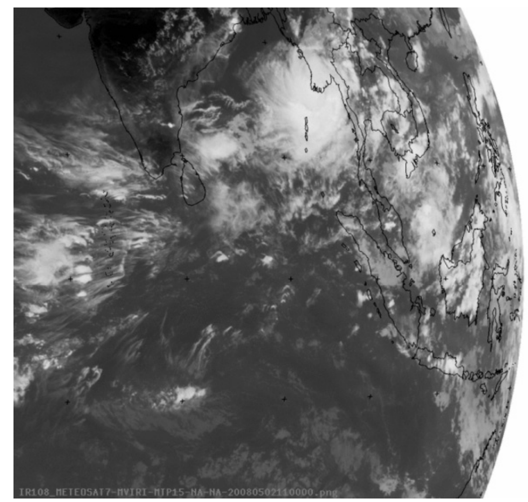
Rosie
(21-24 Apr)

12z Apr 27



Formation of Nargis

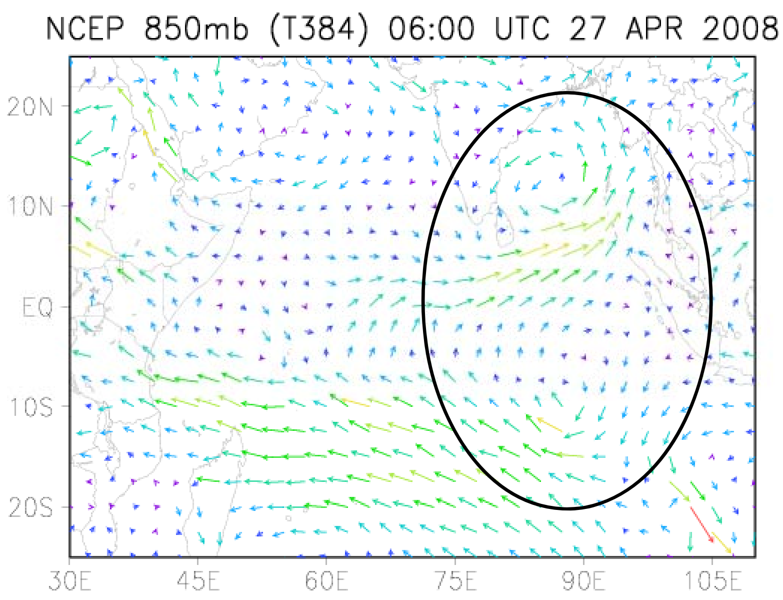
11z May 2



Landfall in Myanmar

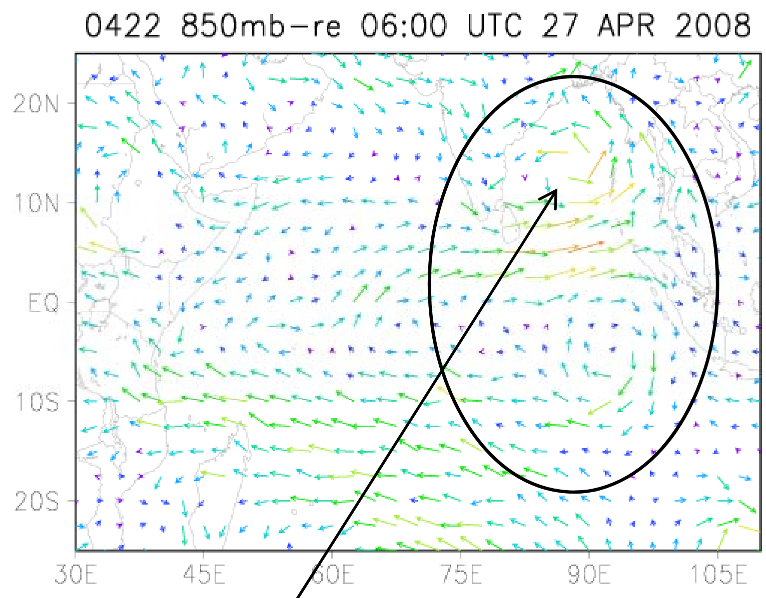
126-h Simulation of 850-hPa Winds

NCEP Analysis (T384)



Equatorial Rossby Waves

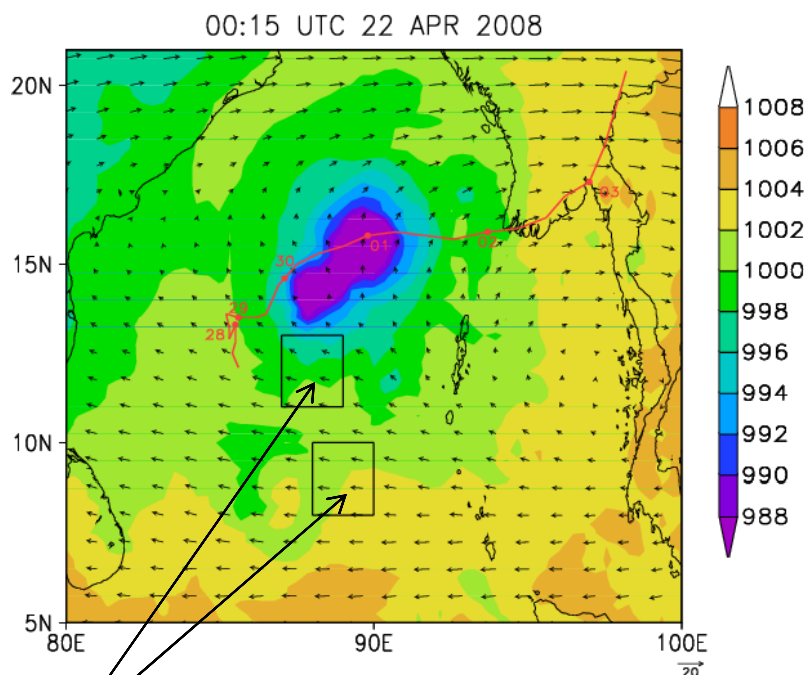
Model Simulation



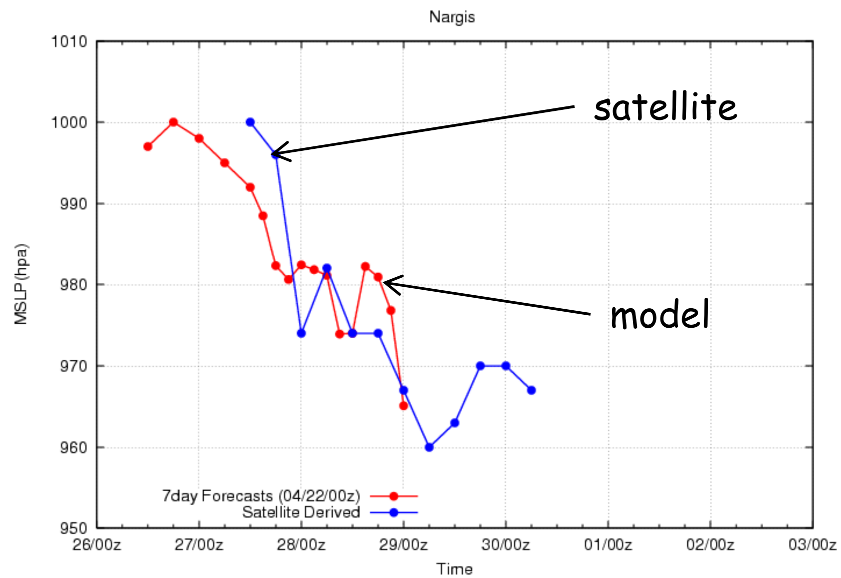
TC Nargis (2008)

7-day Forecast of Nargis' Intensity
(min SLP)

min SLP over the 7-day integration



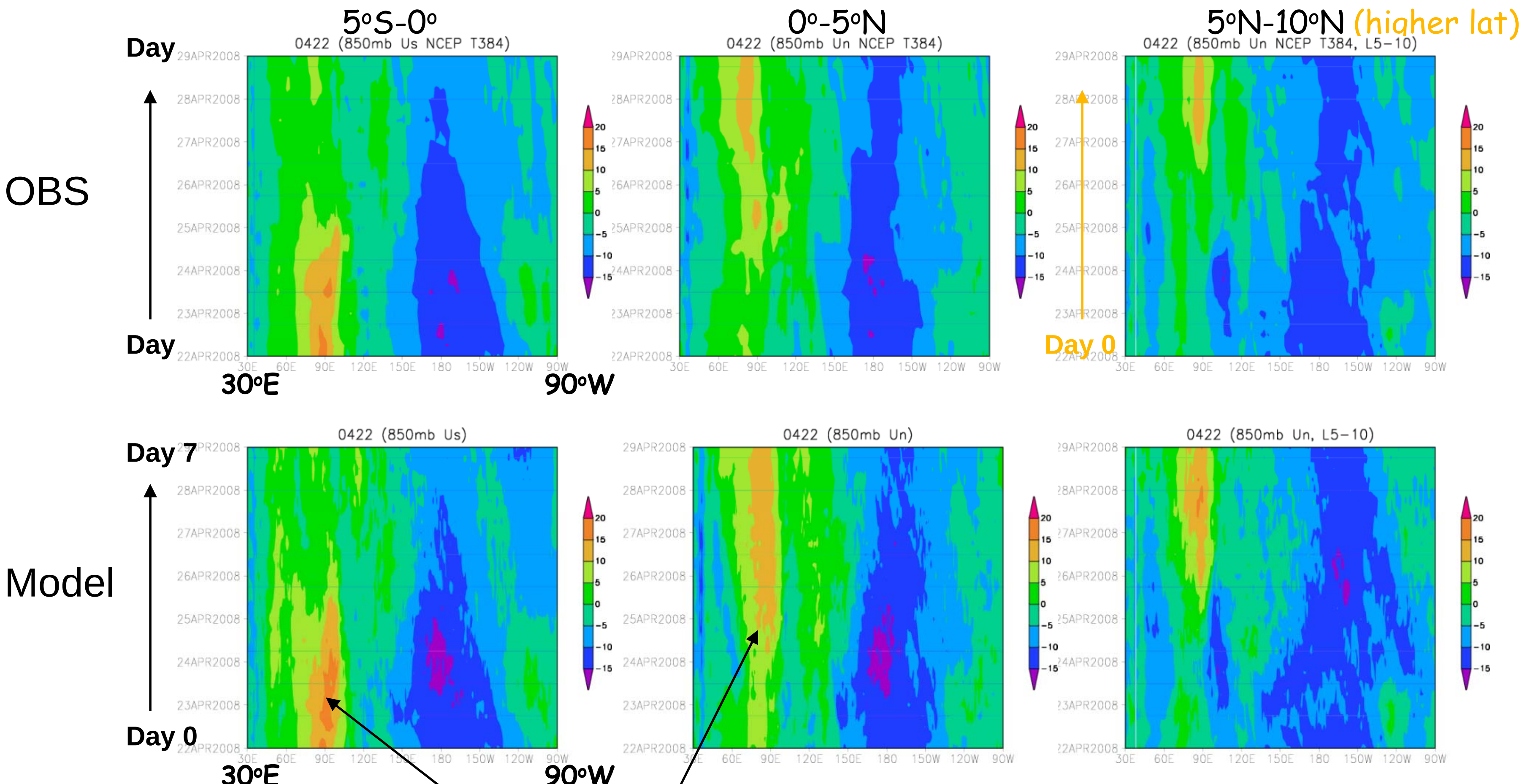
Intensity evolution from day 5 to day 7



Formation of a pre-TC mesoscale vortex, which is related to (1) the occurrence of westerly wind burst and (2) peak of low-level convergence, as discussed later.

Northward Movement of the WWB

(averaged 850-hPa U winds)



Westerly Wind Belt/Burst

Monsoonal circulation

(e.g., McBride and Zehr, 1989)

U-winds averaged over longitude 80°E to 90°E

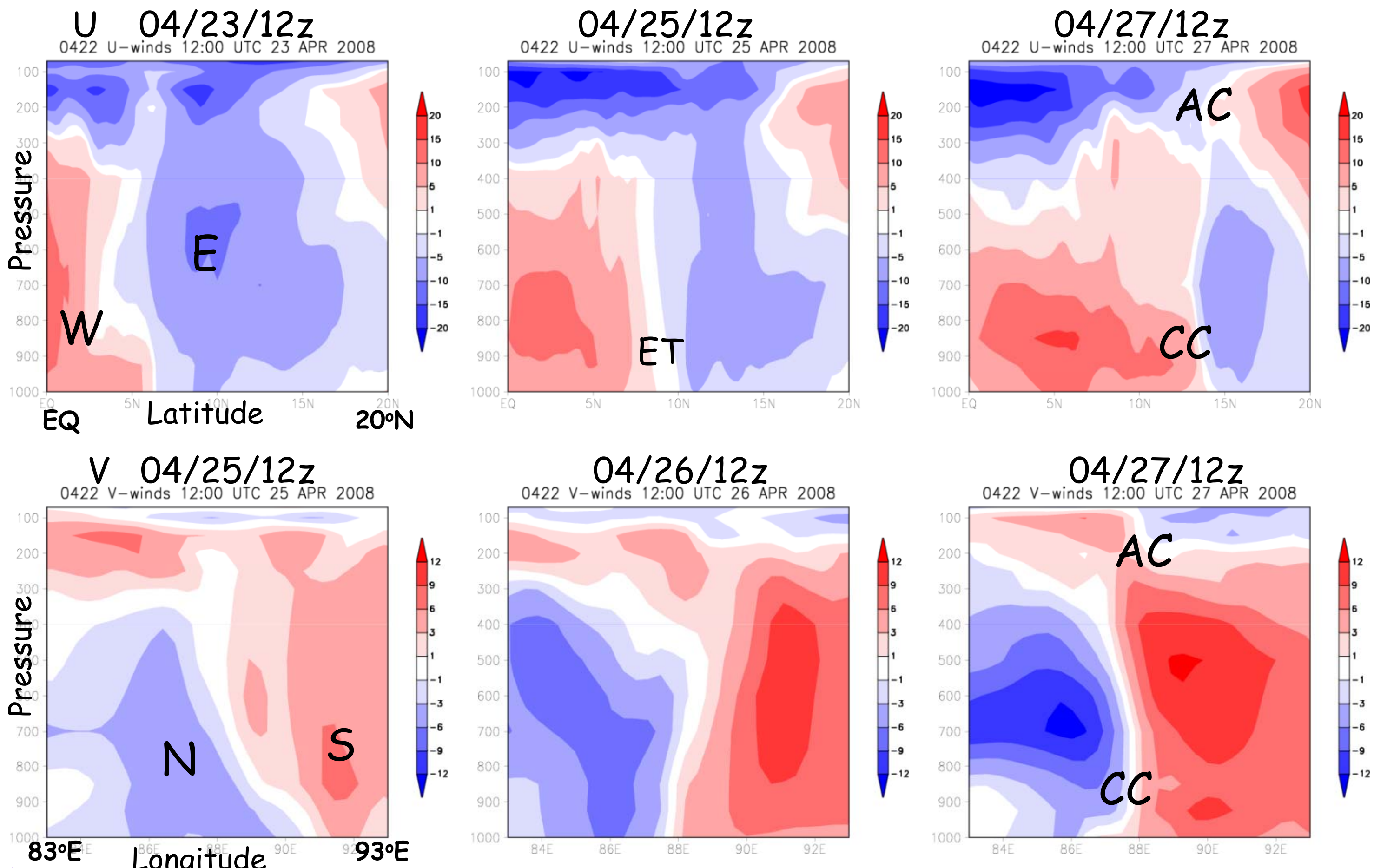
Red: Westerly Winds;
Blue: Easterly Winds

ET: equatorial trough
CC: cyclonic circulation
AC: anti-cyclonic circulation

V-winds averaged over latitude 9°N to 16°N

Red: Southerly Winds;
Blue: Northerly Winds

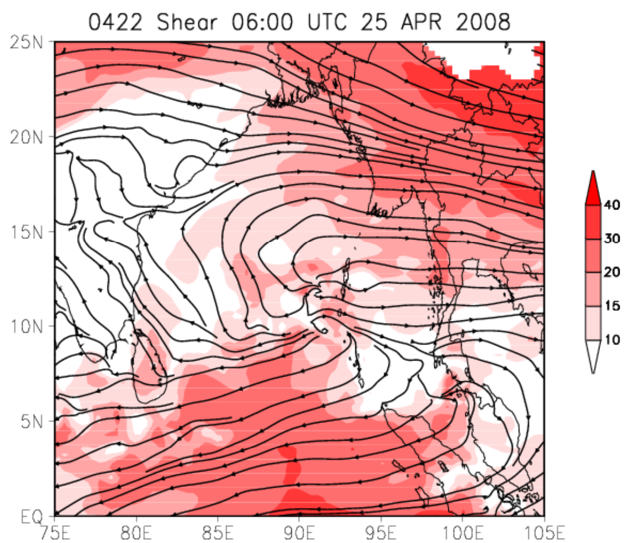
Stronger CC near 700-850 hPa, but not at the surface



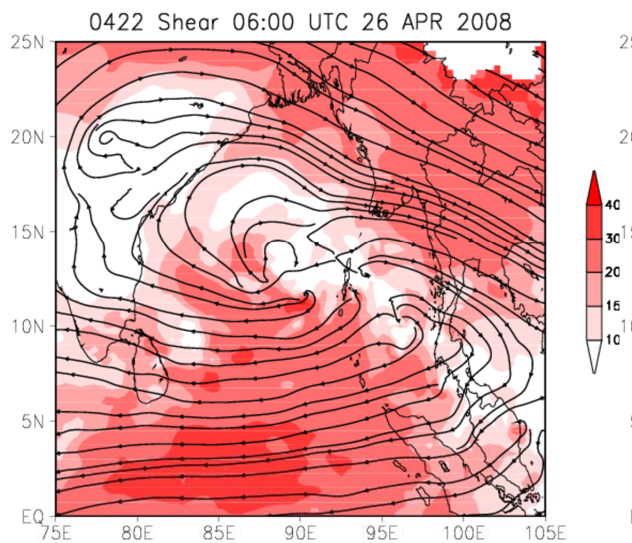
200-850 hPa Wind Shear

(dynamics instability, Anthes, 1982)

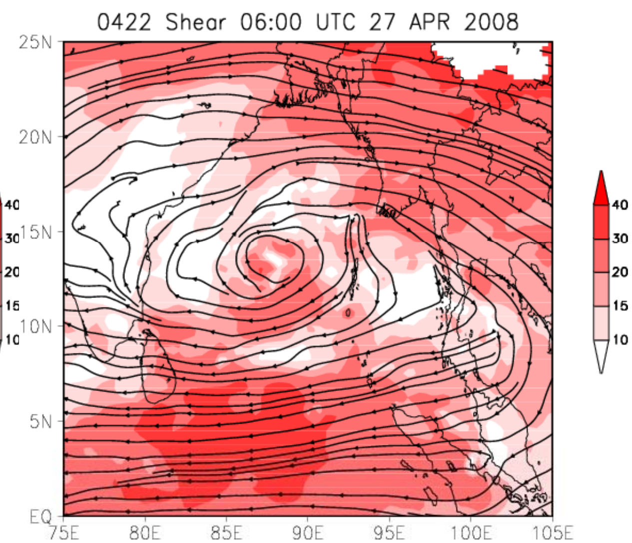
78h



102h



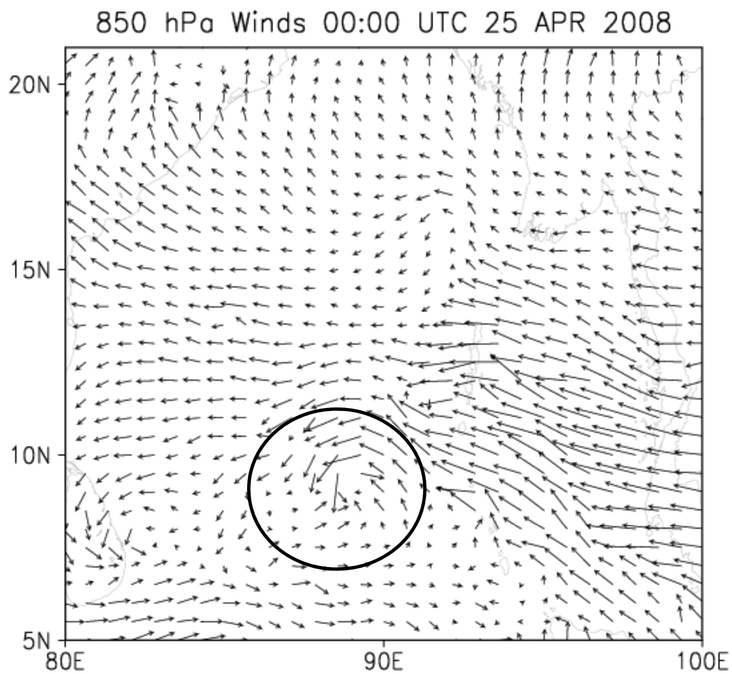
126h



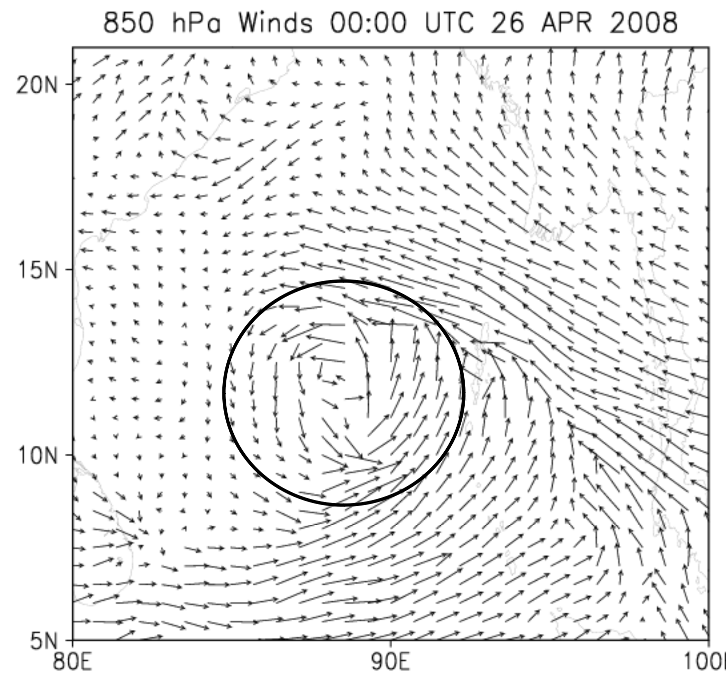
Anti-cyclonic wind shear
Good outflow

Simulations of a pre-TC Mesoscale Vortex

72 h simulation valid at 04/25/00z



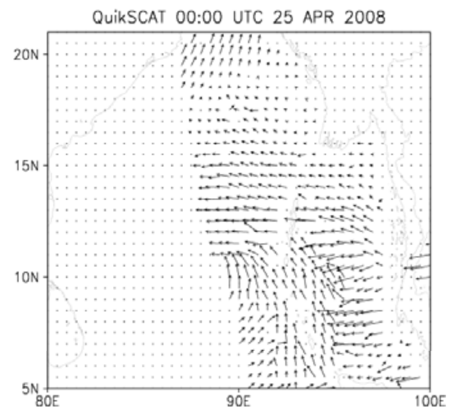
96 h simulation valid at 04/26/00z



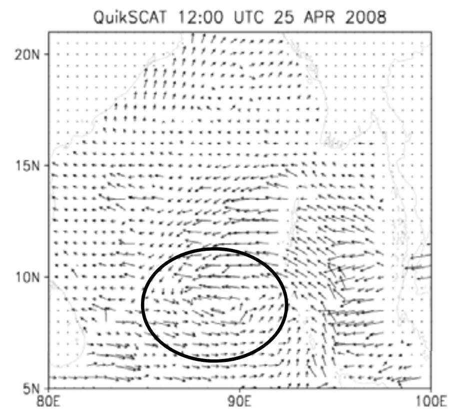
Formation and "enhancement" of a pre-TC mesoscale vortex seems to be related to the appearance of westerly wind "burst" and peak of low-level convergence, shown in the next two slide

Mesoscale Vortex revealed in QuikSCAT winds

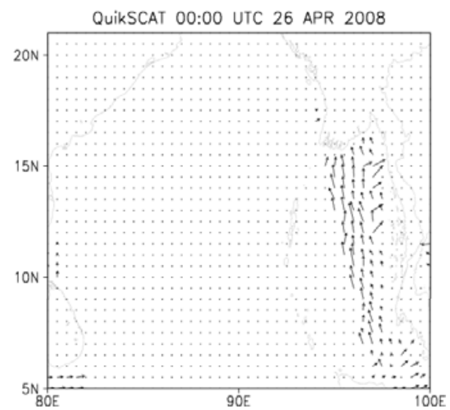
04/25/00z



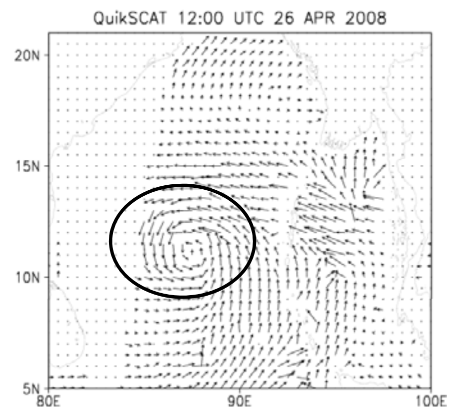
04/25/12z



04/26/00z

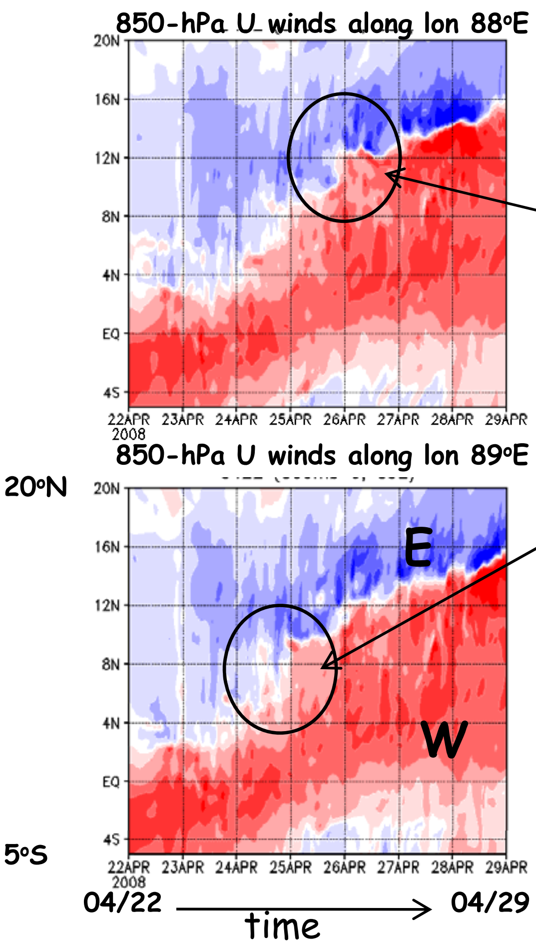


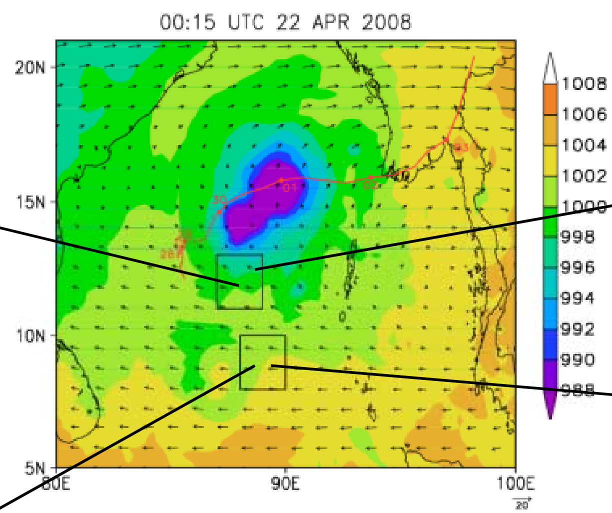
04/26/12z

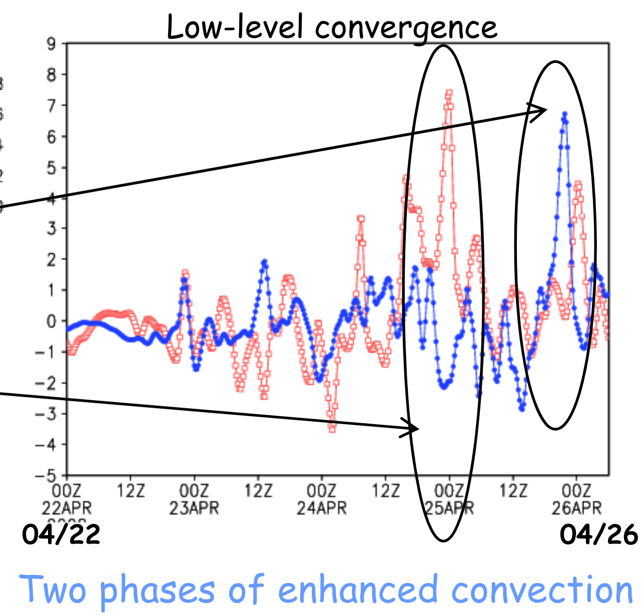


Westerly Wind Bursts and Low-level Convergence in 7-day Simulations

associated with the formation of a pre-TC mesoscale vortex



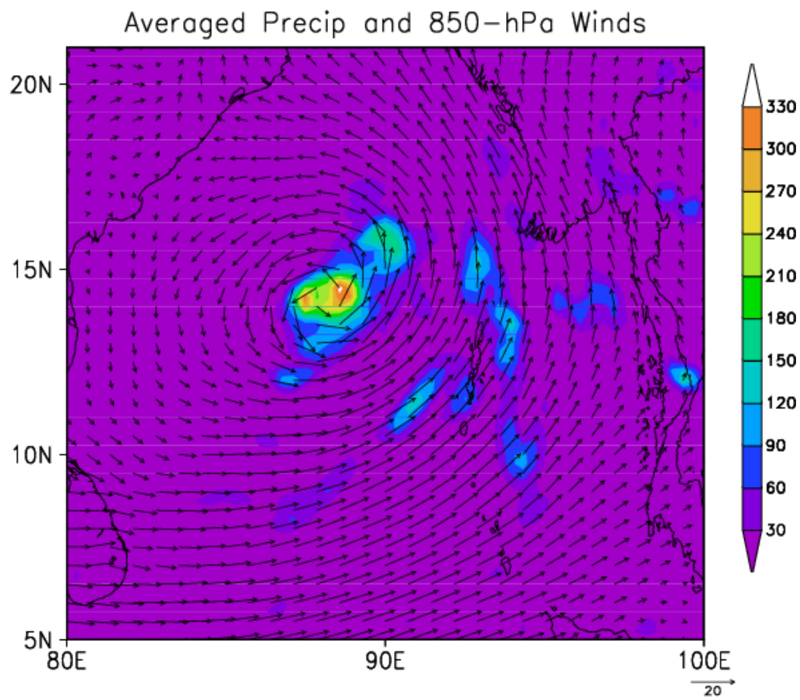




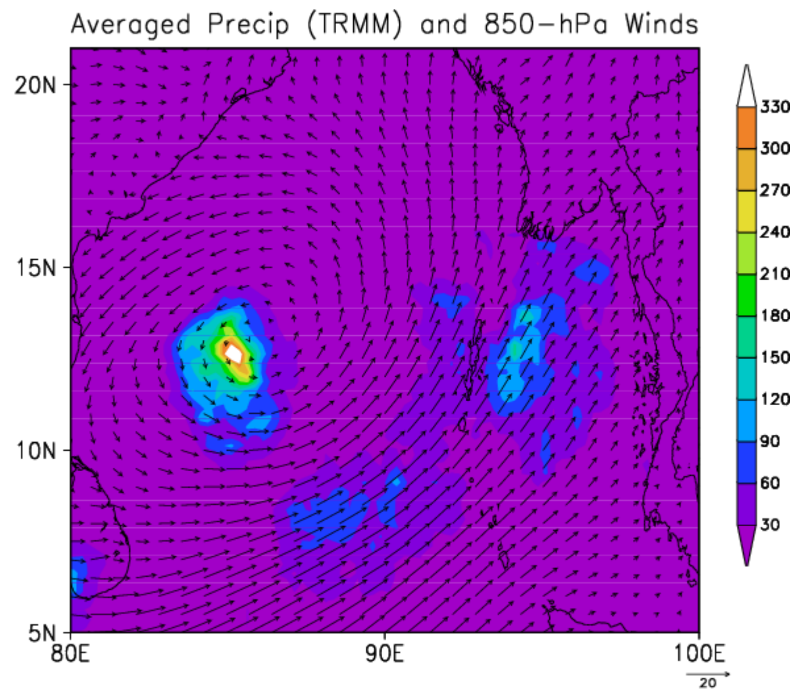
Formation/intensification of a pre-TC mesoscale vortex is related to (1) the occurrence of westerly wind burst and (2) peak of low-level convergence.

Averaged precip and 850-hPa winds

Averaged preccip and 850-hPa winds from 04/27 (day 5) to 04/29 (day 7)



Averaged NASA TRMM precip and NCEP Reanalysis winds

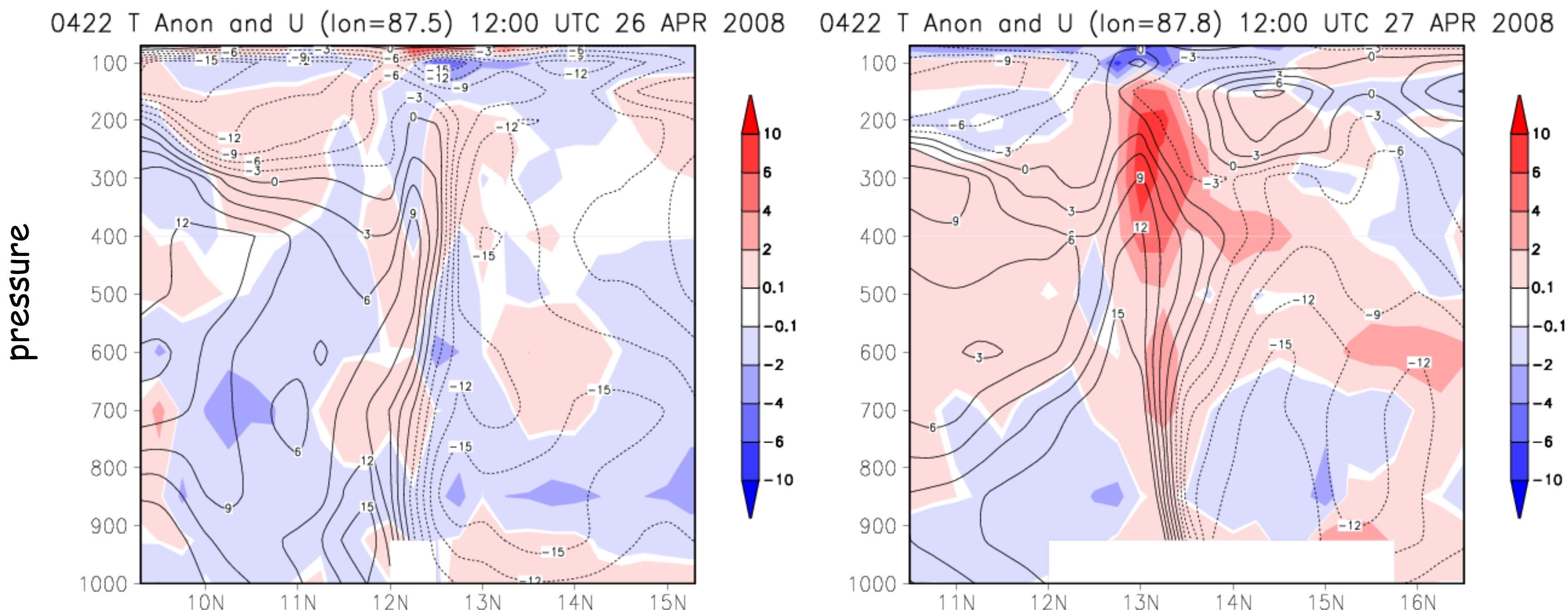


- Suggesting that the aggregate effects of moist processes (latent heating release, surface fluxes and water vapor transport) are simulated reasonably well ?
- Upscaling interactions associated with moist covection?

Formation of a Warm Core

108h simulations valid at 04/26/12z

132h simulations valid at 04/27/12z

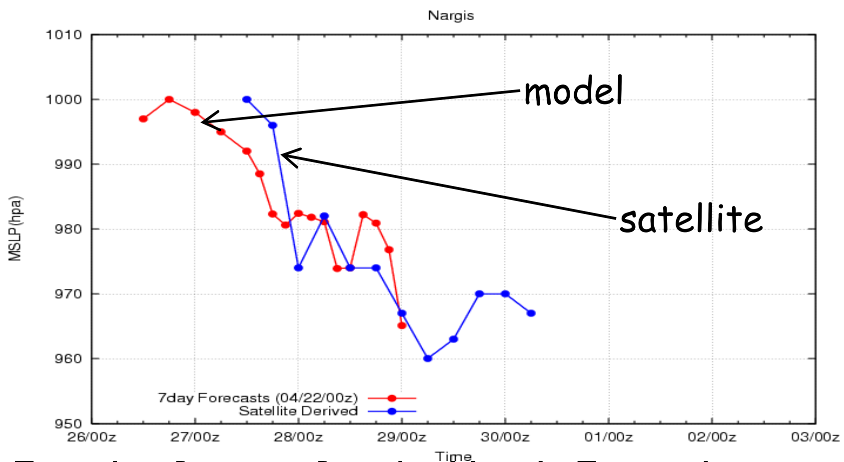


Vertical cross section of Horizontal winds and temperature anomalies

7-days Simulations of TC Nargis (2008)

(Shen, Tao, Lau, Atlas, 2009, accepted by JGR)

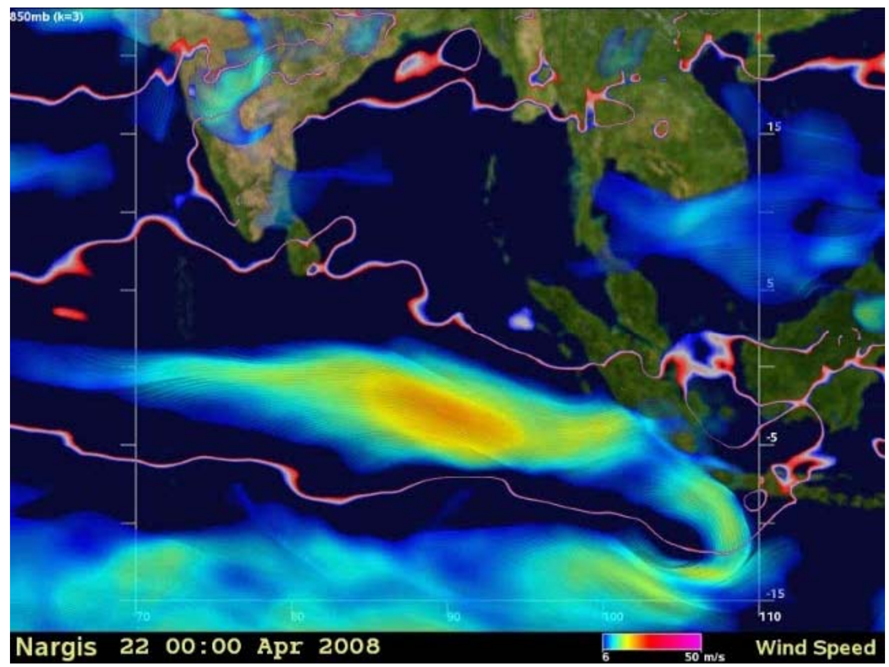
Simulated Intensity from Day-5 to Day-7



Favorite factors for the Nargis Formation:

- (Leading edge of) the WWB; (North of) the equatorial trough
- Enhanced monsoonal circulation; Zero wind shear line
- A good upper-level outflow; Anti-cyclonic wind shear
- Low- and middle-level moistening; Surface fluxes ; low-level convergence (two phases of enhanced convection)

initialized at 0000 UTC April 22, 2008



Nargis was first reported at 1200 UTC April 27, 2008.

Outline

Introduction

Global Mesoscale Modeling with NASA Supercomputing Technology

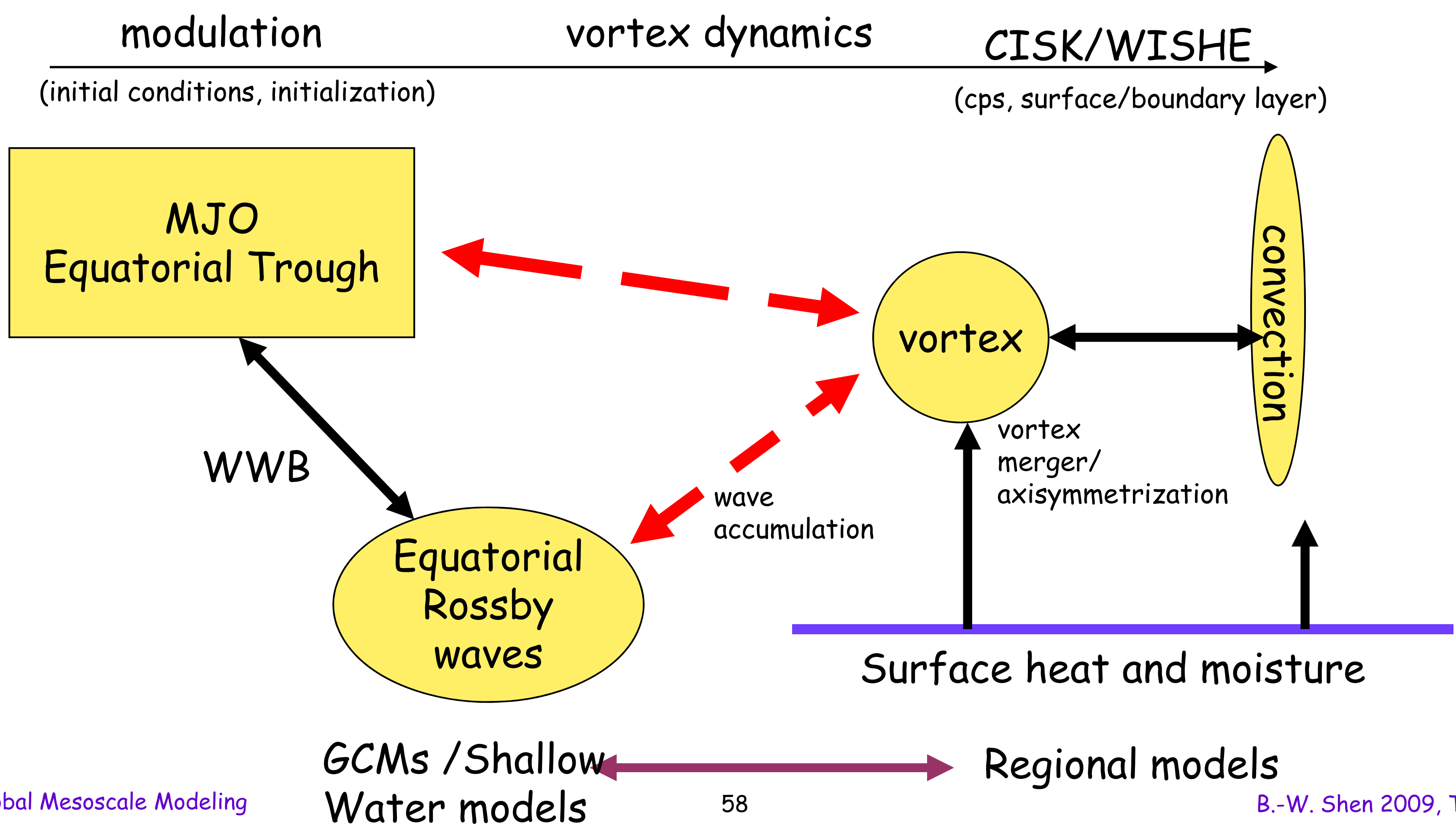
Simulations of High-impact Tropical Weather

- 5-day track/intensity forecasts of Katrina (2005) and Ivan (2004)
- 10-day genesis forecasts of Twin TCs (2002)
- Multiscale interactions during the formation of Nargis (2008)
- 15/30-day simulations of Madden-Julian Oscillations in 2002/2006
- Five AEWs and genesis of Hurricane Helene (2006) in 30-day runs

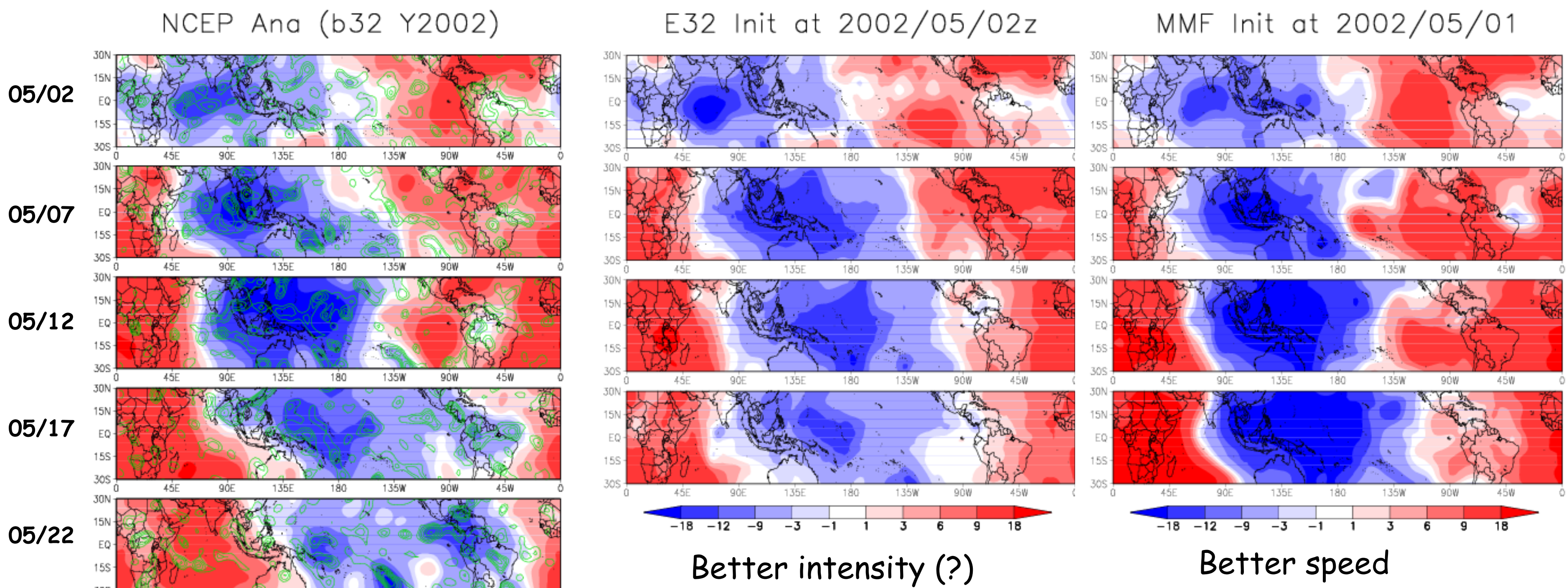
Global Mesoscale Model as a New Research Tool

Summary and Conclusions

Unified View on TC Genesis



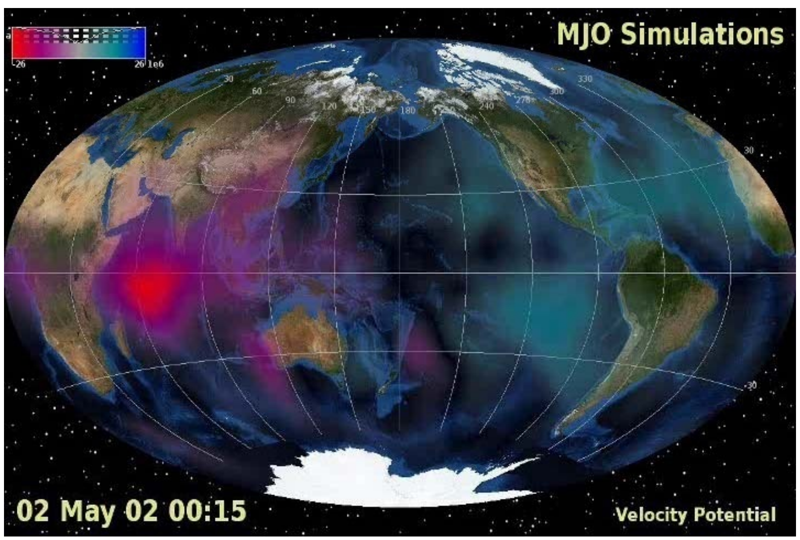
15-day Simulations of an MJO in May 2002

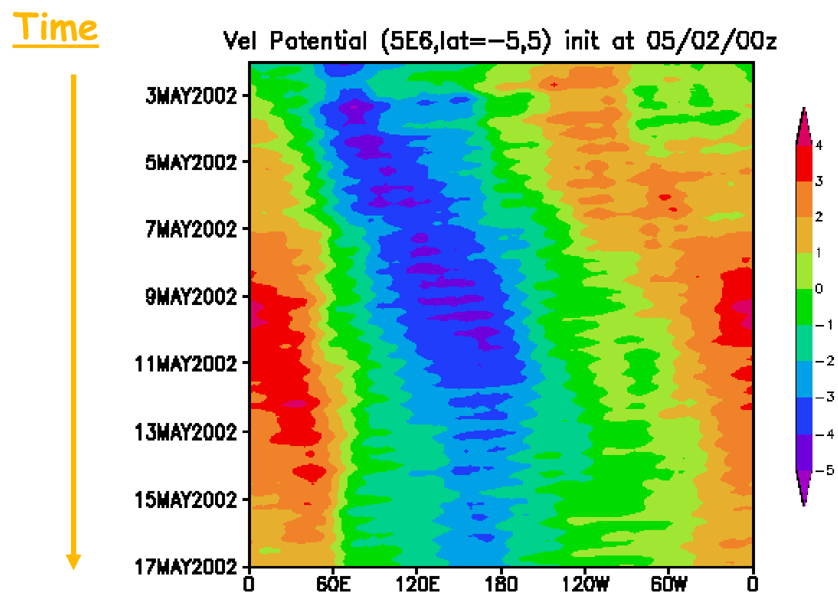


Velocity Potential at 200 hPa

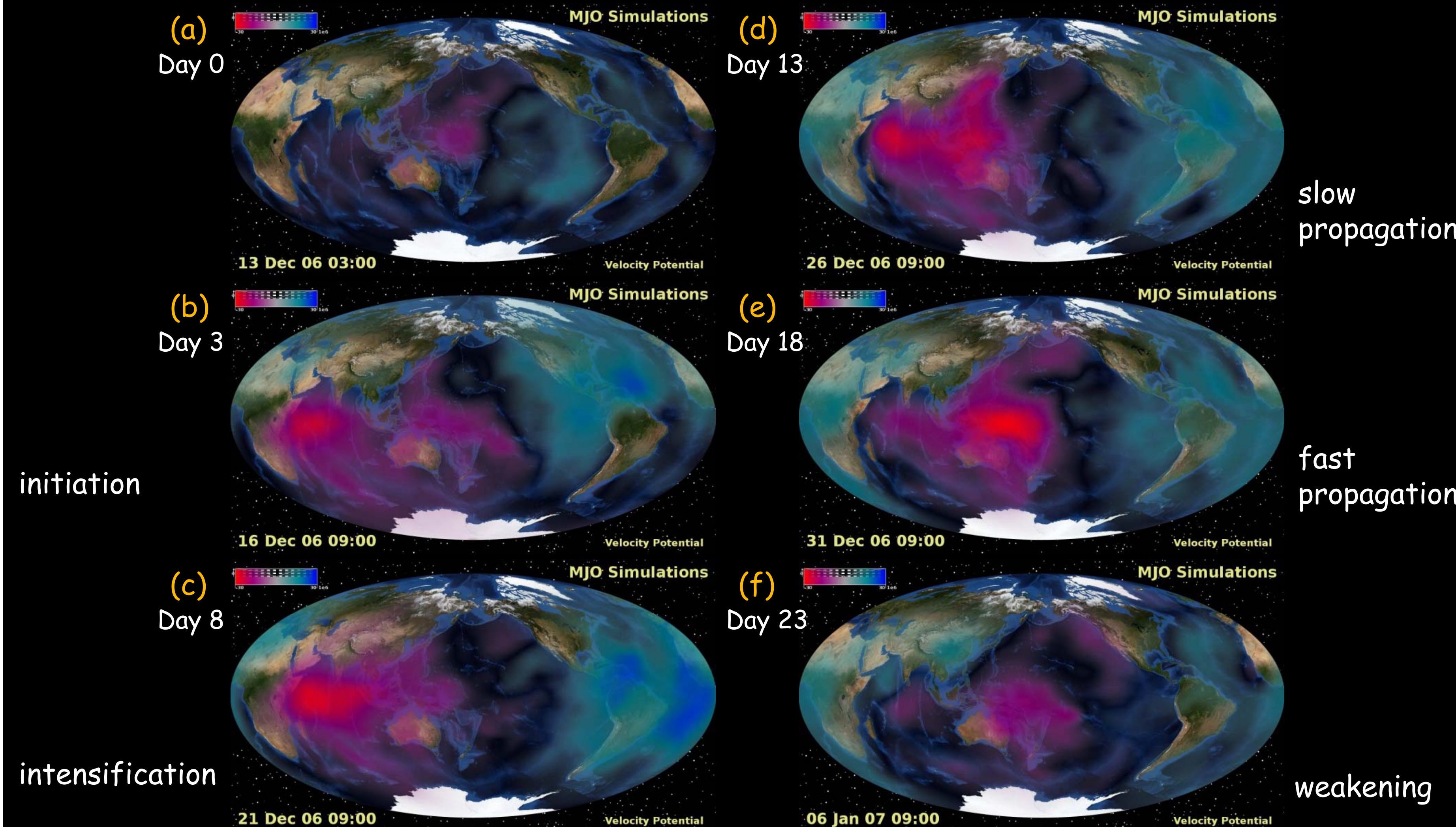
15-day Simulations of an MJO in 2002

Shen, Tao, Chern, Peters-Lidard, Li, 2008: Extended-Range Predictions of Madden-Julian Oscillations with the Goddard Multi-scale Modeling System (in preparation)





Semidiurnal (?)



A 30-day simulation of an MJO initialized at 0000 UTC December 13, 2006, as shown in 200 hpa velocity potential. This MMF simulation captures several major features usually associated with an MJO: (1) initiation of large-scale organized convection in the Indian Ocean in panel (b), (2) intensification as shown in panel (c), (3) slow propagation (prior to reaching the Maritime continent), (4) followed by fast propagation, and (5) weakening. However, this simulated MJO also produces stronger vertical motion than does the NCEP/GSF reanalysis.

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African Easterly Waves (AEWs)

- During the summer time (from June to early October), African easterly waves (AEWs) appear as one of the dominant synoptic weather systems in West Africa.
- These waves are characterized by an average westward-propagating speed of 11.6 m/s, an average wavelength of 2200km, and a period of about 2 to 5 days.
- It has been documented that some AEWs could develop into hurricanes in the Atlantic and even East Pacific regions (e.g., Carlson, 1969). These hurricanes, which are usually intense, are called "Cape Verde" storms.
- In addition, studies also suggested that AEWs could modulate the features of the Inter-Tropical Discontinuity (ITD) over the African continent (e.g., Berry and Thorncroft, 2005 and references therein), where the African northeasterly trade winds and southwesterly monsoon flows meet.
- Therefore, improving our understanding and predictions of the **West African rainfall and hurricane formation** in the Atlantic would rely on the accurate simulations of the AEWs.

African Easterly Jet (AEJ)

Thorncroft and Blackburn, 1999

- AEJ is a midtropospheric jet located over tropical north Africa during the northern hemisphere summer
- AEJ is seen as a prominent feature in the zonal wind, with a maximum of around 12.5 m/s at 600-700 hPa and 15^{o}N.
- Its vertical shears are crucial in organizing moist convection and generation of squall lines;
- Its horizontal and vertical shears are important for the growth of easterly waves;
- Below the AEJ, the easterly wind shear is in thermal wind balance with the surface temperature gradient (BWS)
- One may view the AEJ as resulting from the combination of diabatically forced meridional circulations which maintain it and easterly waves which weaken it. As the nature of diabatic forcing (e.g., moist or dry convection) differs between models, simulated AEJ is likely to be different (e.g., different heights and/or strengths, which will subsequently affect the easterly waves -→ model climate
- The rate at which the AEJ is maintained is likely to be particularly sensitive to the boundary layer parameterization
- Other factors should be included: radiation; the establishment of the surface temperature and humidity gradients themselves; etc

Map of North Africa

Berry and Thorncroft (2005, MWR)

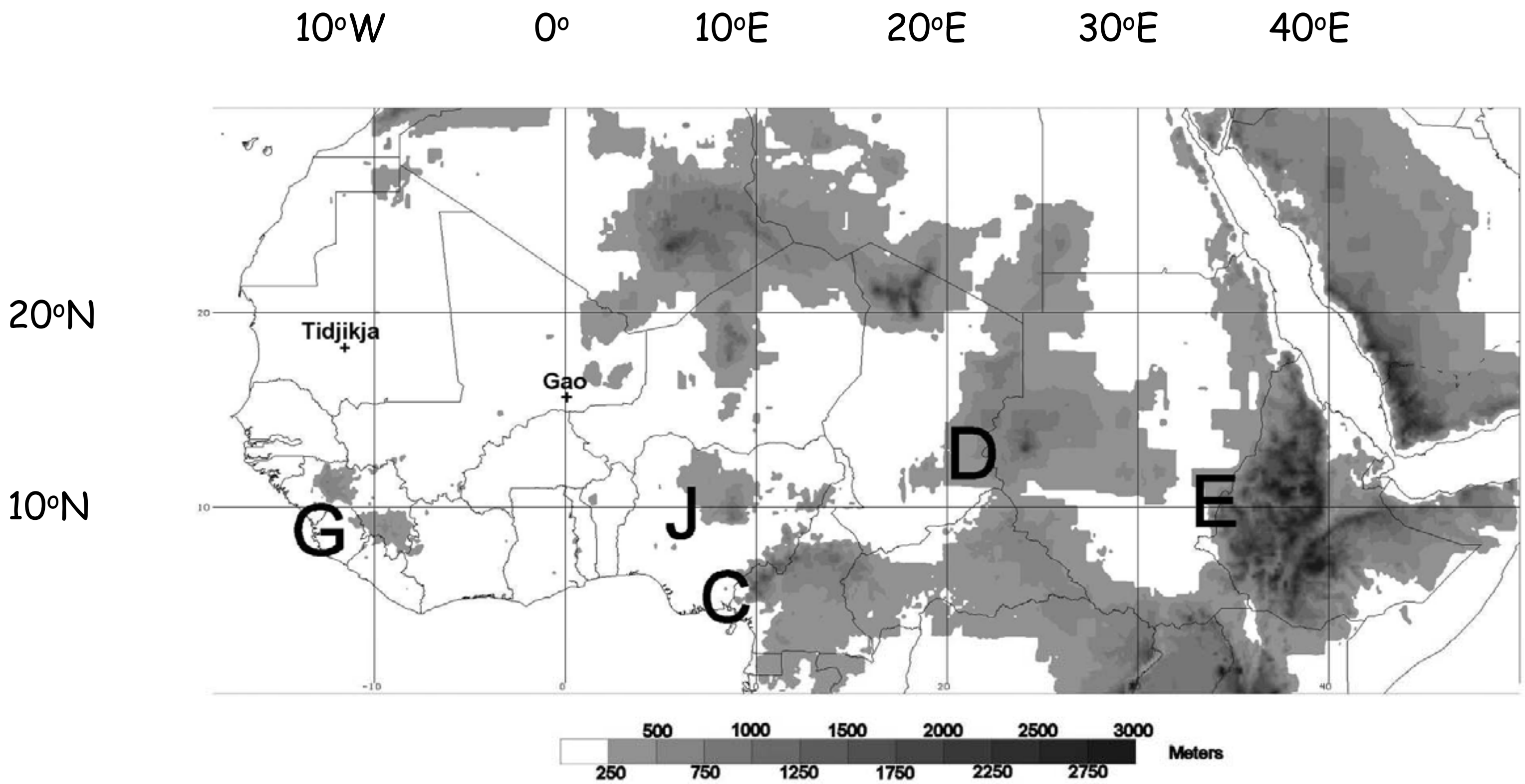
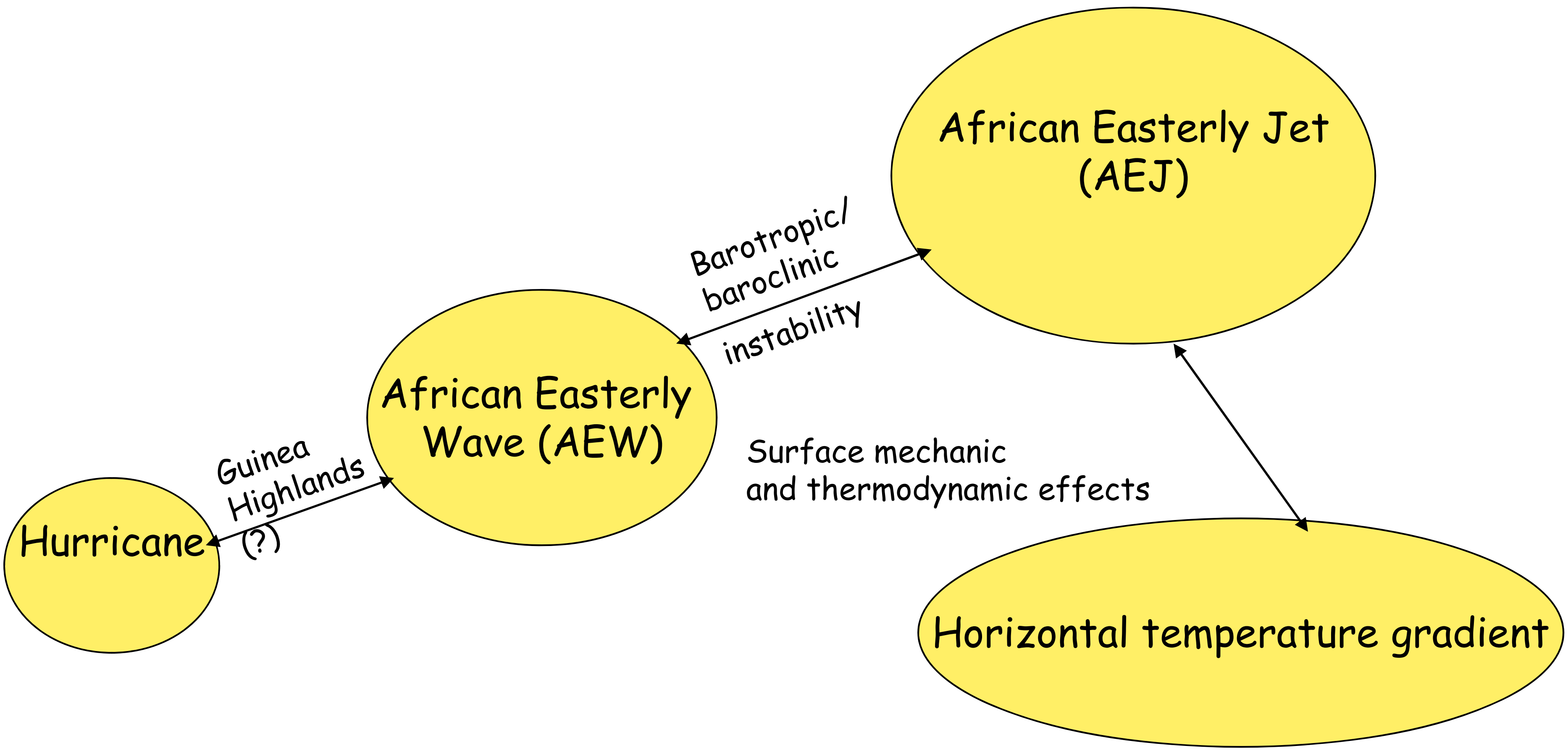


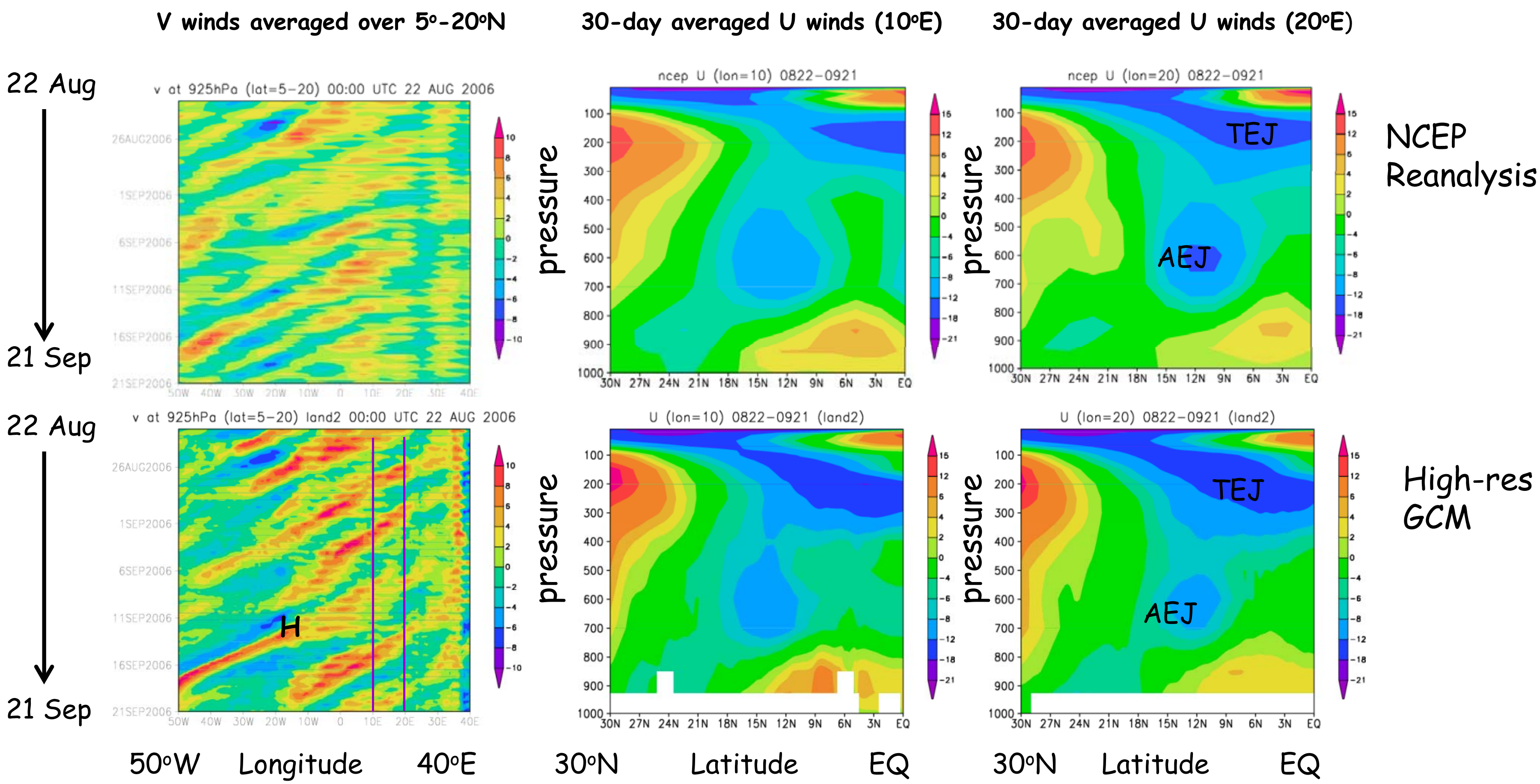
FIG. 1. Map of North Africa, including coastline and national borders. Relief over 250 m is shaded, with key at the bottom of the figure. Labels on the western side of orography identify the following regions: G = Guinea highlands, J = Jos Plateau, C = Cameroon highlands, D = Darfur highlands, and E = Ethiopian highlands. Locations of synoptic observations are marked by a cross and labeled with the station name.

Multiscale Interaction during Hurricane Formation



Five AEWs in 30-day Simulations

(init at 00zz Aug 22, 2006)

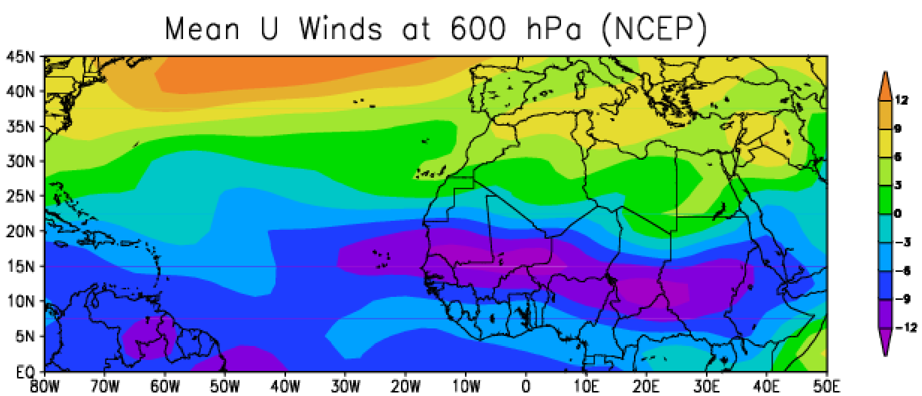


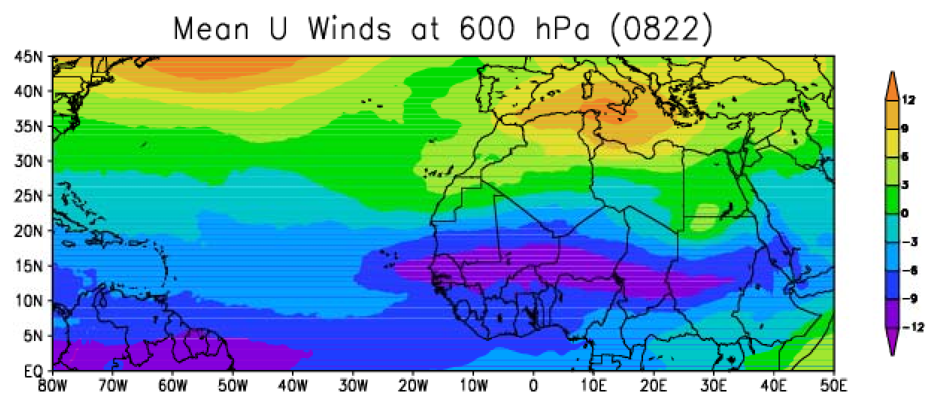
30-days Averaged U Winds and Temp

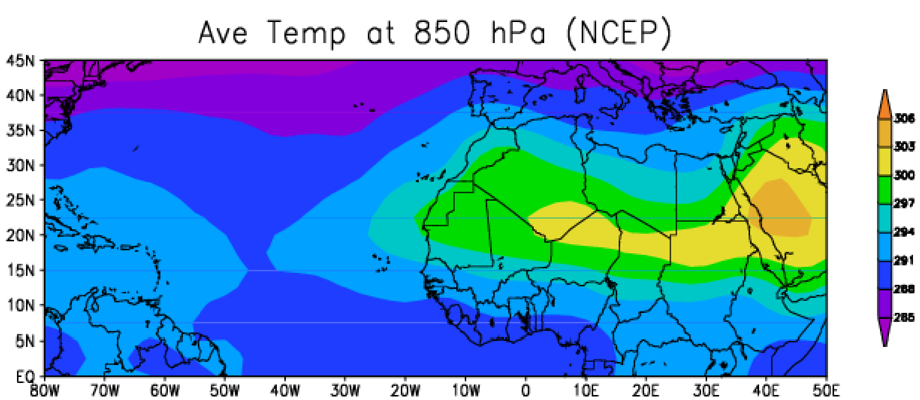
(init at 08/22/00z)

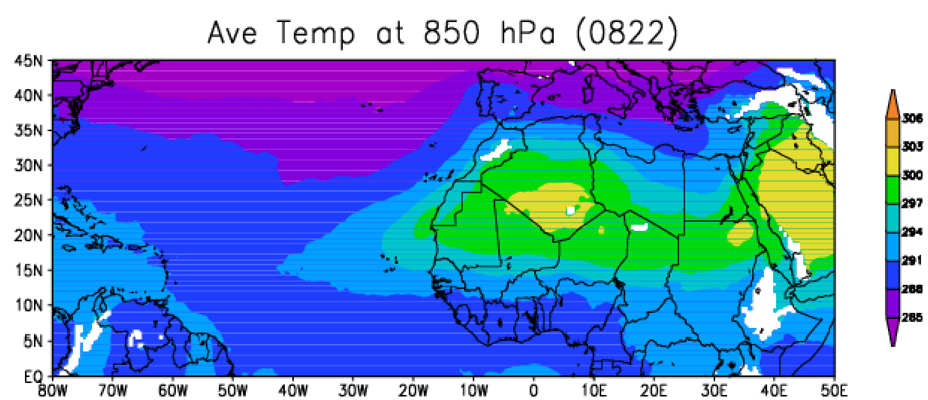
NCEP Reanalysis

Model Simulations





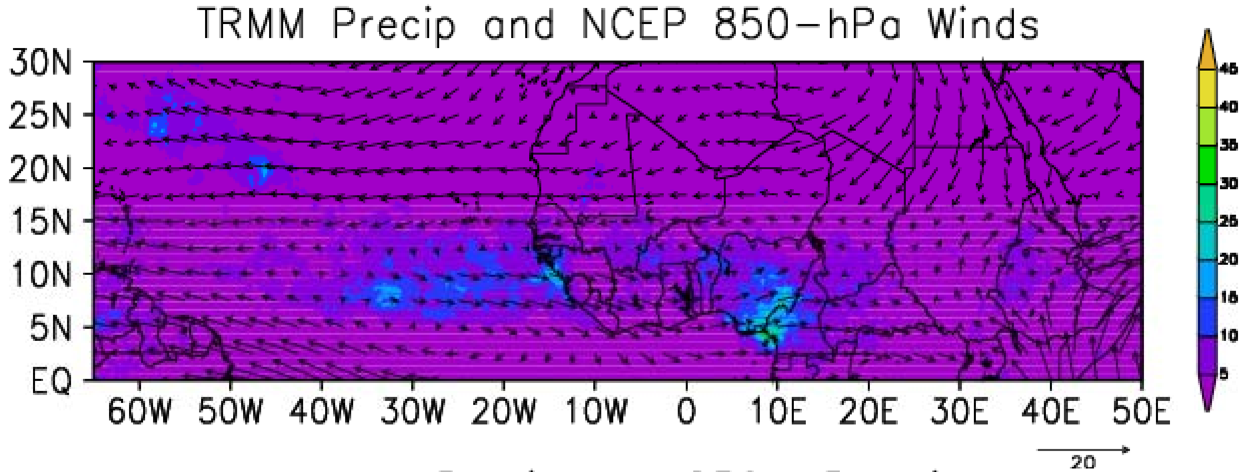




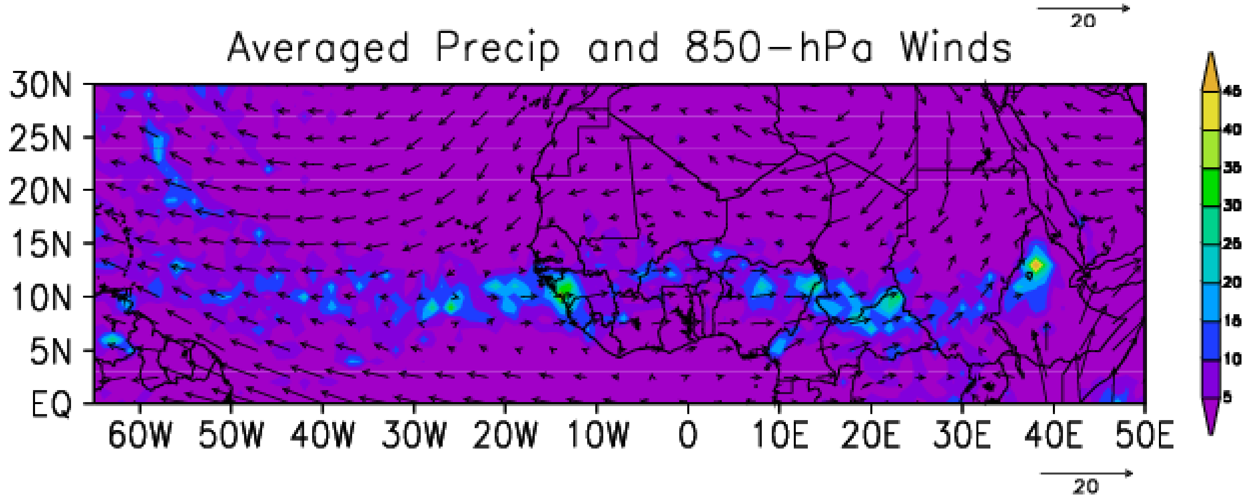
30-days Averaged Precip and 850 hPa Winds

(init at 08/22/00z)

TRMM Precip and NCEP Aeanalysis Winds



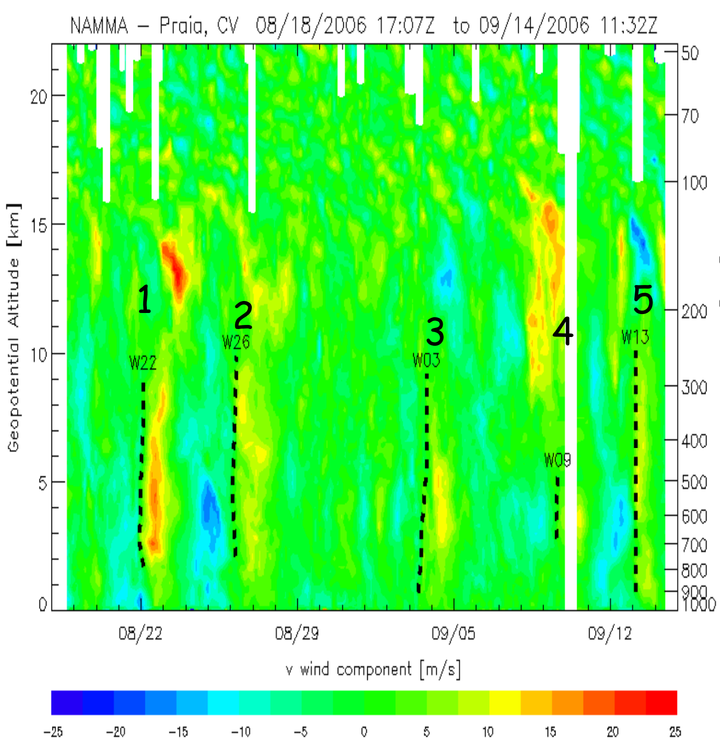
Model Simulations



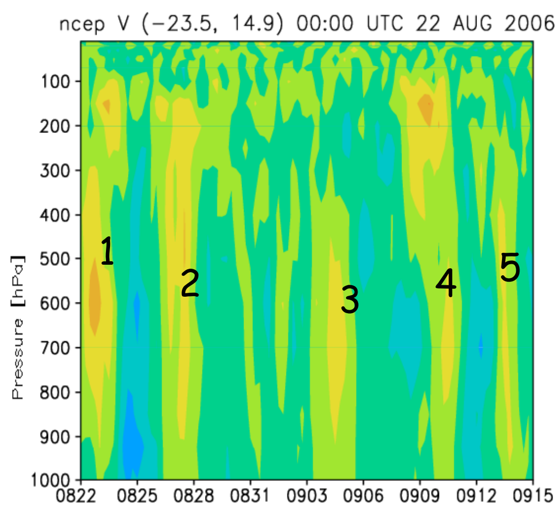
Verification with NAMMA Observations

Praia, CV @ (23.5^{o}W, 14.9^{o}N)

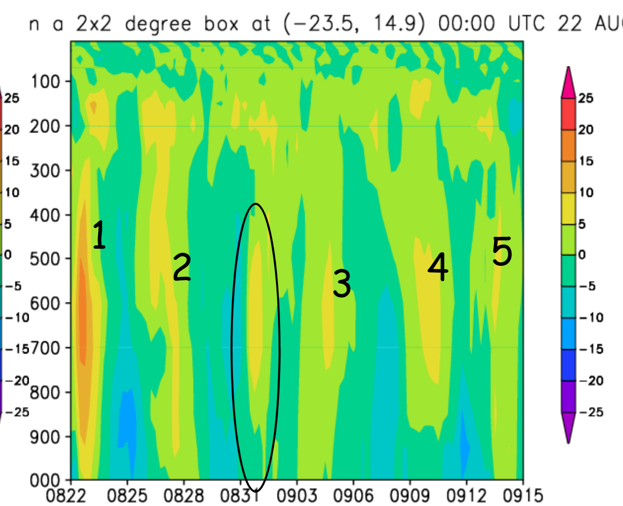
NAMMA OBS



NCEP Reanalysis



Model simulation



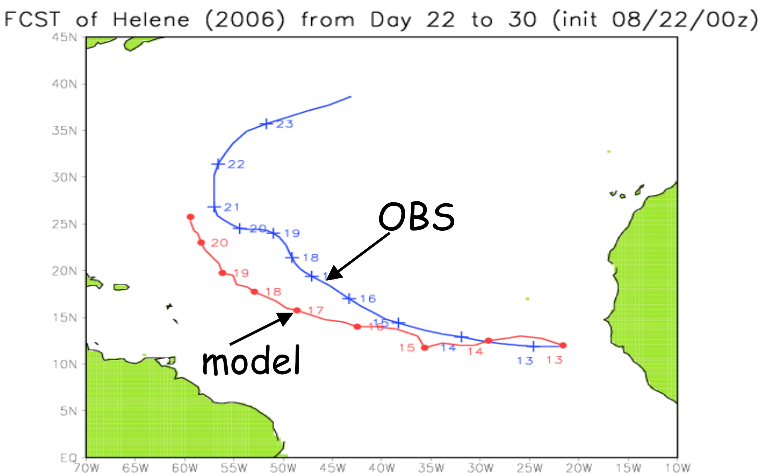
Left panel: Schmidlin, F. J., B. Morrison, T. Baldwin, E. T. Northam, 2007: High Resolution Radiosonde Measurements from Cape Verde: Details of Easterly Wave Passage. AGU 2007 Fall Meeting.

NAMMA: NASA African Monsoon Multidisciplinary Analyses

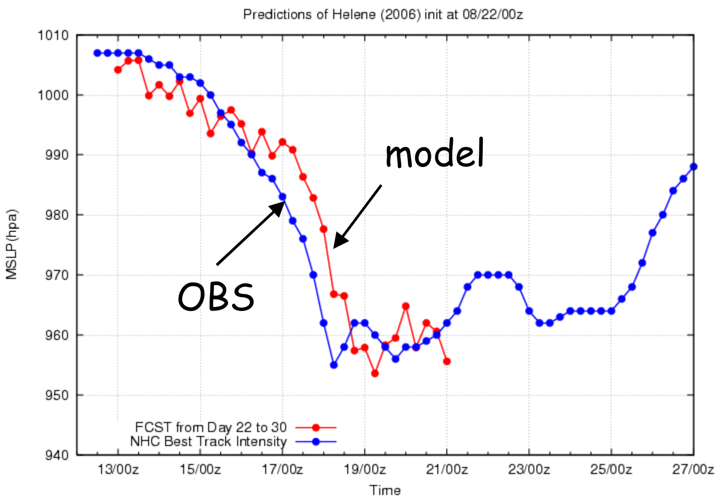
Simulations of Helene (2006) between Day 22-30

Helene: 12-24 September, 2006

Track Forecast



Intensity Forecast



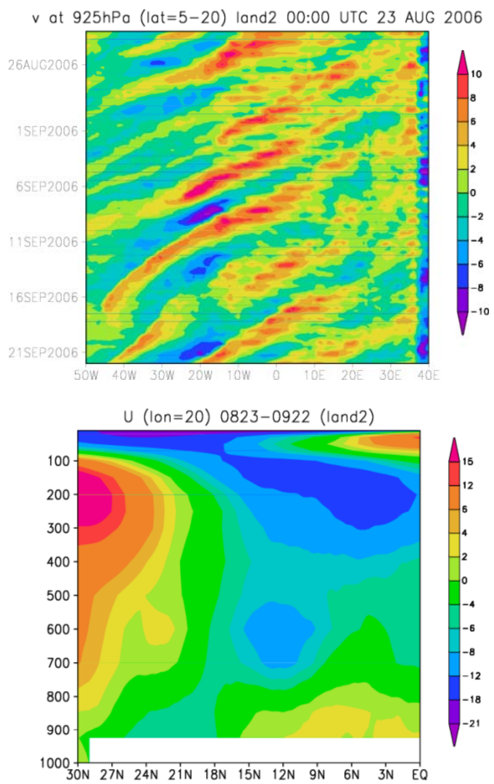
Future work:
to study multiscale interactions among TEJ, AEJ, AEWs, hurricanes and surface mechanic and thermodynamic processes

Sensitivity Experiments

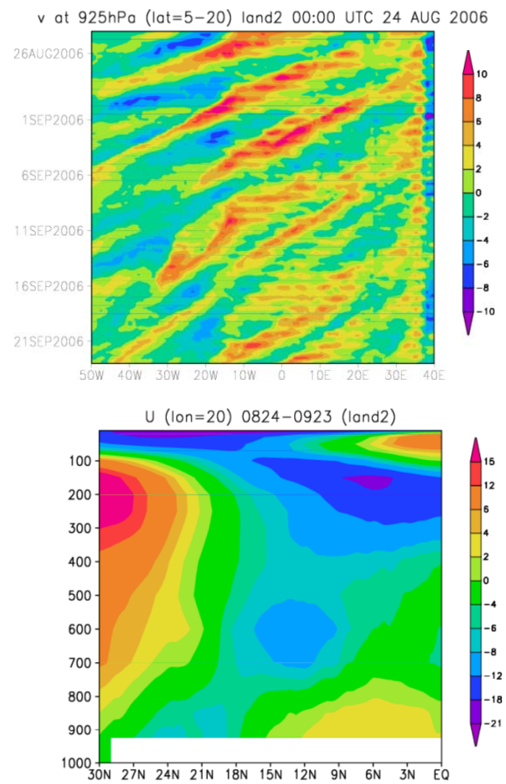
Case id	Dynamic IC	Clm and Physics IC	SST	Guinea Highlands	Remarks
cntl	08/22	08/22	weekly		
C823	08/23	08/23	weekly		
C824	08/24	08/24	weekly		
C825	08/25	08/25	weekly		
Clm0	08/22	Climate clm	weekly		
Clm1	08/22	02/22	weekly		
Clim-sst	08/22	08/22	climate		
C422	04/22	04/22	weekly		Changed date to be 08/22/2006
C622	06/22	06/22	weekly		Changed date to be 08/22/2006
Cntl-g06	08/22	08/22	weekly	A factor of 0.6 in heights	

Sensitivity Tests with different ICs

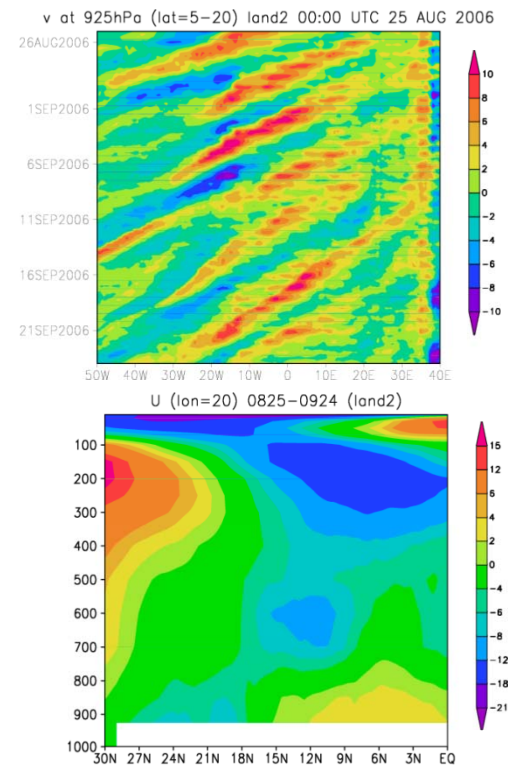
Init at 08/23/00z



Init at 08/24/00z



Init at 08/25/00z

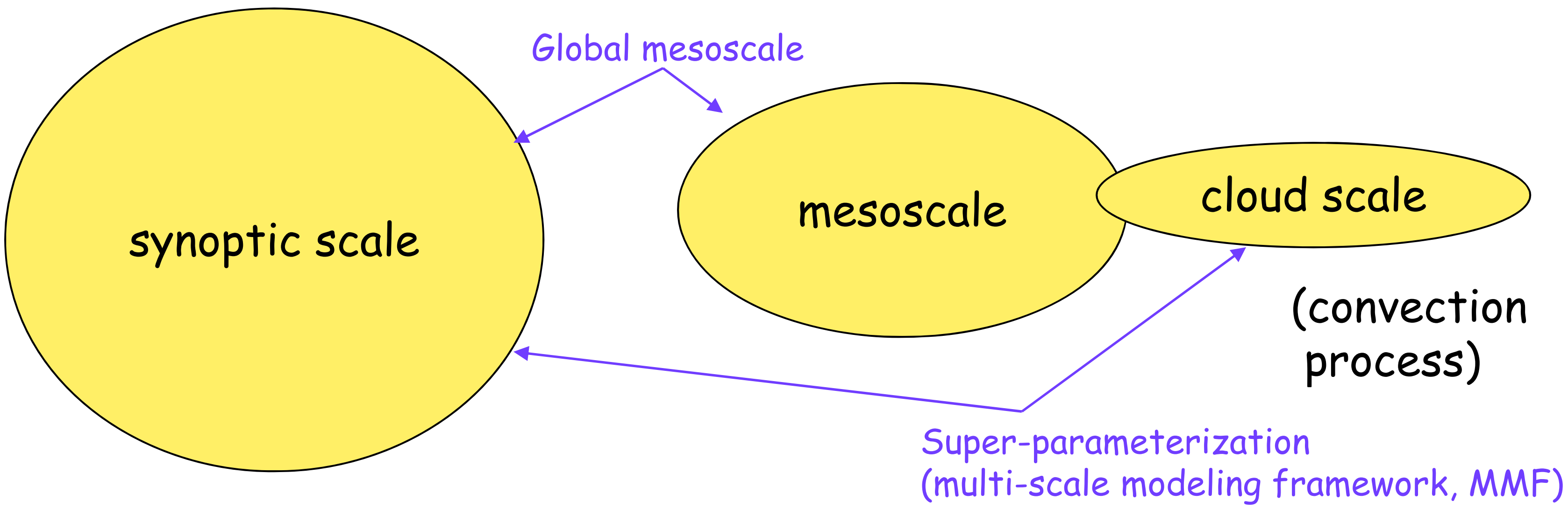


Computational performance

- 10 days, 70 mins with 240 cpus on columbia
- 90 days, 75 mins with 720 cpus on pleiades

- 5 days, about 3 hours with **60 cores**, → suitable for running on clusters and/or multi-core system

Predictability at Different Scales



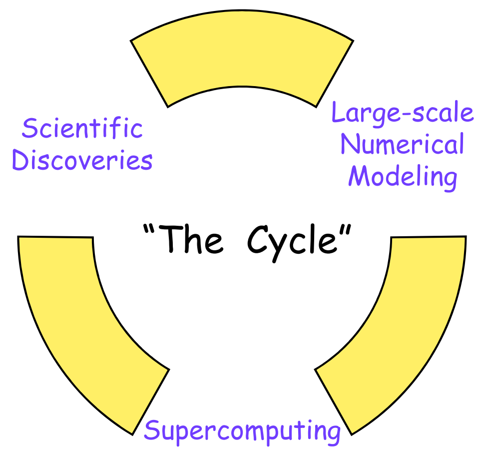
- Predictability at different scales may not be totally independent.
- With regional models, researchers previously focused on improving convective-scale flows and their upscaling/feedback (timing and location) processes, and thus mesoscale flows.
- Here we try to point out the importance of improving two-way interactions between these synoptic- and meso-scale using a global mesoscale model, in particular, if the above approach may have a "theoretical limit" on the improvement of the mesoscale predictability.
- In addition, the aforementioned multiscale interaciotns with resolved convection seem to be more realistic, after the uncertainties of CPs are removed.

Summary

Improved forecasts of TC track, intensity and formation
Improved extended-range (15~30 –days) simulations of MJOs and AEWs.

A unified view on TC formation, including modulation by large-scale flows and interaction between mesoscale vortices, surface fluxes and convection.
→ **hierarchical multiscale interactions**

<u>Future work:</u> extending the current approach to study hurricane climate and impact of global change on hurricane climate.



NASA Global Mesoscale Model: one of the first ultra-high resolution GCMs
NASA Multi-scale Model Framework: consisting of the NASA global model and tens of thousands of copies of NASA cloud resolving model (GCE)
Approaches with explicitly-resolved convection and/or its effects to reduce the uncertainties of cumulus parameterizations
Model Validations with mesoscale weather systems such as the Catalina Eddy, Hawaiian Wake, Mei-Yu front etc

Columbia: SGI Altix, 14,336 cores (Itanium II)
Pleiades: SGI Altix ICE, 51,200 cores (Xeon)
Hyperwall-2: 128 panels

Summary

- High-resolution global modeling with high-end supercomputing technology has shown a potential of improving the multiscale interactions for short-term weather extended-range weather (and climate), e.g., tropical cyclogenesis associated with modulations by large-scale forcing and feedbacks of small-scale motions; simulations of TC formation in fine temporal and spatial resolution (i.e., more realistic/accurate evolution)
- For short-term integration, detailed simulations of small-scale flows (i.e., response to the large-scale/environmental forcing) are important. However, for long-term integration (e.g., climate simulations), their feedbacks (i.e., aggregate effects) are important.
- Favorite factors for the formation of Nargis (2008) include westerly wind burst (WWB), monsoonal circulation, and formation of a pre-TC vortex (which are associated with wind "burst" and peaks of low-level convergence), good outflow with anti-cyclonic wind shear, and moist processes.

愚者　以東為東 以西為西 以南為南 以北為北

智者　知東不必為東 知西不必為西

賢者　知東不必為東 而以東為東

看得破 氣不過

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

PI: Bo-Wen Shen (UMD/ESSIC)

Objective

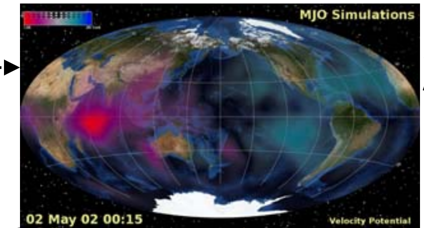
Develop CAMVis weather prediction tool to improve predictions of tropical high-impact weather systems. The tool will seamlessly integrate NASA technologies

- Advanced supercomputing
- Concurrent visualization (CV)
- Multi-scale (global-, meso-, cloud-scale) modeling systems

The goal is to improve the understanding of the roles of atmospheric moist thermodynamic processes (i.e., the changes of precipitation, temperature, and humidity) and cloud-radiation-aerosol interactions.

CAMVis supports NRC Decadal Survey Earth Science missions: CLARREO, ACE, PATH, 3D-Winds

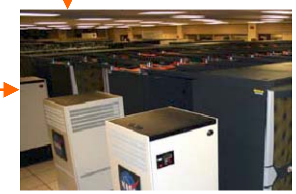
fvGCM, showing a 7-day forecast of tropical cyclone Nargis (2008) and westerly wind belt in the Indian Ocean



Multiscale modeling system, simulating planetary-scale Madden-Julia Oscillation. The system consists of the fvGCM and tens of thousands copies of GCEs.

GCE, simulating high-fidelity clouds motions

Concurrent visualization (CV) system on the 128-panel hyperwall-2



Pleiades supercomputer with 51,200 cores

Approach

- Improve parallel scalability of the multi-scale modeling system to take full advantage of the next-generation peta- scale supercomputers (e.g., NASA Pleiades)
- Integrate NASA multi- scale (global, regional, cloud-scale) model system, including Goddard Cloud Ensemble model (GCE) and the finite-volume General Circulation Model (fvGCM), and the concurrent visualization (CV) system
- Significantly streamline data flow for fast pre- and post-processing and visualizations
- Conduct high-resolution numerical simulations and visualizations for high-impact tropical weather events
- Test coupled systems

Co-I's/Partners

- Co-I's: Wei-Kuo Tao (GSFC, CO-PI), Bryan Green (CO-PI), Chris Henze, Piyush Mehrotra, (ARC), Jui-Lin Li (JPL)
- Partners: Antonio Busalacchi (UMD), Peggy Li (JPL)

Key Milestones

- Implement (update) model components and CV on the Pleiades (Columbia) supercomputer; Conduct initial benchmarks — 09/2009
- Improve parallel scalability of model components; Integrate the NASA fvGCM and CV; Develop the super-component mgGCE — 03/2010
- Couple the NASA mgGCE and CV; Implement and test an I/O module — 09/2010
- Integrate the fvMMF (fvGCM+mgGCE) and CV — 03/2011
- Streamline data flow for production runs — 09/2011
- Test the CAMVis system; Produce results — 03/2012

TRL_{in} = 3