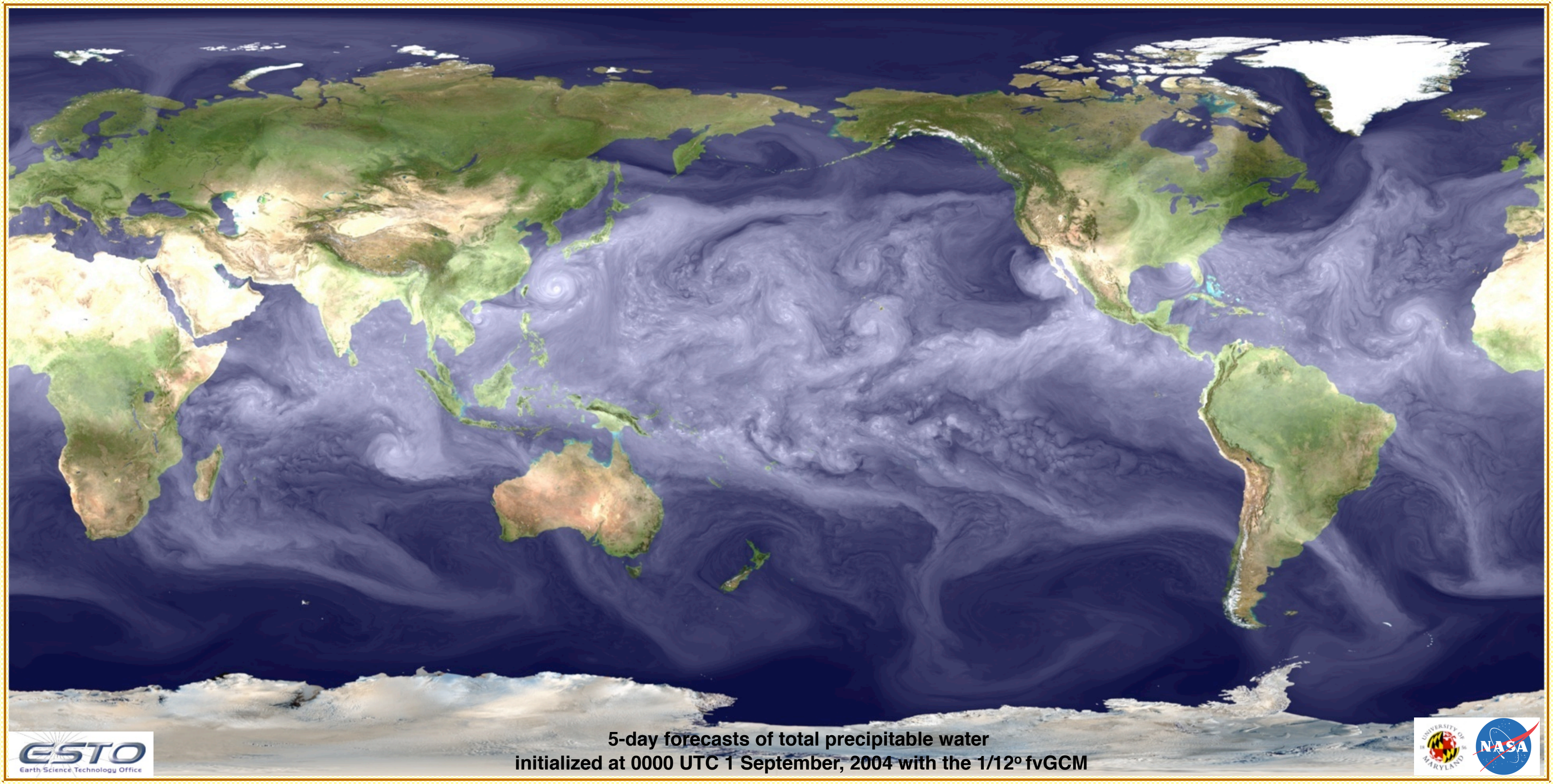
# Hierarchical Multi-scale Interactions during Tropical Cyclone Formation associated with an MJO or AEW




Bo-Wen Shen[1,2], Wei-Kuo Tao[2], William K. Lau[2], Robert Atlas[3], Jiundar Chern[2,4]
[1]UMCP/ESSIC; [2]NASA/GSFC; [3]NOAA/AOML; [4]UMBC/GEST

# Collaborators (since 2005)

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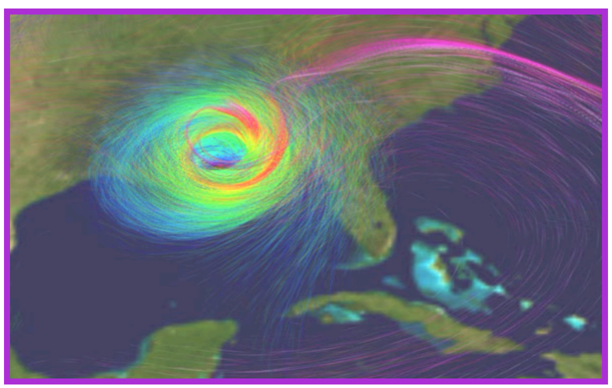
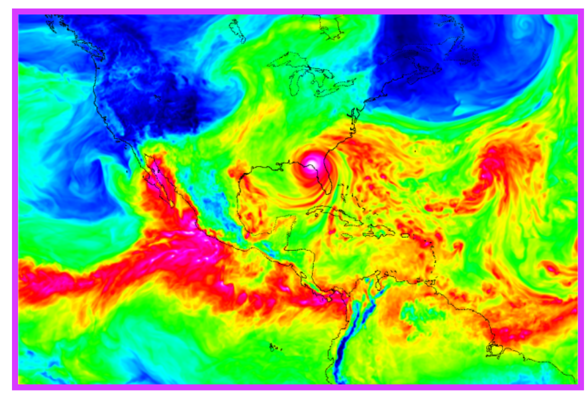
**NASA/ARC:** Bryan Green, Chris Henze, Piyush Mehrotra, Samson Cheung, Henry, Jin, Johnny Chang,

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

**NOAA:** Robert Atlas (AOML)

Acknowledgements: Drs. 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),



# Outline

**Introduction**

**Global Multiscale Modeling**

**Simulations of High-impact Tropical Weather**

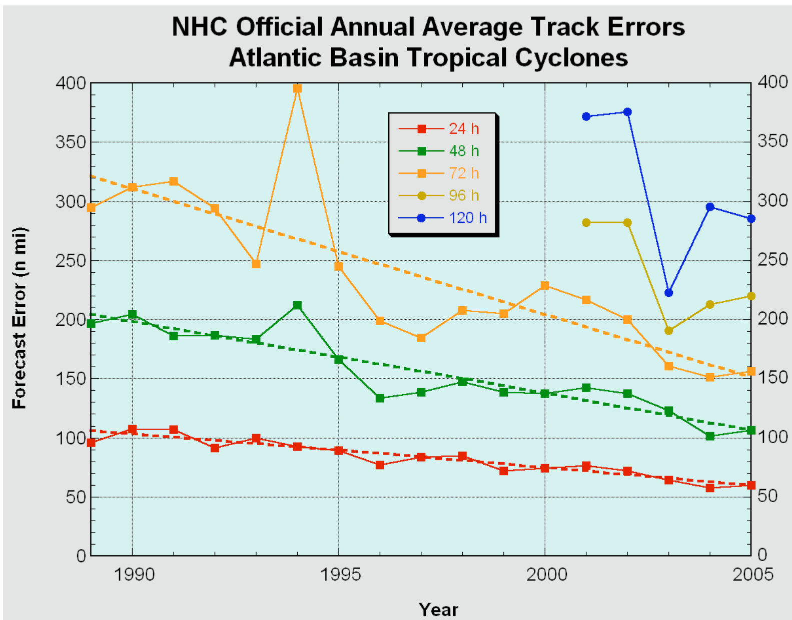
- track and intensity forecasts of Katrina (2005) in 5-day run
- genesis of Twin TCs (2002) in 10-day forecasts
- genesis and intensity forecasts of Nargis (2008) in a 7-day run
- Madden-Julian Oscillations (MJOs) in 15-day forecasts
- 5 African Easterly waves and genesis of Hurricane Helene in a 30-days simulation (2006)

**Summary and Conclusions**

# Progress of Hurricane Forecasts
## (by National Hurricane Center)

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

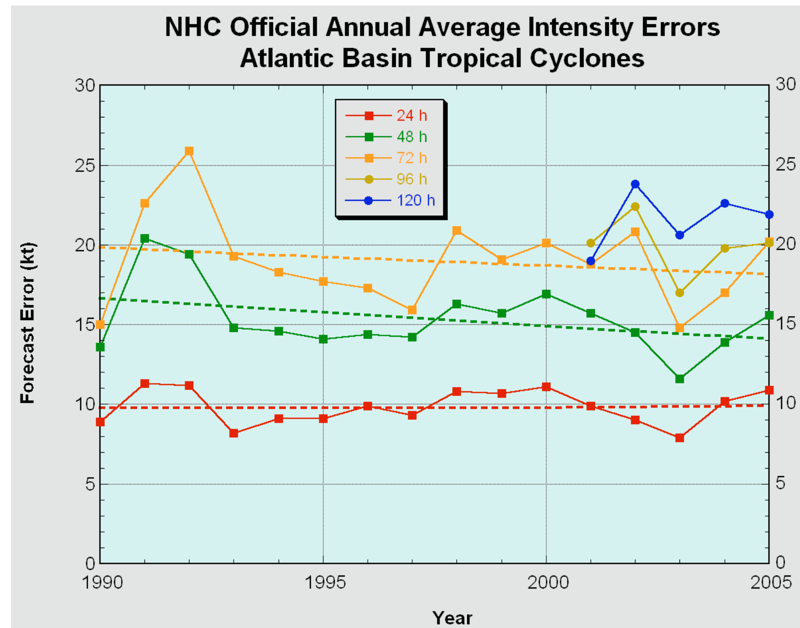
### Track Errors




better

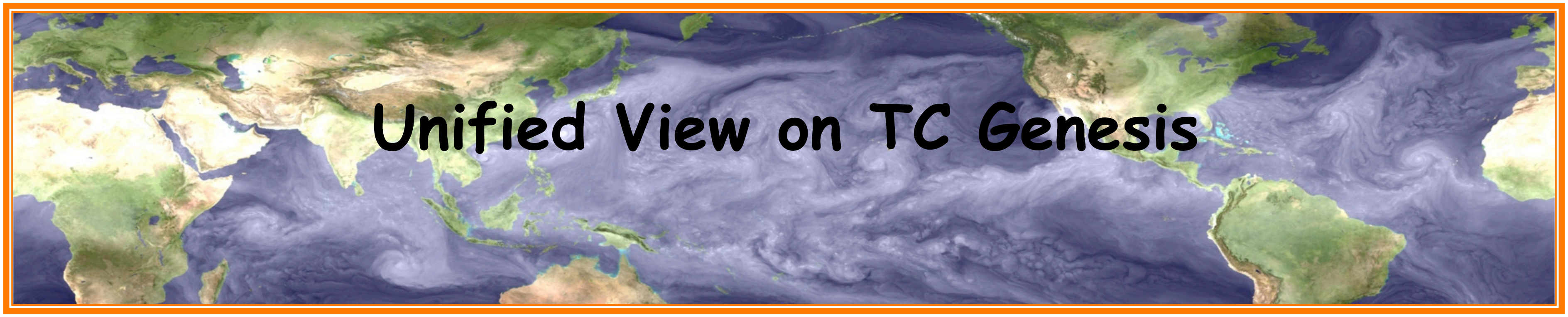
Track forecasts have been steadily improving.

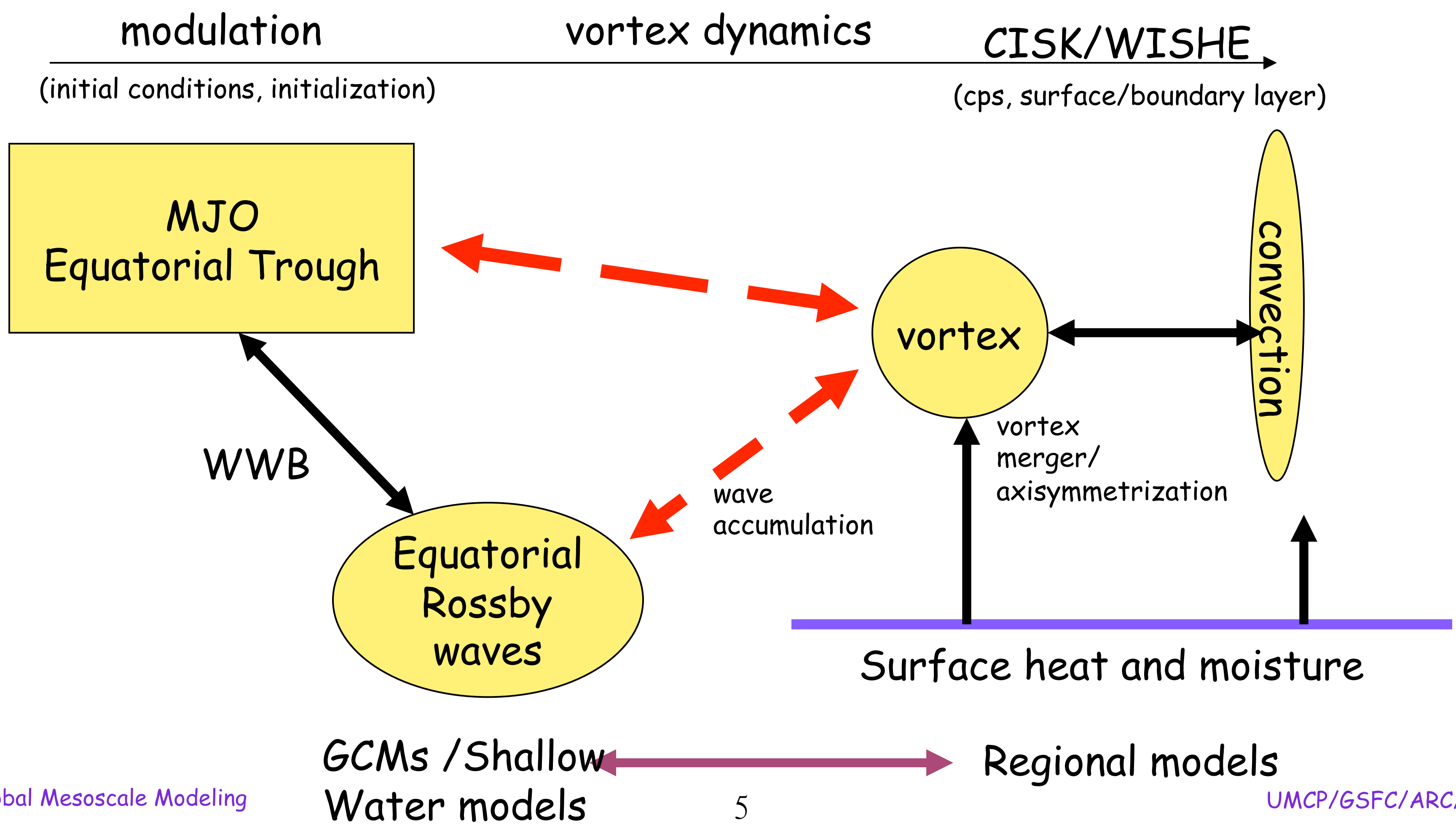
### Intensity Errors



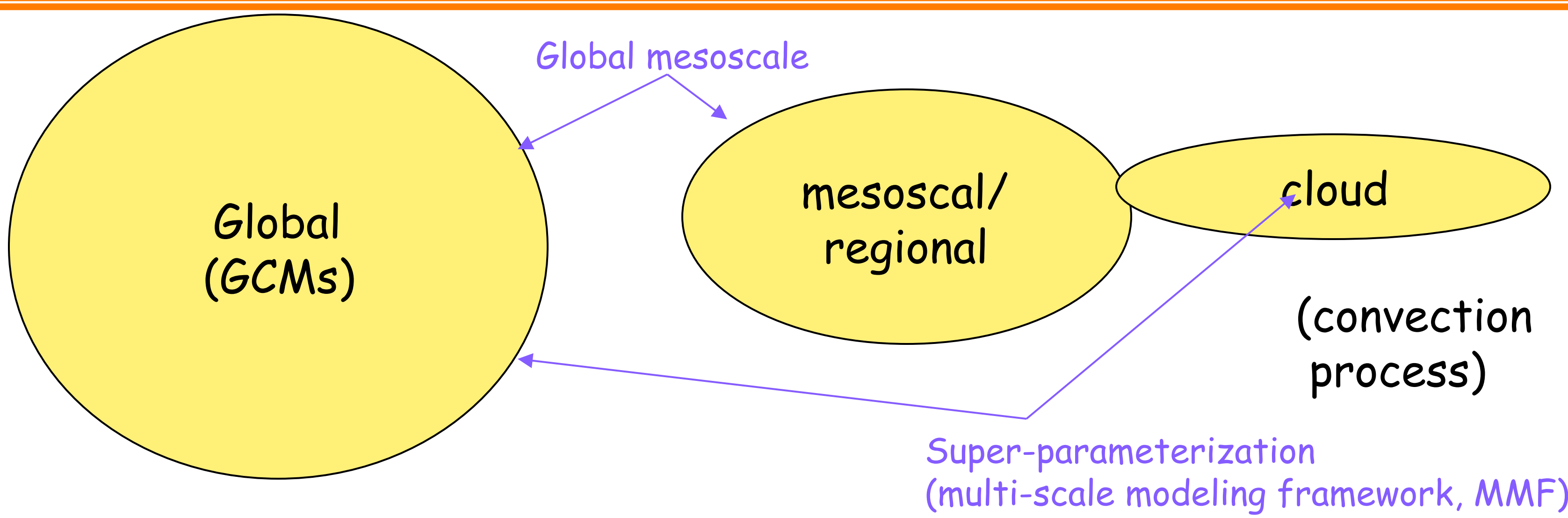

Intensity forecasts have lagged behind.

# Unified View on TC Genesis





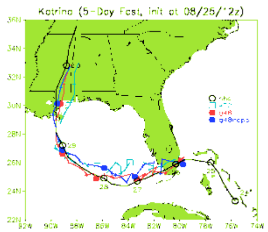
# Modeling at Different Scales



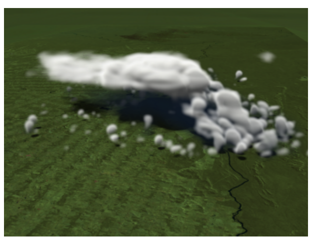

- To understand if effects/impacts of (resolved) "convection" on the system scale of the MJO/TC/AEW are better simulated with our approaches than with a traditional GCM where Cumulus Parameterizations (CPs) are applied.

# The Goddard Multi-Scale Modeling System with Unified Physics

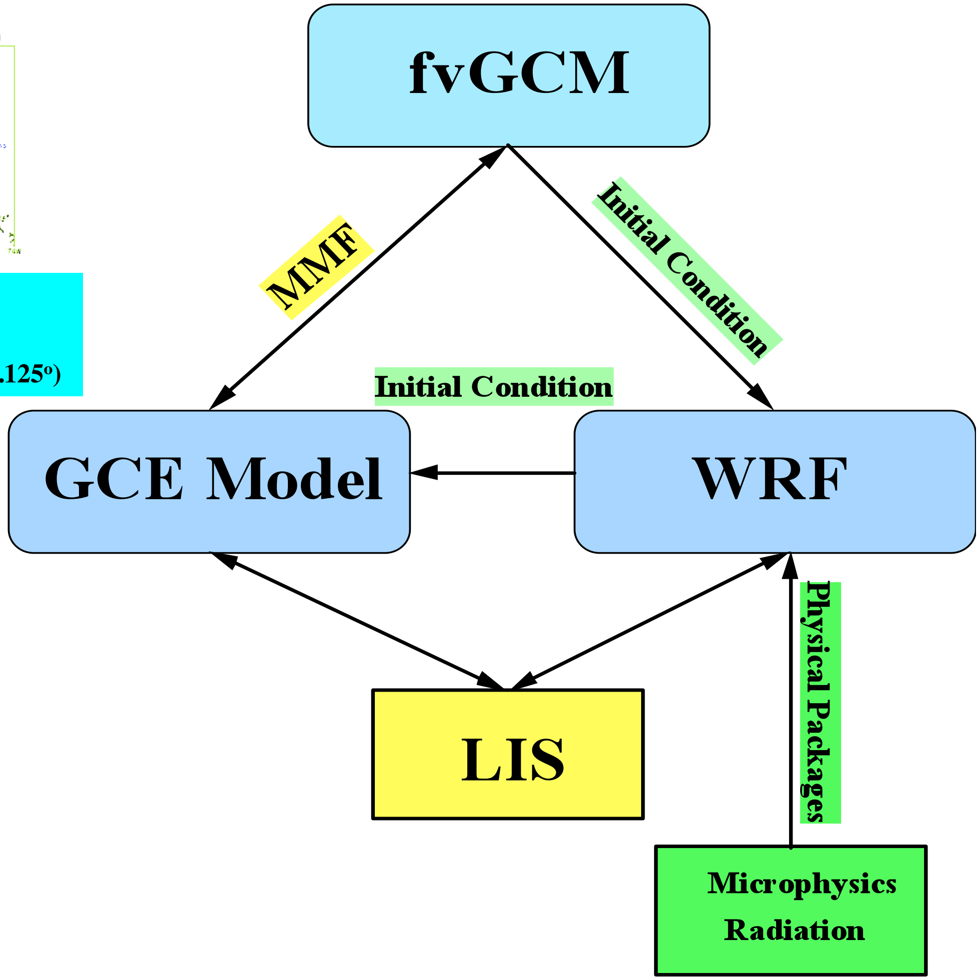
Tao et al., 2009, BAMS



*Hurricane Katrina*
*High-resolution fvGCM*
*5 day forecast* (0.125° x 0.125°)

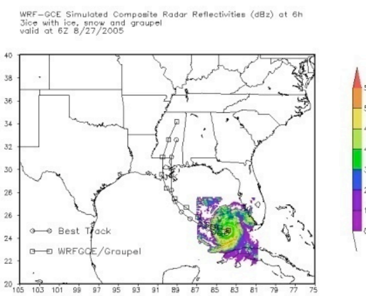


GCE - LBA (250 m)




Observation

Satellite Data
Field Campaigns
Re-analyses



WRF- *Hurricane Katrina* (1.67 km)

Microphysical Package (3 options)
& Long/Shortwave Radiative Transfer
(including cloud-radiation interaction)

MMF: Multi-Scale Modeling Framework
LIS: Land Information System
GCE: Goddard Cumulus Ensemble Model
WRF: Weather Research Forecast

# NASA Major Supercomputers

**Columbia Supercomputer** (ranked 2nd in late 2004)

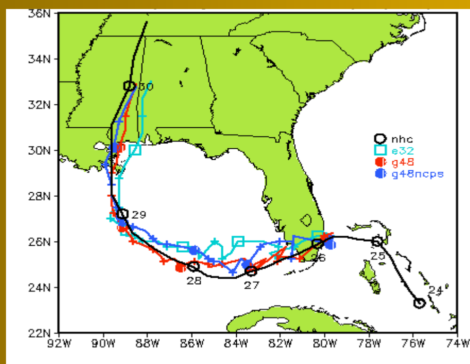
- **Based on SGI® NUMAflex™ architecture** 20 SGI® Altix™ 3700 superclusters, each with 512 processors Global shared memory across 512 processors
- **10,240 Intel Itanium® 2 CPUs**; Current processor speed: 1.5 gigahertz; Current cache: 6 megabytes
- **20 terabytes total memory;** 1 terabyte of memory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

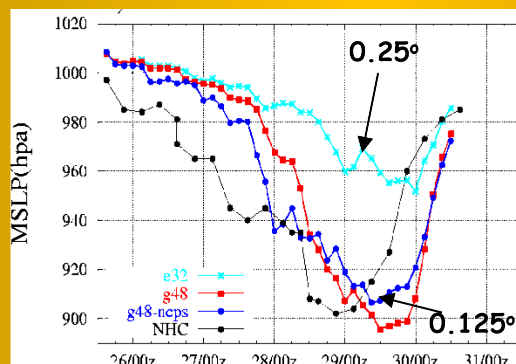
**Pleiades Supercomputer** (ranked 3rd in late 2008)

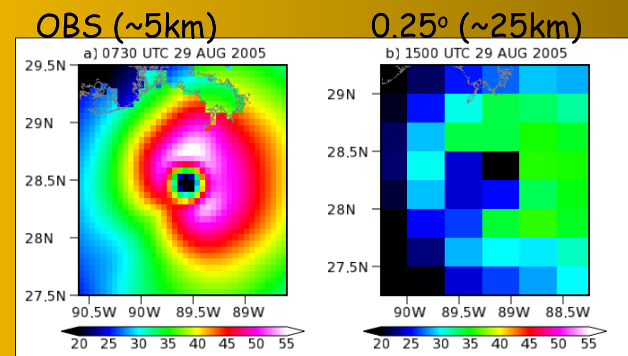
- **92 Compute Cabinets (64 nodes per cabinet; 2,560 nodes; 2 quad-core processors per node)**
- **quad-core Xeon 5472 (Harpertown) processors, speed - 3GHz; Cache - 12MB per processor**
- **51,200 cores in total (512 cores per cabinet)**
- **50+ TB memory in total, 1 (8) GB memory per core (node)**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

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

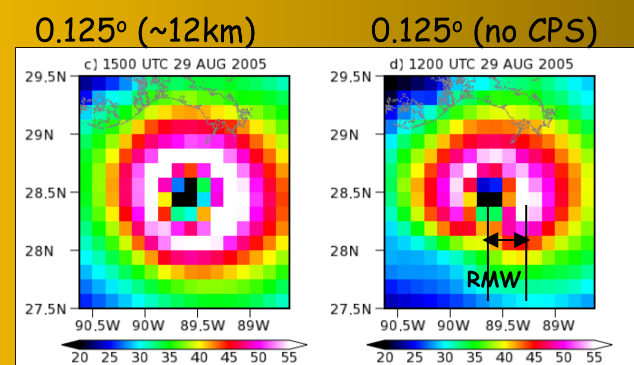
Selected as Journal Highlight by American Geophysical Union
Highlighted by *Science* magazine (July, 2006)
Highlighted in the 2006 Annual report by SAIC (Science Application International Corp.)

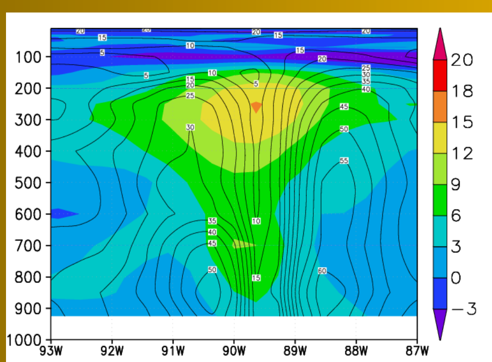


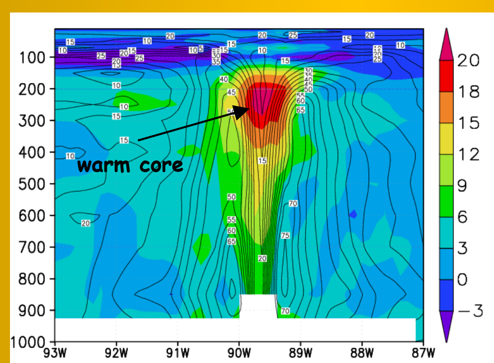




**Landfall errors: e32 (1/4°): 50km, g48(1/8°): 14km, g48ncps (1/8° w/o CPs): 30km**



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

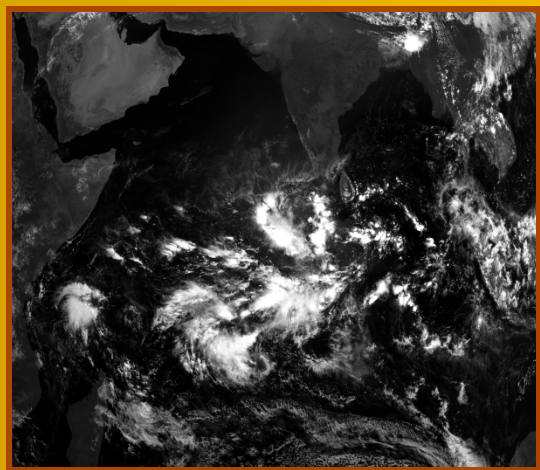



96 h Simulations with no CPS

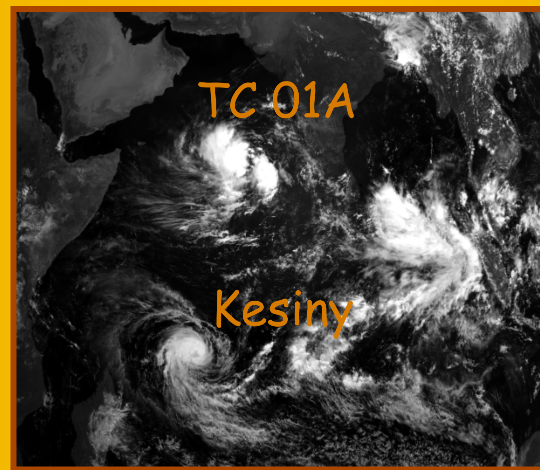
Near-eye Wind Distributions in a 2°x2° box (a) AOML high-resolution surface wind analysis, (b) the 0.25° 99h simulations, (c) the 0.125° 99h simulations, (d) the 0.125° 96h simulations without convection parameterizations (CPs).

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

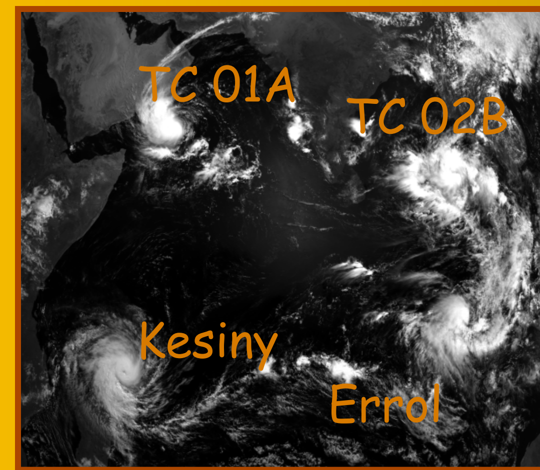
0630 UTC 1 May 2002



0630 UTC 6 May 2002

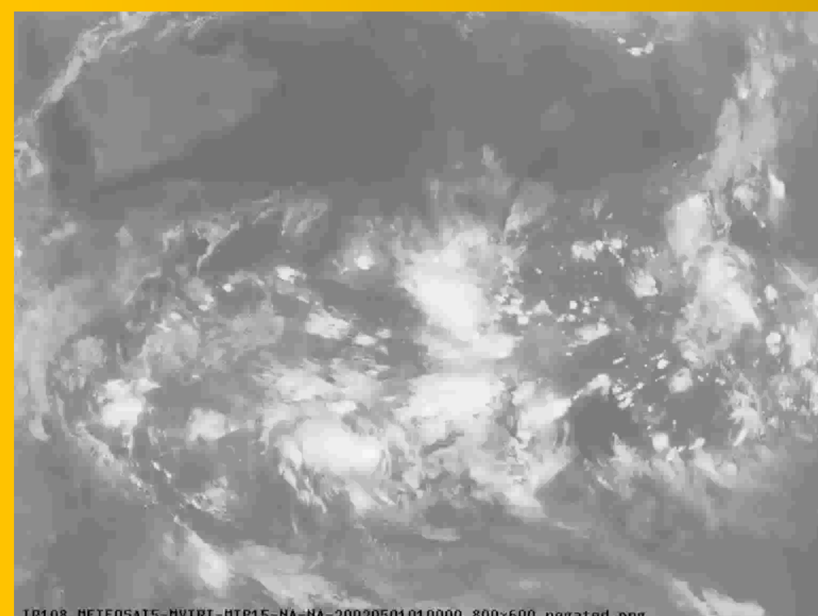


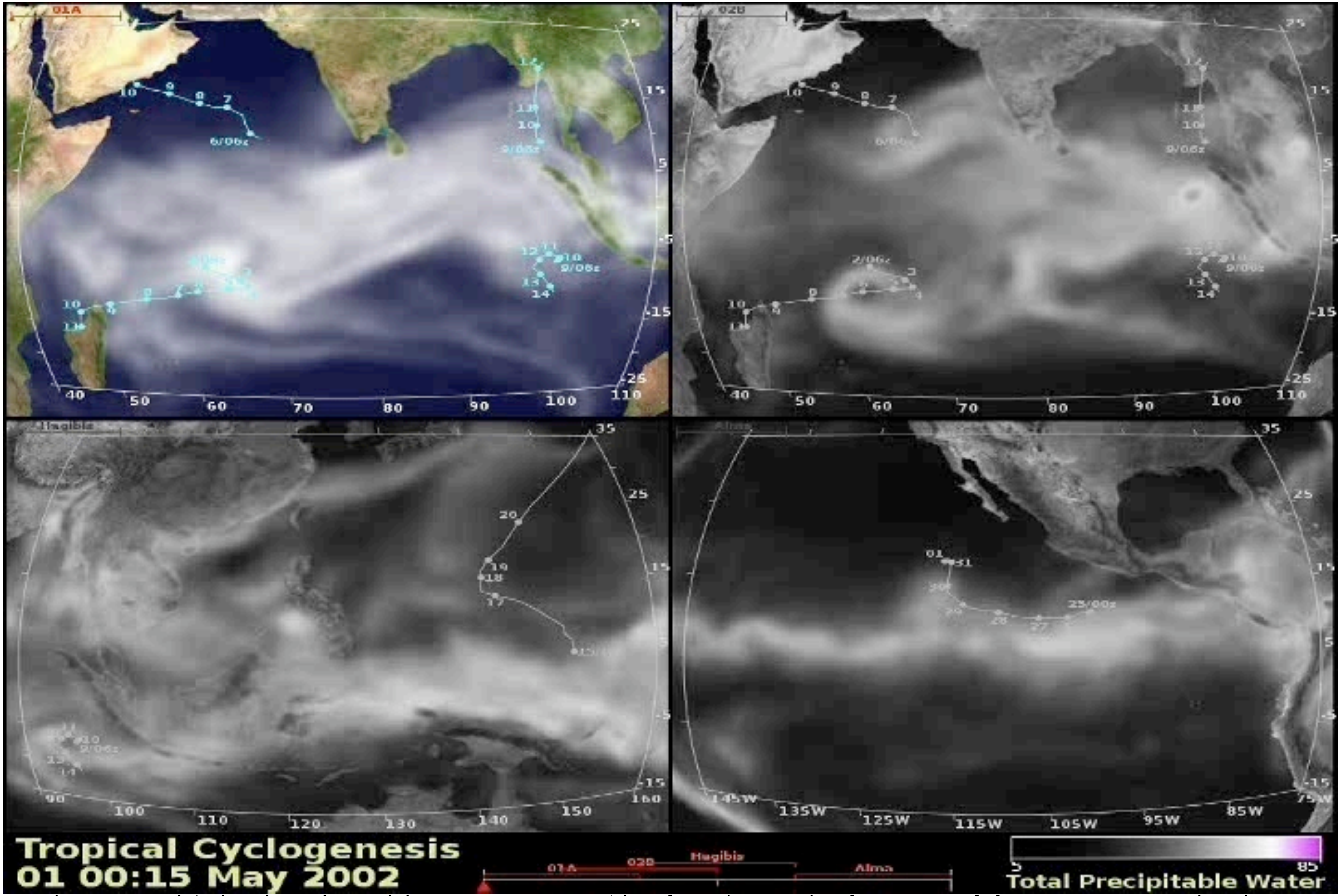

0630 UTC 9 May 2002




•Two pairs of twin TCs appeared sequentially after an Madden- Julian Oscillation (MJO) propagated eastward through these areas. (see also Moncrieff et al., 2007; Shen et al., in revision)

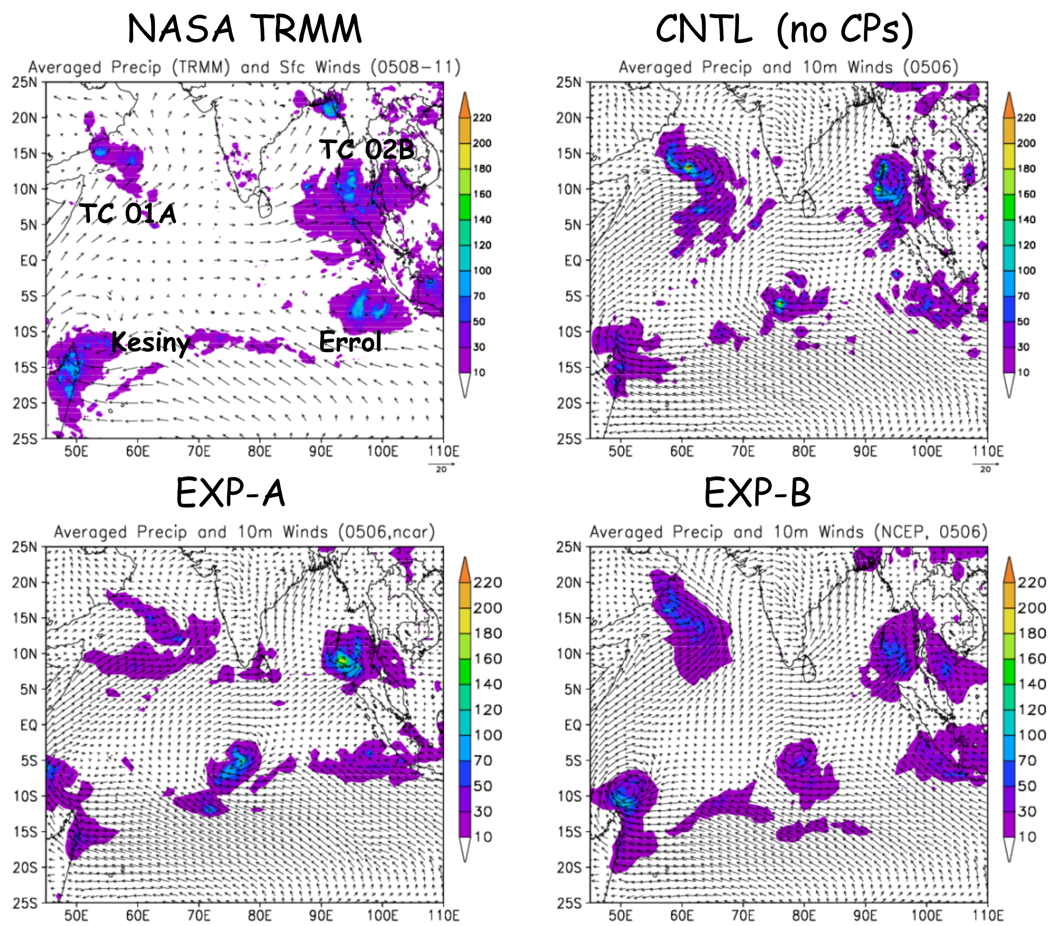
Six TCs appearing in May 2002 include:
**Kesiny** (3-11) and **TC 01A** (6-10, May)
**Errol** (9-14) and **TC 02B** (9-12 May)
Supertyphoon **Hagibis** (15-21 May)
Hurricane **Alma** (25 May – 1 June)






The NASA global multiscale modeling system is capable of predicting the formation of five TCs associated with an MJO in May 2002 about two to three days in advance. The subsequent movements of these TCs are also simulated well, as compared to the best tracks (observations, in blue) ( see Shen, Tao, Atlas, Lin, Peters-Lidard, Chern, Kuo, 2009, in preparation)

# Forecasts of Twin TCs: Averaged precipitation over May 8 – 11, 2002

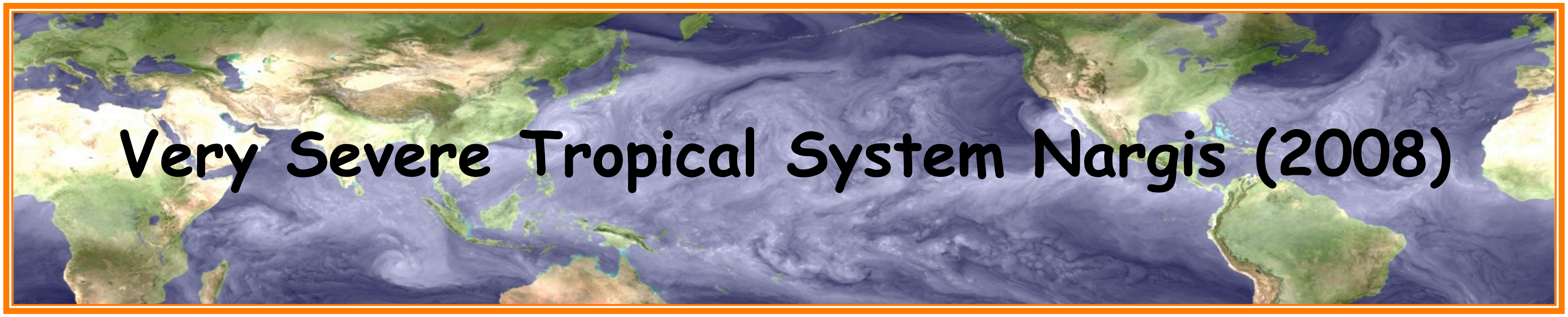



All of three runs (CNTL, EXP-A and EXP-B) are initialized at 0000 UTC May 6, 2002 with different moist physical processes.

**CNTL:** No CPs

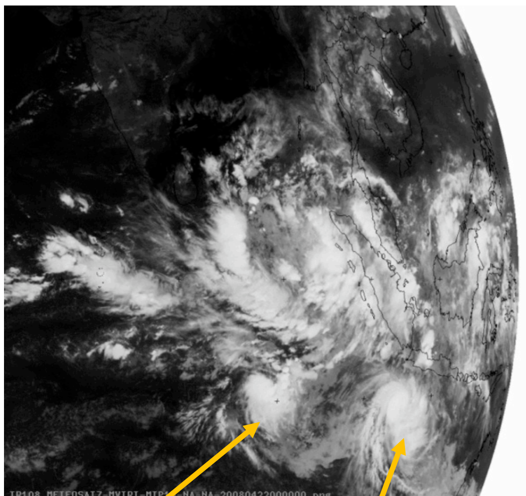
**EXP-A:** with Zhang and McFarlane (1995) and Hack (1994) schemes for deep and shallow-and-midlevel convection, respectively.

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



# Very Severe Tropical System Nargis (2008)

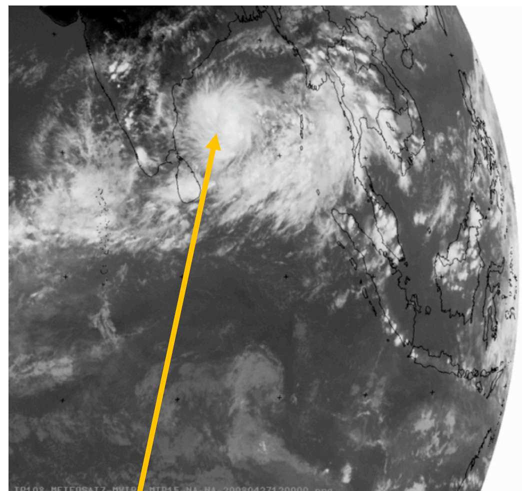
00Z Apr 22



Durga
(22-24 Apr)

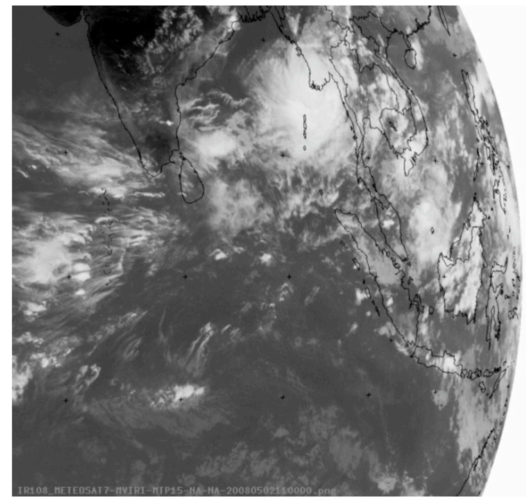
Rosie
(21-24 Apr)

12z Apr 27

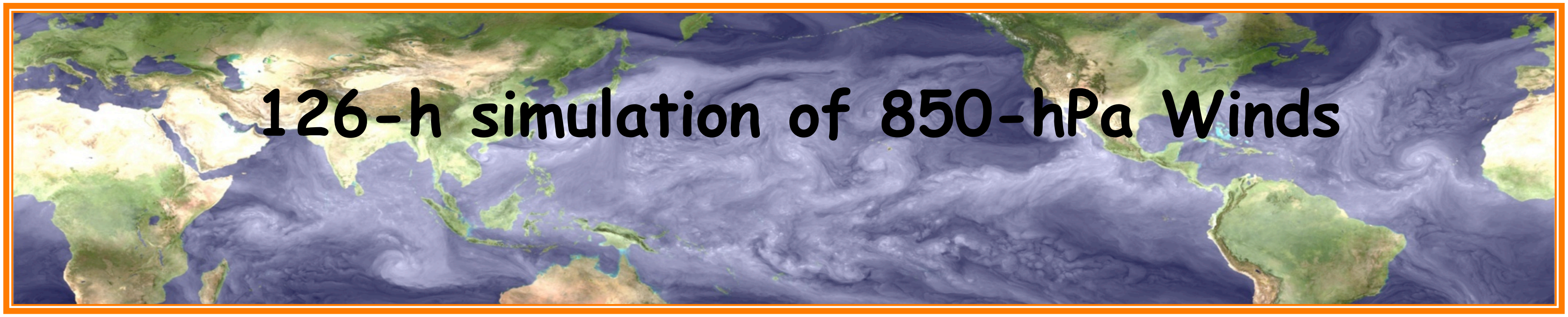


Formation of Nargis

11z May 2

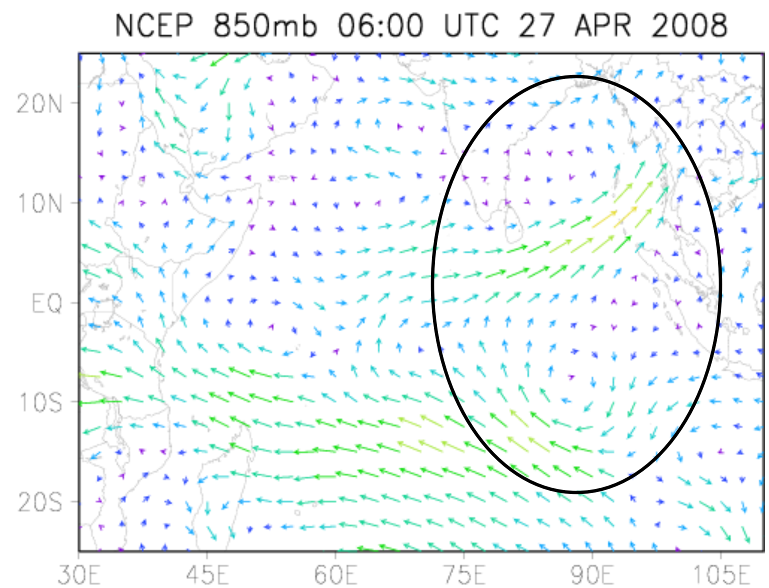


Landfall in Myanmar

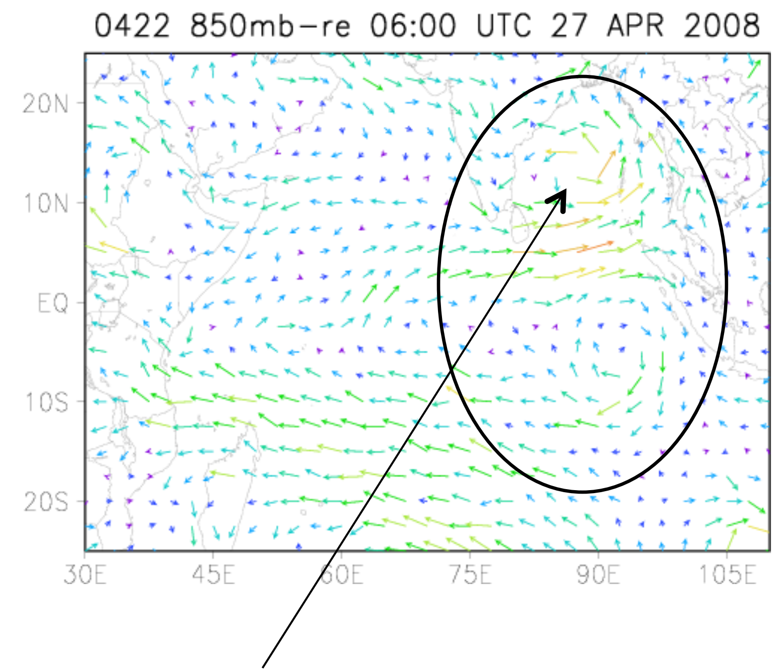


# 126-h simulation of 850-hPa Winds

NCEP Reanalysis



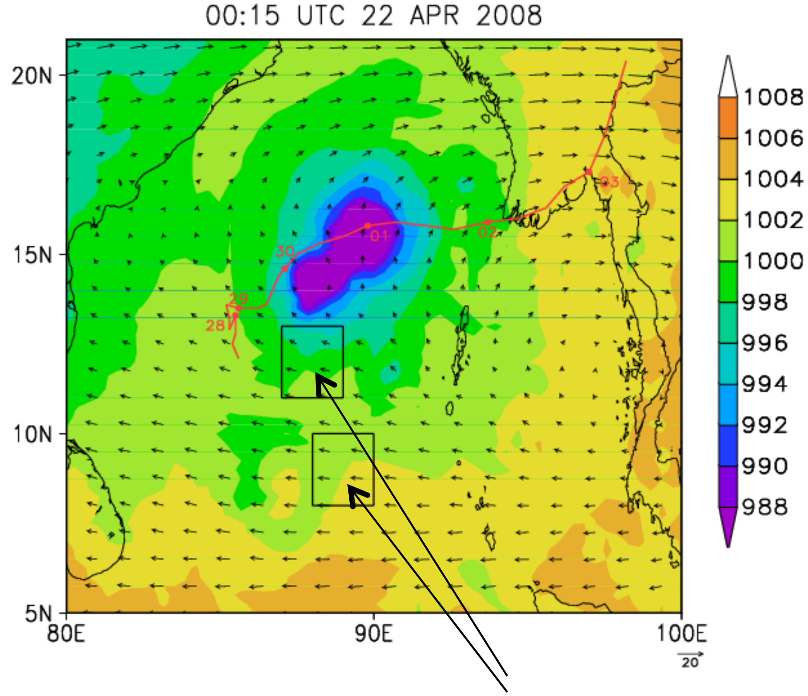

Model Simulation



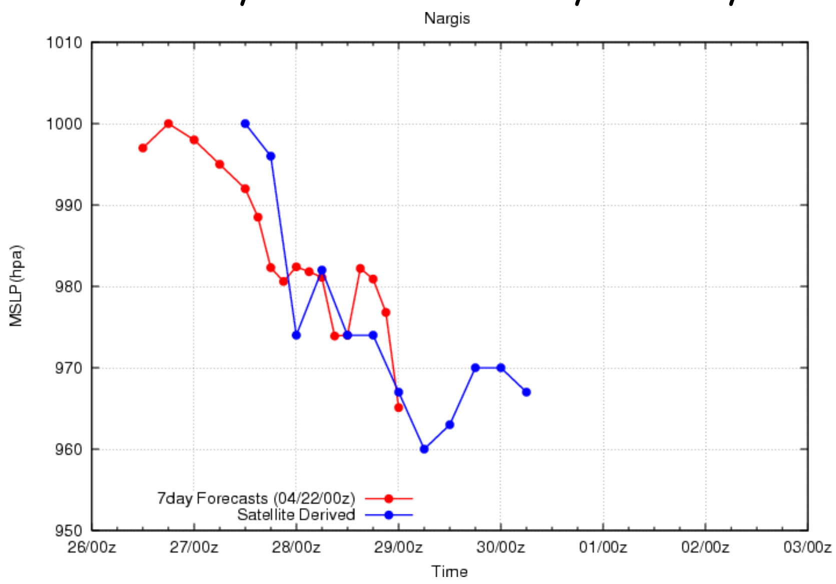

TC Nargis (2008)

# 7-day forecast of Nargis' intensity (min SLP)

min SLP over the 7-day integration



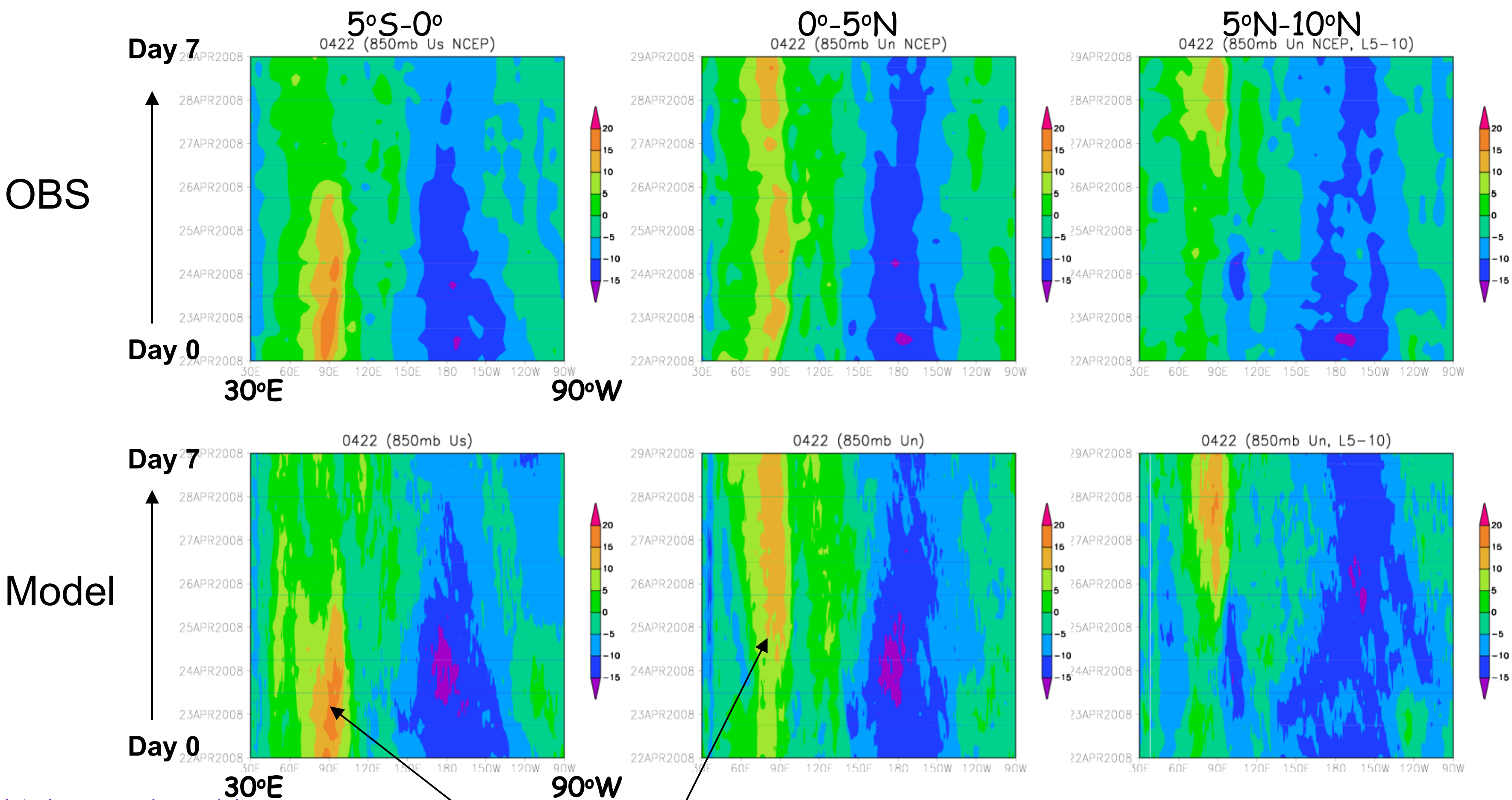

Intensity evolution from day 5 to day 7




Location of a pre-TC mesoscale vortex

# Northward Movement of the WWB

(averaged 850-hPa U winds)




**Westerly Wind Belt/Burst**

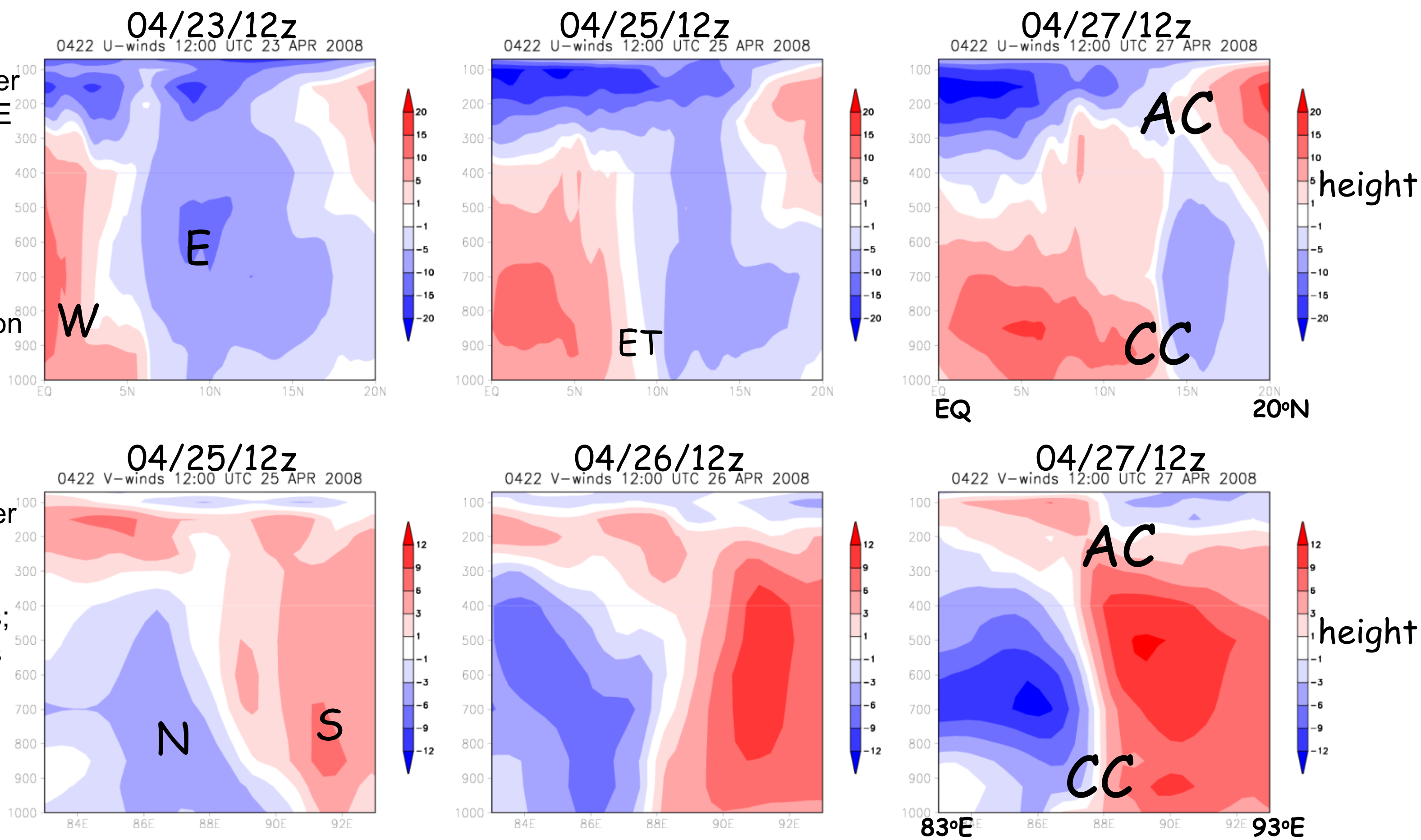

U-winds averaged over longitude 80°E to 90°E

Red: Westerly Winds;
Blue: Easterly Winds

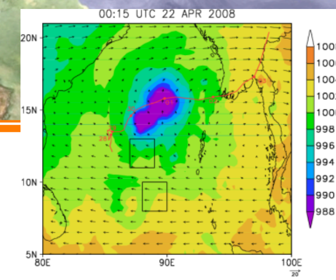
**ET:** equatorial trough
**CC:** cyclonic circulation
**AC:** anti-cyclonic circulation

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

Red: Southerly Winds;
Blue: Northerly Winds

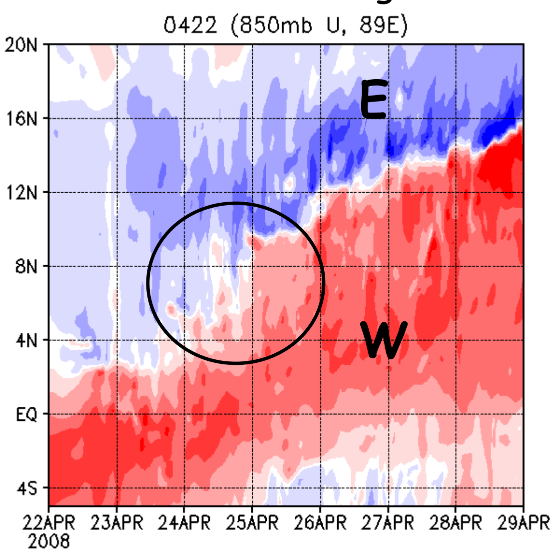


# Westerly Wind Bursts in 7-day Simulations



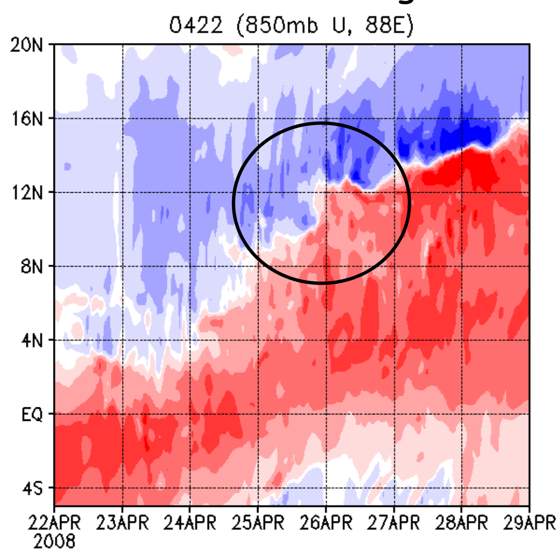

850-hPa U winds along lon 89°E

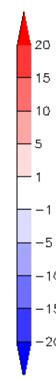
20°N




5°S

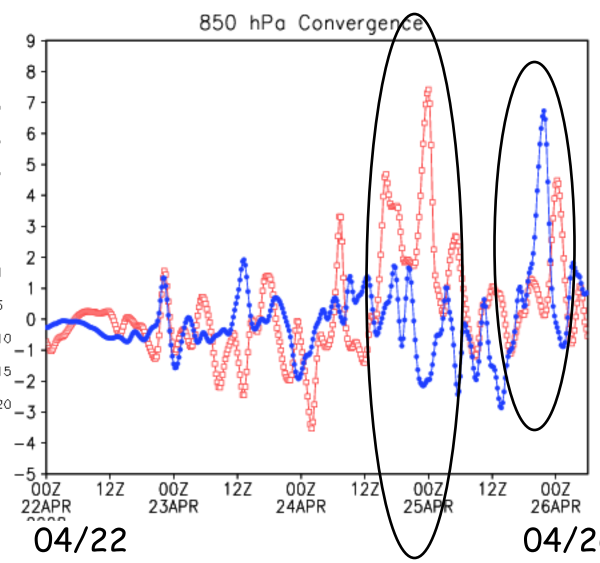
850-hPa U winds along lon 88°E




04/22 time 04/29

Low-level convergence

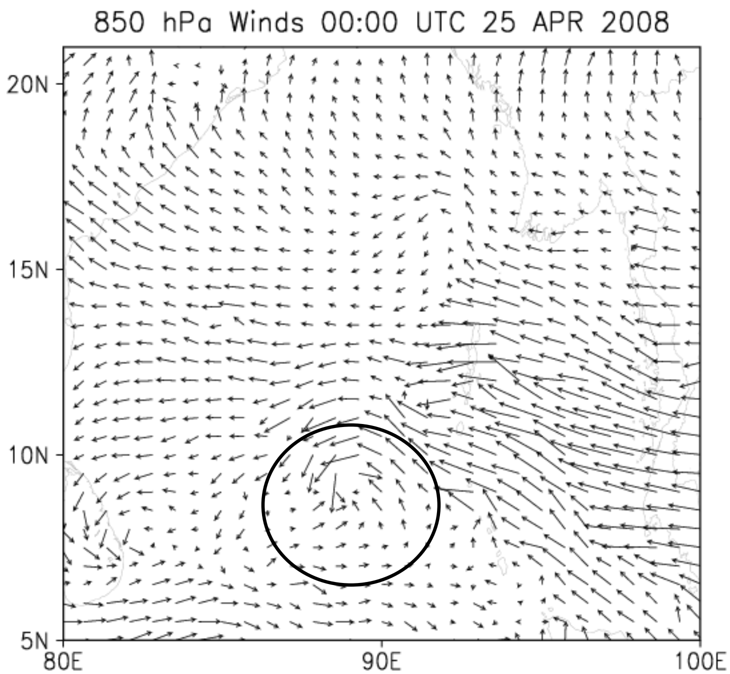



04/22 04/26

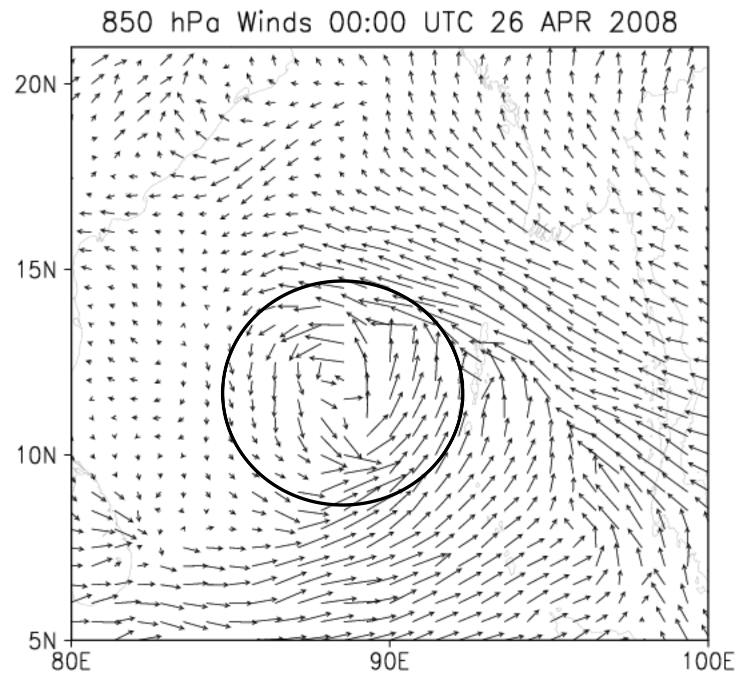
Two phases of enhanced convection

# Simulations of a pre-TC mesoscale vortex

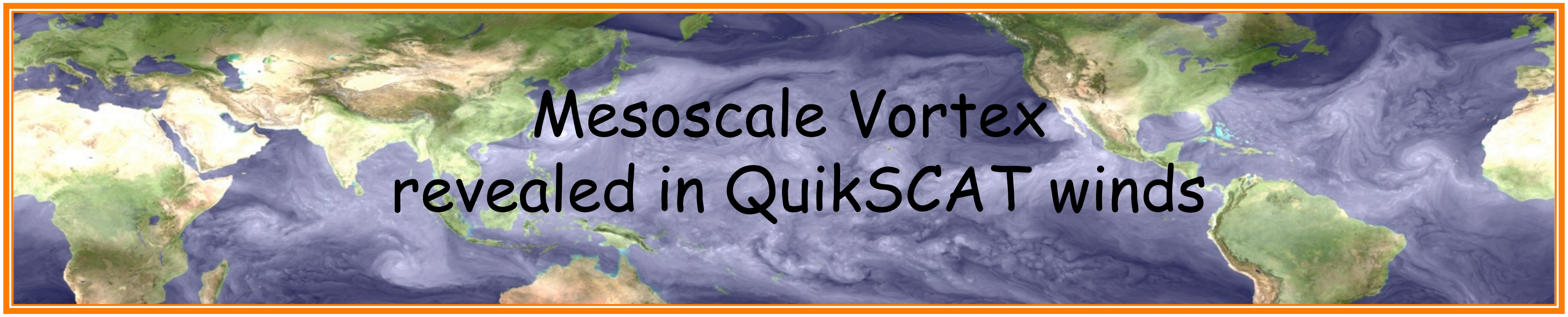
72 h simulation valid at 04/25/00z



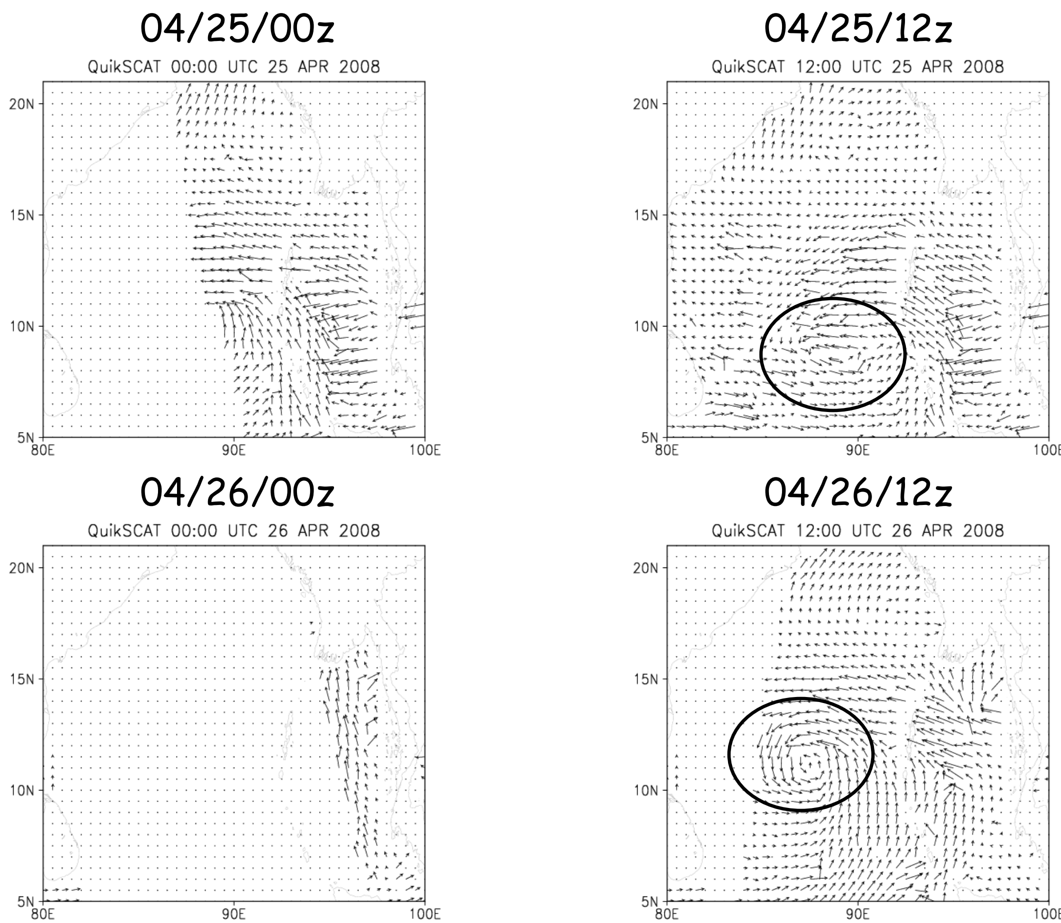

96 h simulation valid at 04/26/00z



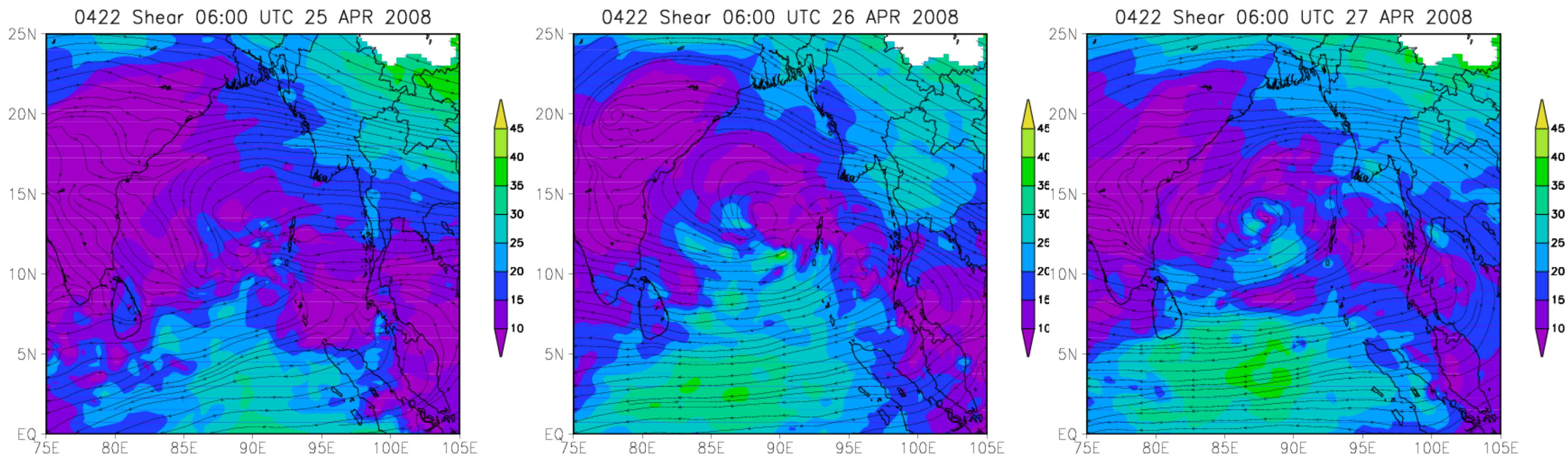

Formation and "enhancement" of a pre-TC mesoscale vortex seems to be related to the appearance of westerly wind "burst" and peak of low-level convergence



# Mesoscale Vortex revealed in QuikSCAT winds



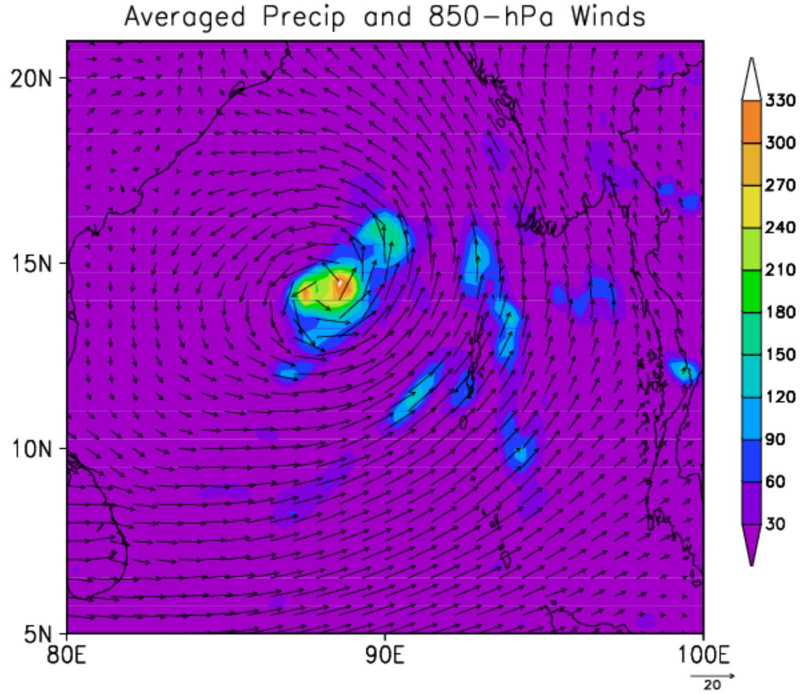
# 200-800 hPa Wind Shear



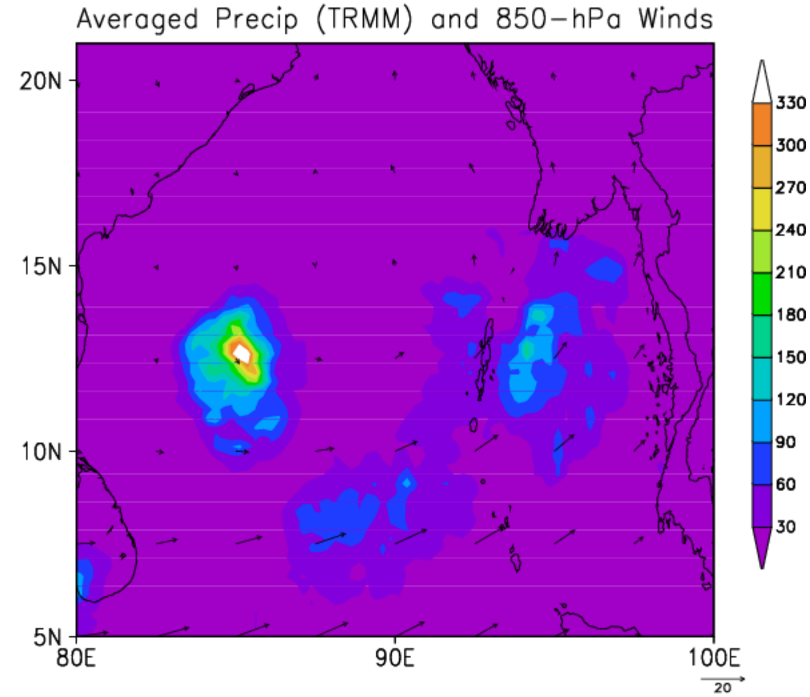

Anti-cyclonic wind shear
Good outflow

# Averaged precip and 850-hPa winds

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

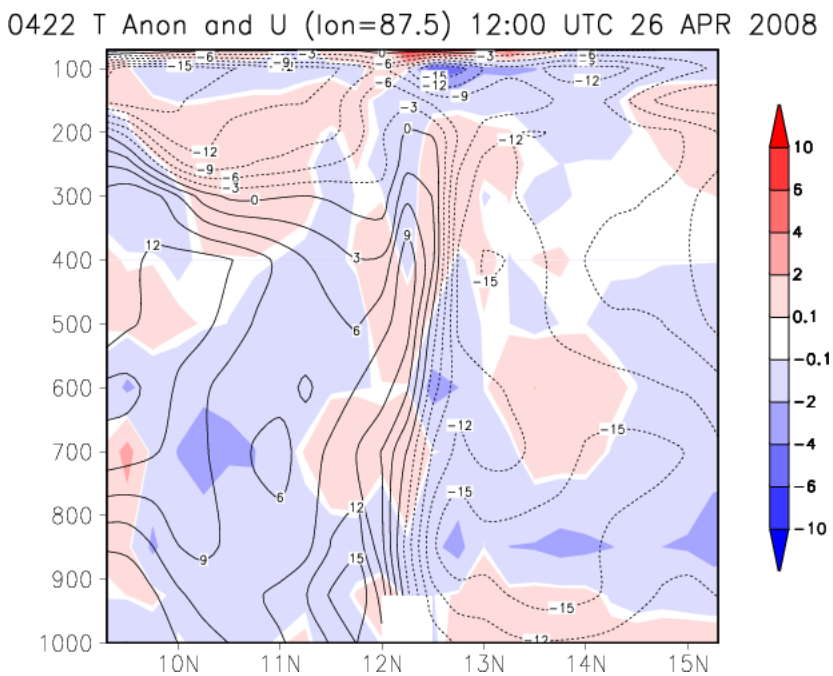



Averaged NASA TRMM precip and
NCEP Reanalysis winds

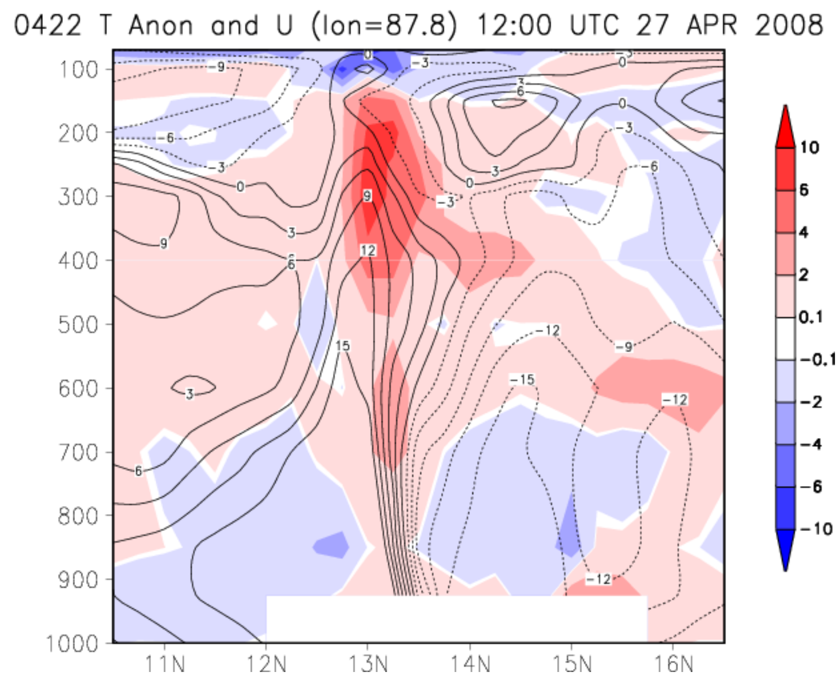


# Formation of a Warm Core

04/26/12z



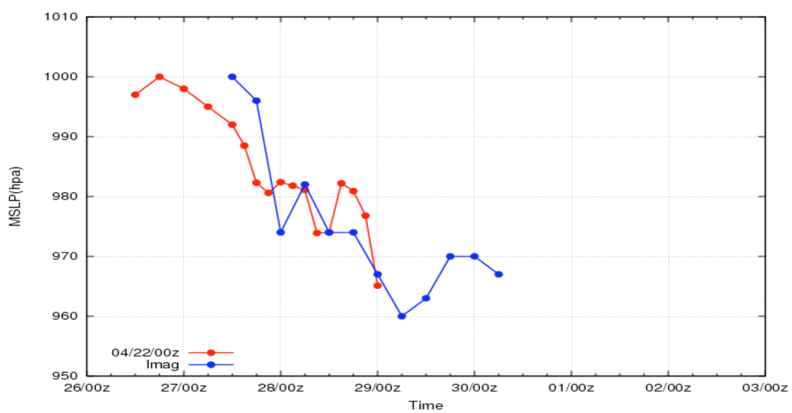

04/27/12z



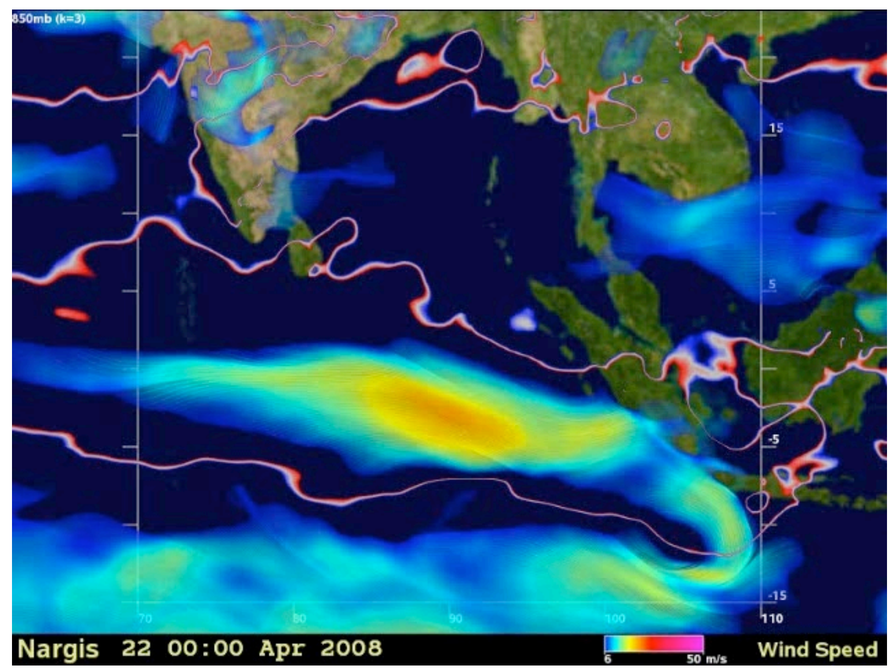
# 7-days simulations of TC Nargis (2008)

(Shen, Tao, Lau, Atlas, 2009, to be submitted)

**Simulated Intensity from Day-5 to Day-7**



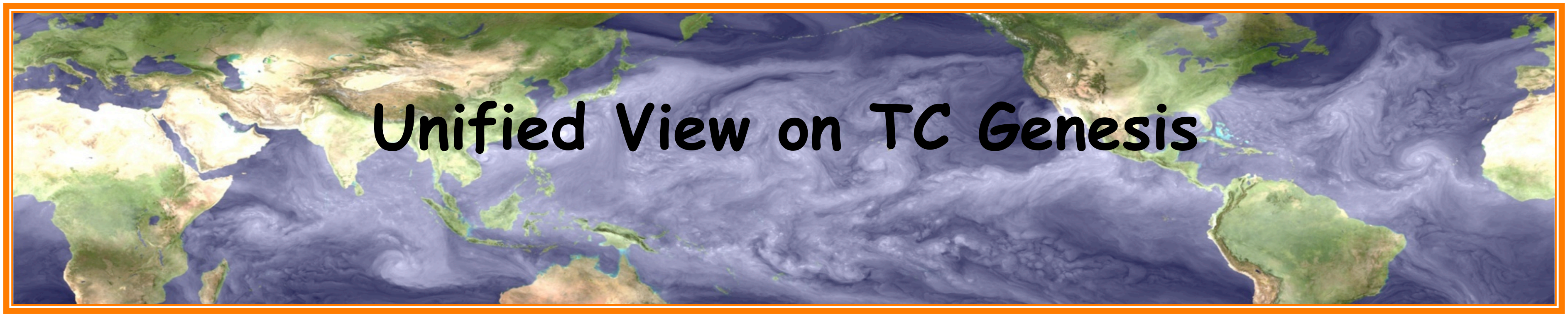

**initialized at 0000 UTC April 22, 2008**



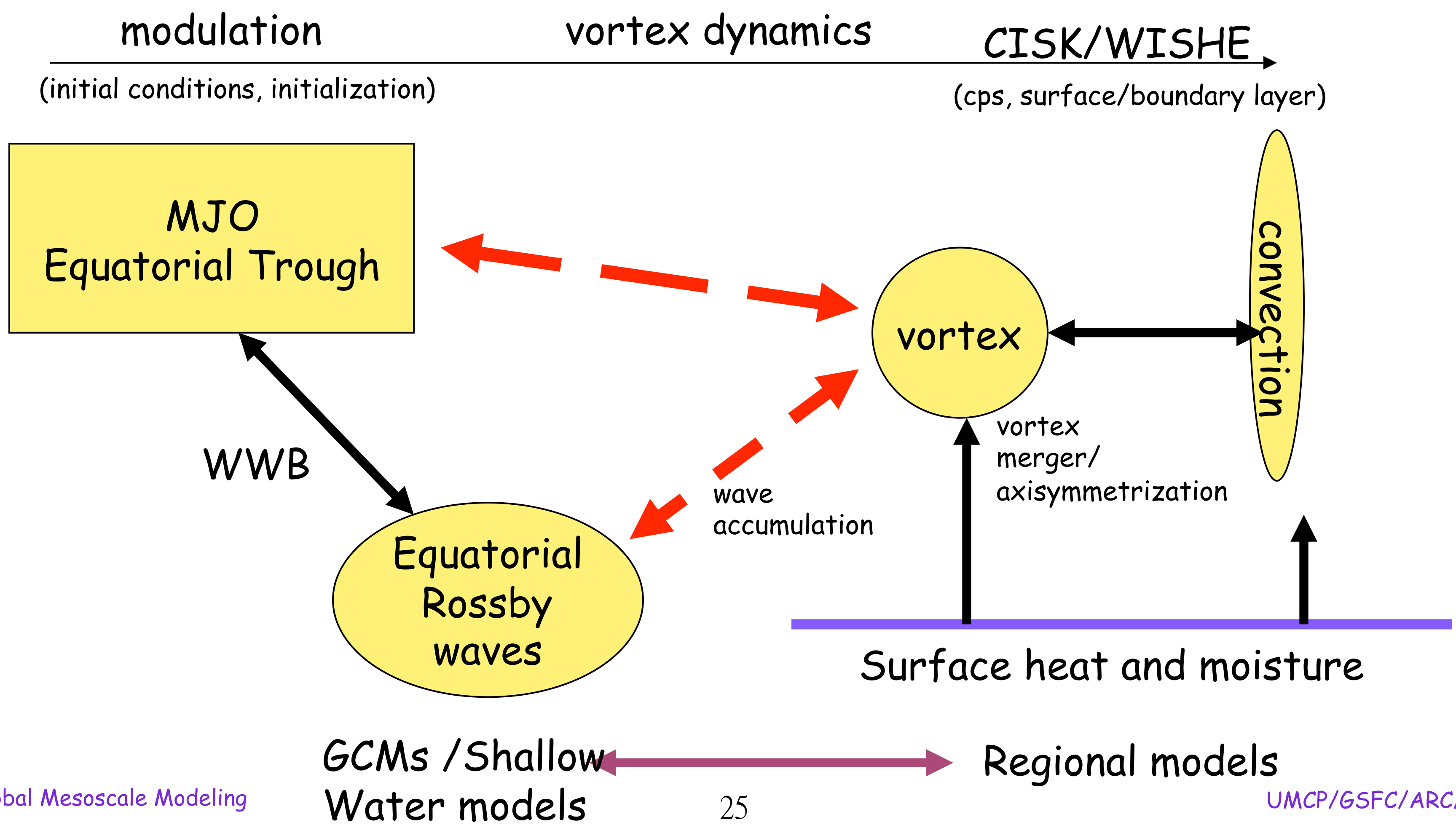

Nargis was first reported at 1200 UTC April 27, 2008.

Favorite factors for the Nargis Formation:

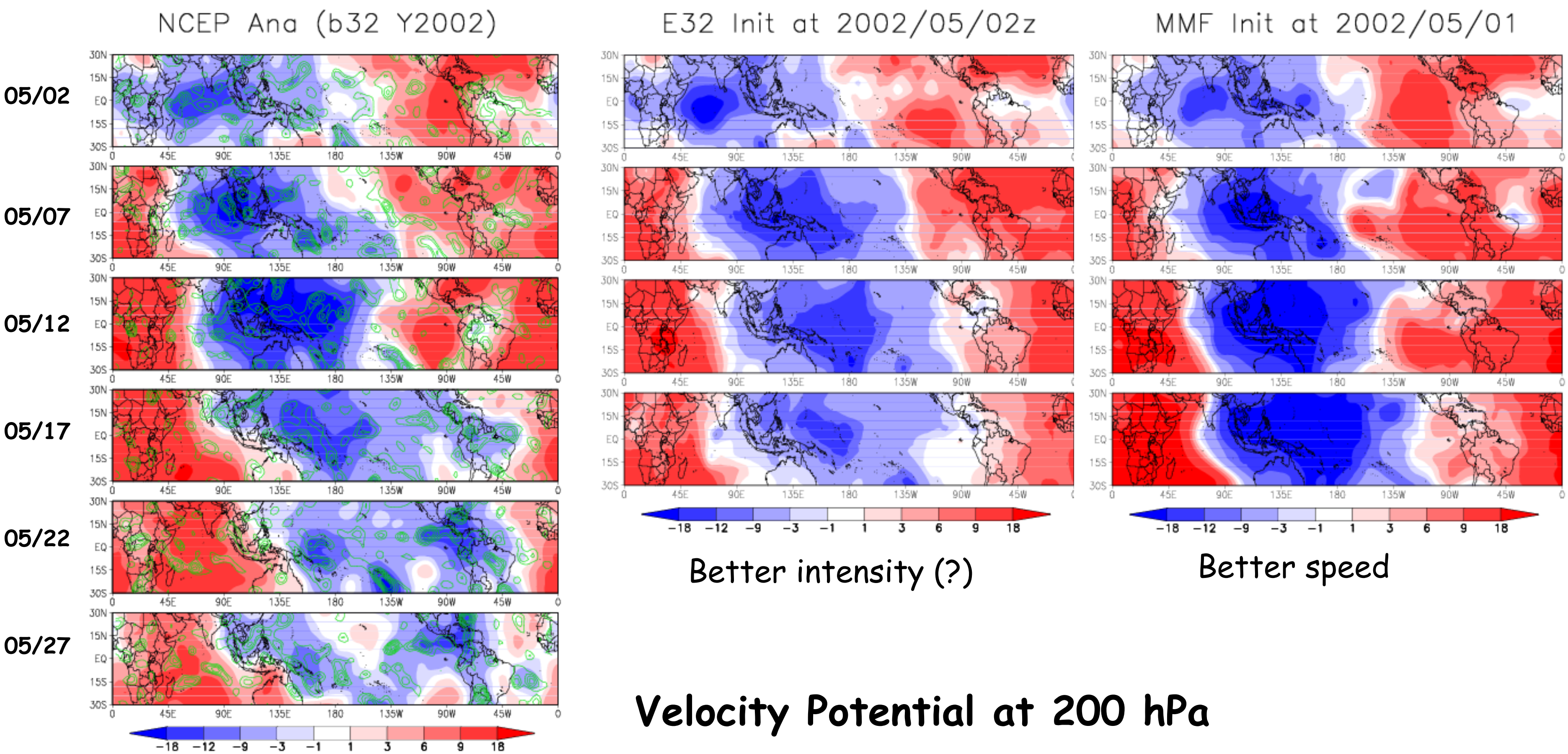
- (Leading edge of) the WWB; (North of) the equatorial trough
- Enhanced monsoonal circulation; Zero wind shear line
- A good upper-level outflow; Anti-cyclonic wind shear
- Low- and middle-level moistening; Surface fluxes ; low-level convergence (two phases of enhanced convection)



# Unified View on TC Genesis



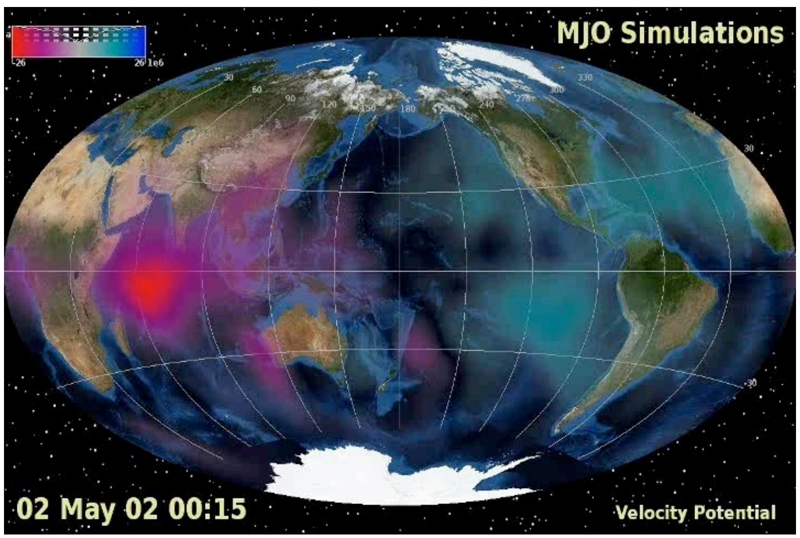
# 15-day Simulations of an MJO in May 2002

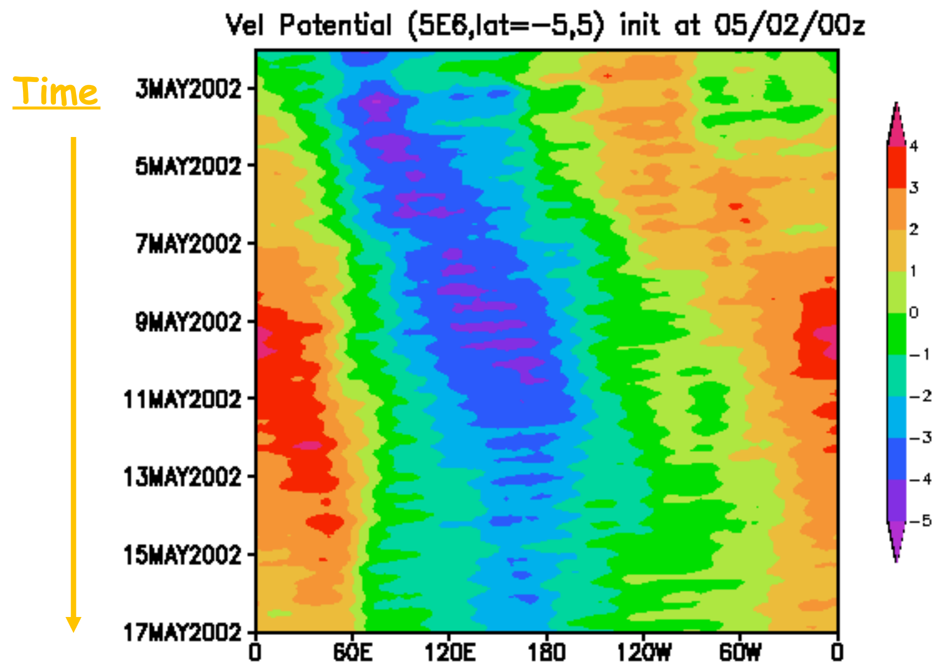



**Velocity Potential at 200 hPa**

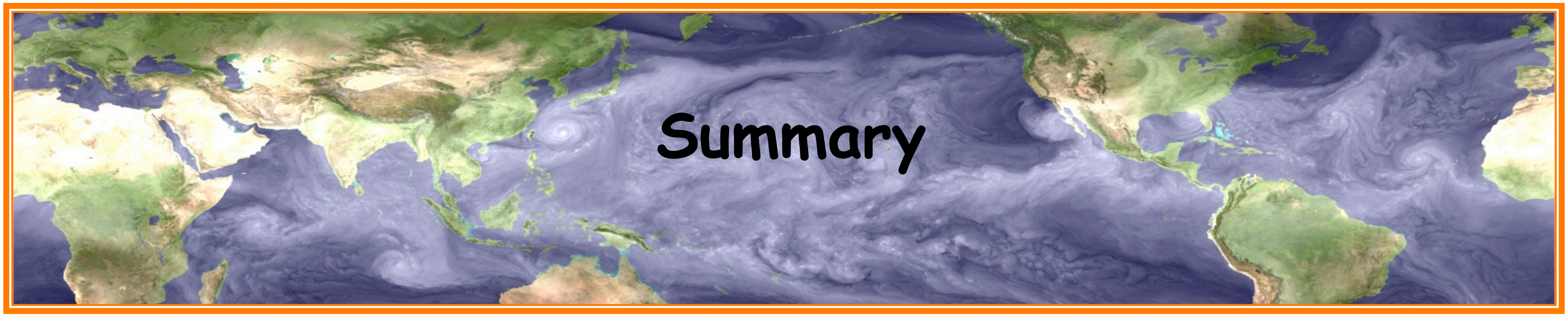
# 15-day Simulations of an MJO in 2002

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



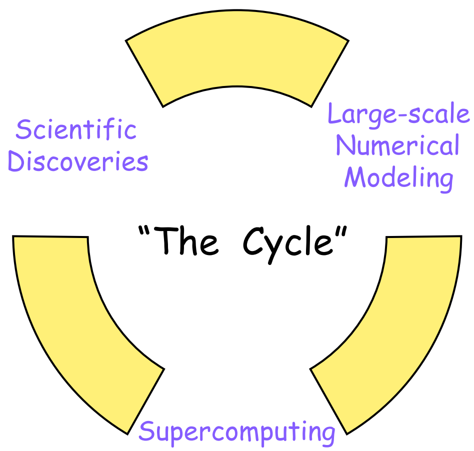




**Semidiurnal (?)**



# Summary

- Improved forecasts of TC track, intensity and formation with the improved high-resolution global model
- 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.
- <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