Simulating the characteristics of Tropical Cyclones over the South West Indian Ocean Using a Stretched-Grid Global Climate Model

Molulaqhooa Linda Maoyi, B.J Abiodun, J Prusa, J Veitch

3rd Place The Telegraph (2012)
2nd Place Huffington Post (2013)

Simulating the characteristics of Tropical Cyclones over the South West Indian Ocean Using a Stretched-Grid Global Climate Model

University of Cape Town • iYunivesithi yaseKapa • Universiteit van Kaapstad

SPES BONA

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Introduction

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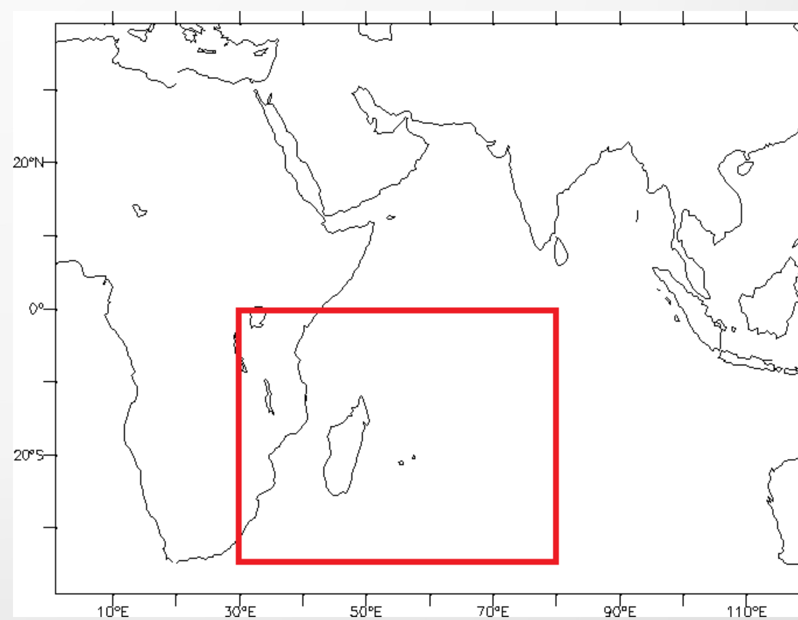
- Tropical Cyclones (TCs) are a threat to the nations of Mozambique and Madagascar.

- TC associated storm surges of up to 5m may occur along the coastline, further aggravating the devastation and lead to social and economic concern.

- Maputo's port, its rail links and oil facilities, which are on an estuary, are also subject to flooding from these storms.



Motivation

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The need to improve TC modelling over the SWIO

- **Global Models**

  Cover the entire Globe

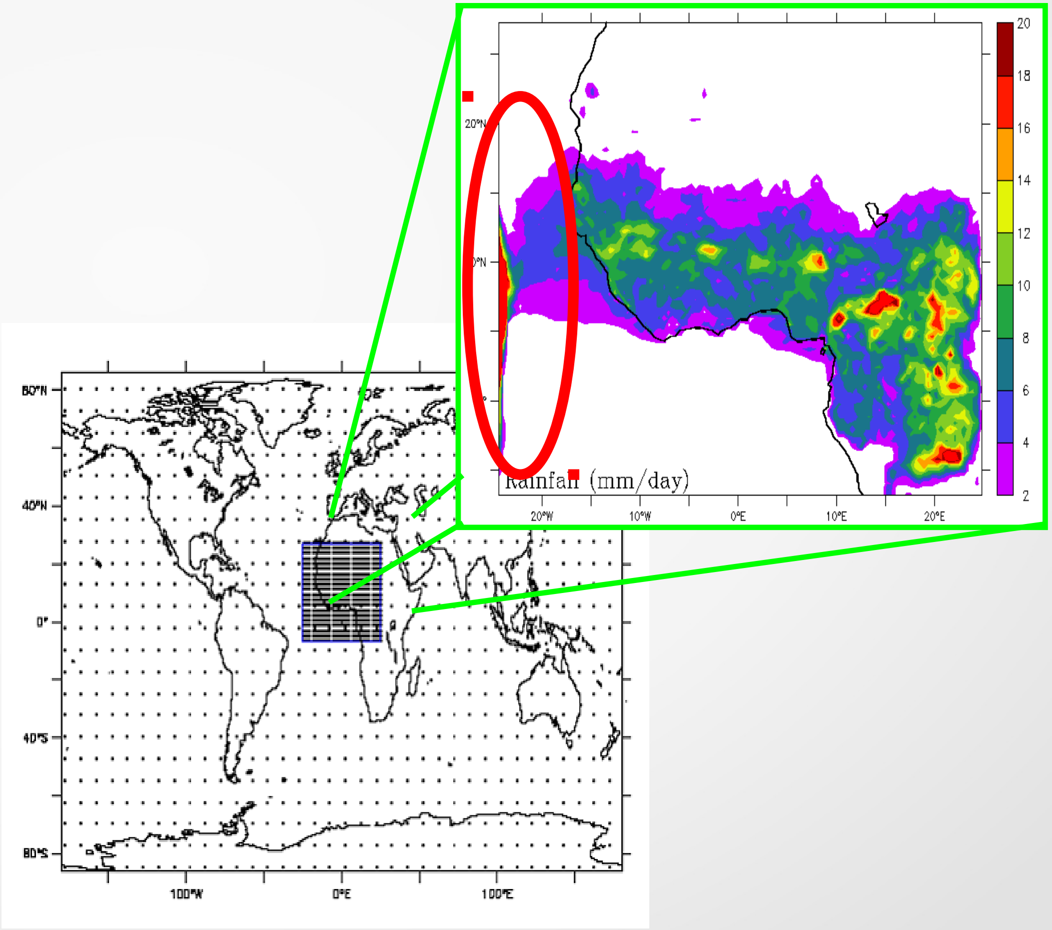
  Computationally expensive

- **Regional Models**

  Cover Limited Area

  High Resolution

  Boundary Problems



CAM-EULAG

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- **CAM-EULAG**: Non-Hydrostatic GCM with grid stretching capabilities.
- **Physics**: Community Atmosphere Model Version 3
- **Dynamical Core**: EULAG, a non-hydrostatic , parallel computational model for all-scale geophysical flows.
- **Non-hydrostatic**: Achieved through anelastic approximation of the equations of motion.

Coupling of CAM3 and EULAG

We adopt the process-spilt method in CEU. Consider the general prediction equation for a variable (ψ)

$$\frac{d\psi}{d\bar{t}} = D(\psi) + P(\psi) \tag{3a}$$

$$\psi^{n+1} = \mathrm{MPDATA}(\tilde{\psi}) + 0.5\Delta t(D_{\psi}^{n+1} + P_{\psi}^{n}) \tag{3b}$$

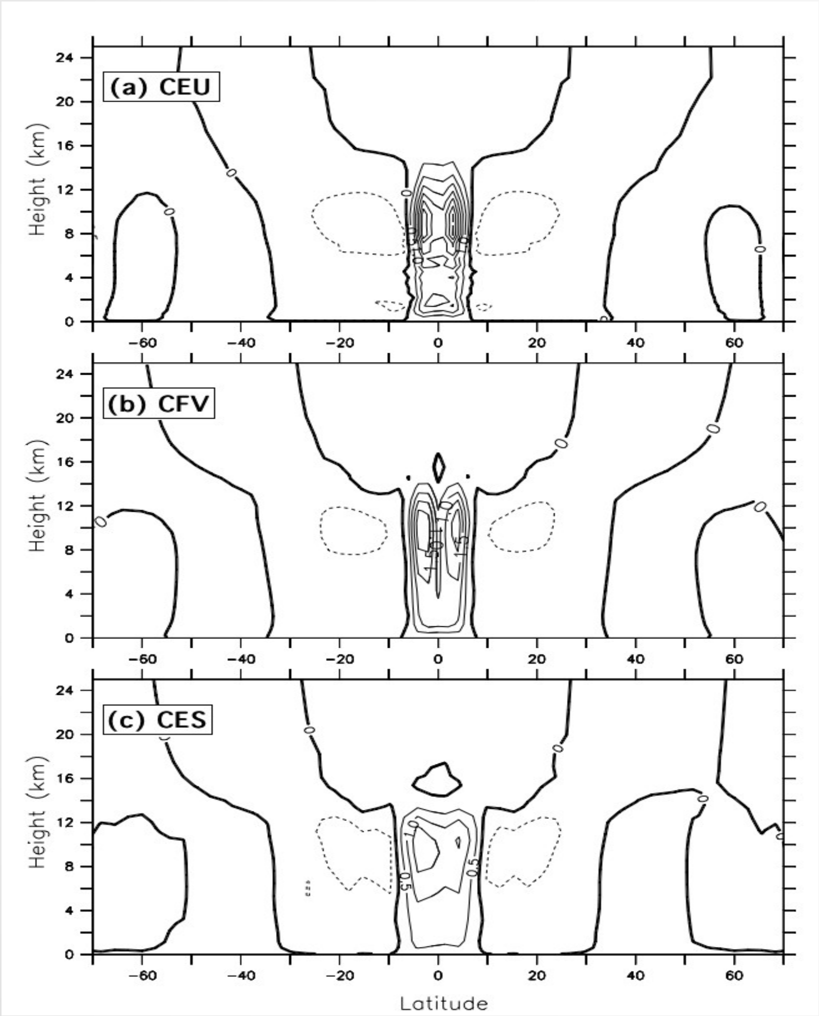
where

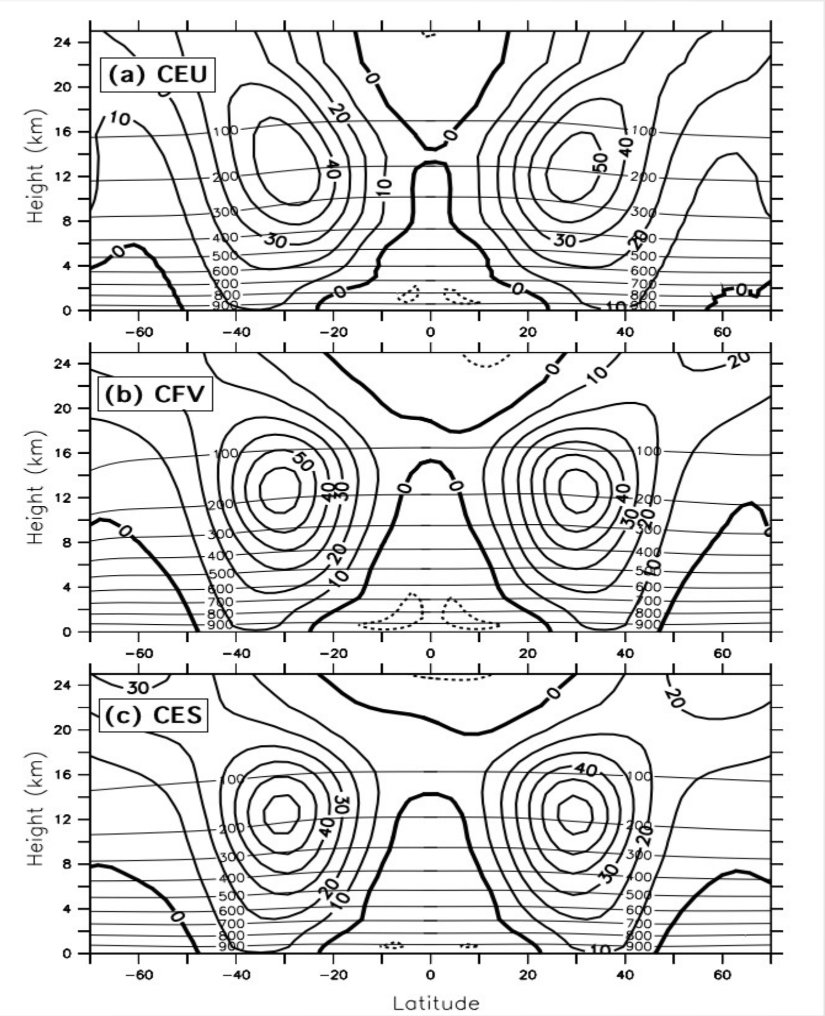
$$\tilde{\psi} = \psi^{n} + 0.5\Delta t(D_{\psi}^{n} + P_{\psi}^{n}). \tag{3c}$$

$$\omega := \frac{dp_{\mathrm{phy}}}{d\bar{t}} = \bar{v}^{*1}\frac{\partial p_{\mathrm{phy}}}{\partial \bar{x}^{i}}.$$

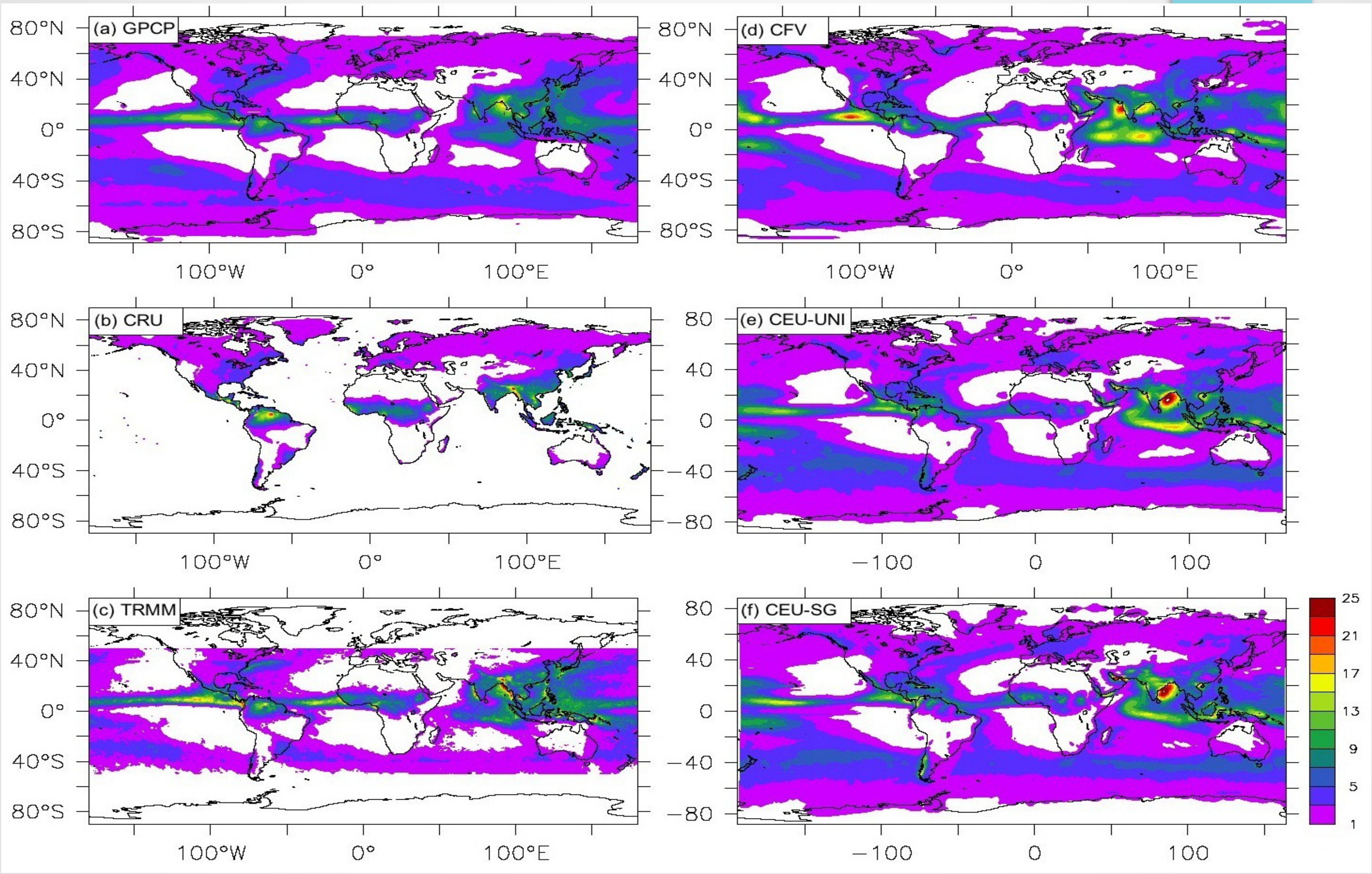
(Abiodun et al,2008)

Zonally Averaged V and U Wind

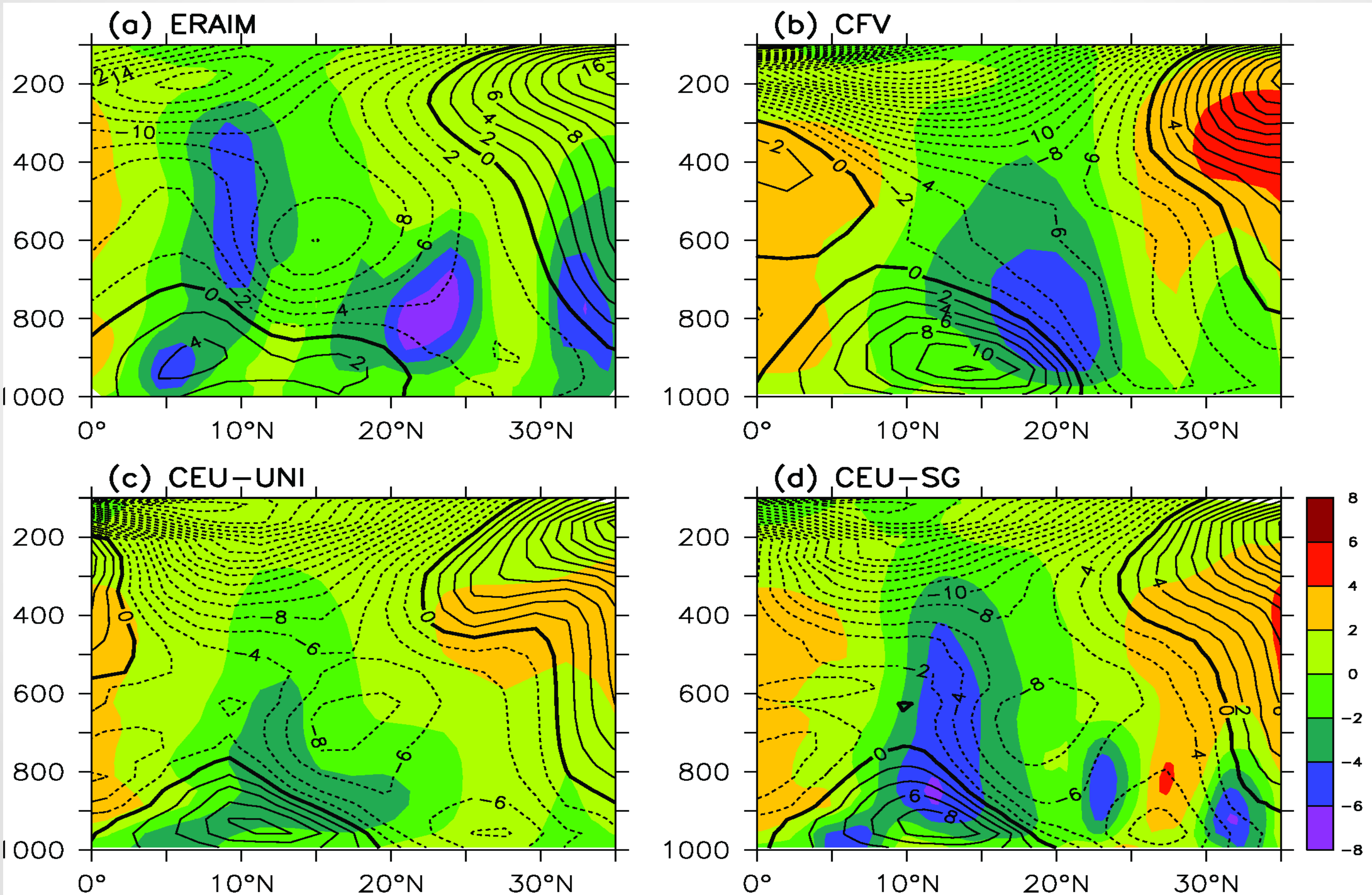




Global Precipitation (mm/day) in June- August



West Africa Monsoon System (August)



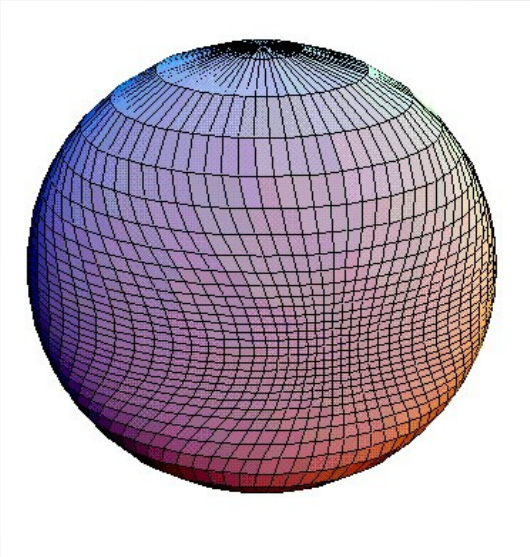
Features of CAM-EULAG

Static GA:

for areas of interest

consistent dynamics over high and low resolution areas

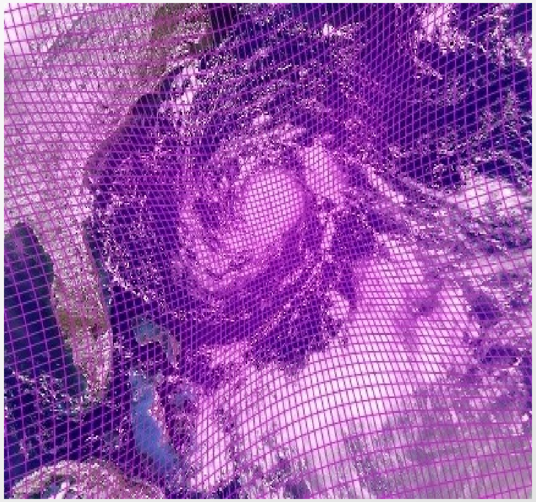
small scale and large scale features are fully coupled



Dynamic GA:

for features of interest

storm tracks, hurricanes, squall lines, frontal precipitation, Asian monsoon, tornadoes, convection



Aim

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Aim:

To evaluate the performance of CAM-EULAG in simulating the characteristics of TCs over the SWIO.

Key Objectives:

- Evaluate the ability of the stretched-grid in simulating the climatology of the SWIO basin during the TC season (November -April)..
- Examine how well the stretched-grid simulates TC structure, intensity and spatial distribution of genesis locations and tracks.
- Investigate interannual and seasonal variability Simulated TCs.

Data and Methods

Data

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Historical Data

- Joint Typhoon Warning Centre (hereafter JTWC) best track data observation.
- Monthly observed precipitation from the Global Precipitation Climatology Project Version 2.2. ERSST v3b in situ SST data
- The monthly and 6-hourly reanalysis precipitation, pressure, wind, vorticity, vertical velocity and temperature data, which has a spatial resolution of 80 km (T255 spectral) on 60 vertical levels from the ERA-Interim (ERAINT).

Simulations

- CAM-EULAG Global Climate Model

Experimental Setup

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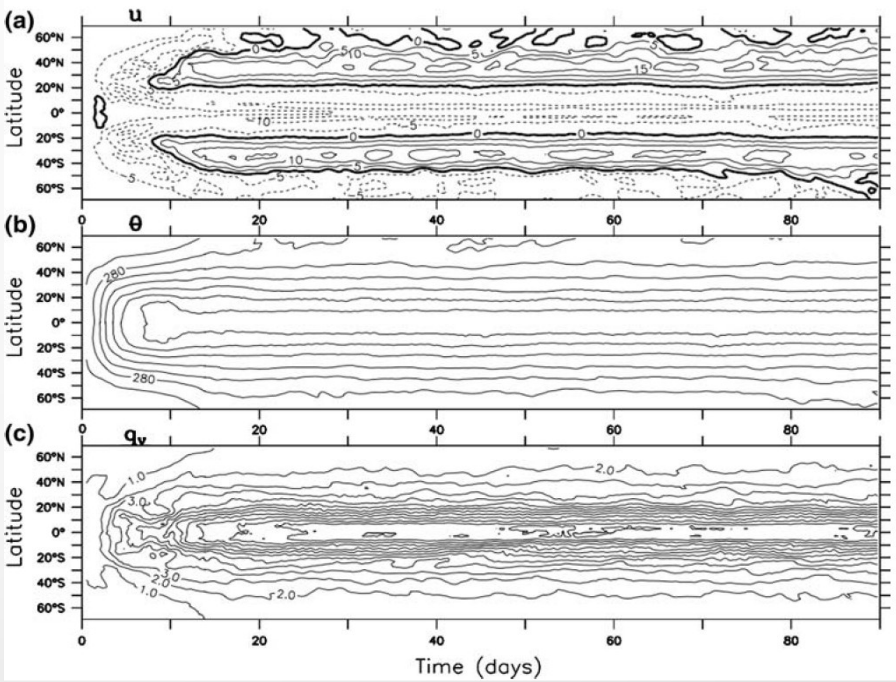
Tsessebe Cluster

- Intel Nehalem Processor
- CPU Clock : 2.93 GHz
- CPU Cores : 2304
- Peak Performance : 24 TFlops

- CEU uses 64 processors
- Spin-up ~40 days (Abiodun et al,2008)



Experimental Setup

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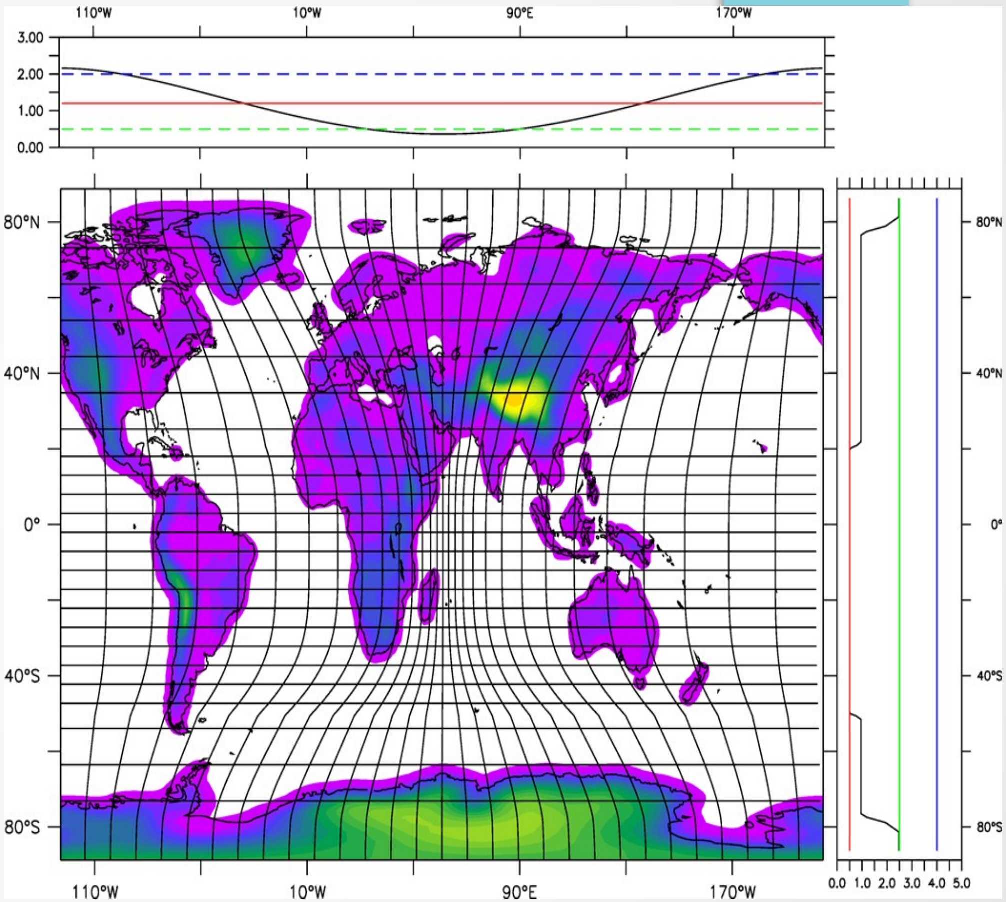
- Stretch Grid of 0.5 x 0.5 over the SWIO. 1°x 1° over much of the Globe and 2°x 2.5° over the Pacific and Poles.
- 26 vertical levels with an integration time step of 30s and a sample output rate of 6-hourly data
- Eleven 1-year simulations were run to create a climatology for the SWIO TC season
- Each 1-year experiment was run from the 1st of August of the previous year until the first of July for each of the years from 1999 to 2010.



TC Tracking

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TC tracking uses a similar method to that described by Vitart *et al*. (1997) and Zarzycki and Jablonowski (2014).

- The centre of a low-pressure system was detected by finding a closed minimum MSLP around an 8x8 grid. For each low-pressure system, the nearest minimum vorticity smaller than $-3.5\text{x}10^{-5}\text{s}^{-1}$ was detected.
- The closest local maximum of 850 – 300 hPa average temperature is defined as the centre of the warm core. The average temperature must be greater than 0°C.
- The wind speed at 10m > 17.00 m/s (61.20 km/h) and must reach at least 32.73 m/s (118.00 km/h) during its lifespan.
- Look for the closest storm within 500 km following the 6-hour period
- To be considered a full trajectory, the storm must persist for at least 2 days

Skills Scores

Hit rate: *The fraction of observed "yes" events that were correctly forecast.*

Range: 0 to 1. Perfect score: 1.

False alarm rate: *The fraction of the observed "no" events that were incorrectly forecast as "yes". Range: 0 to 1. Perfect score: 0.*

Proportion correct: *Measures the overall fraction of simulations that were correct.*

Range: 0 to 1. Perfect score: 1.

False alarm ratio: *The fraction of predicted "yes" events that did not occur.*

Range: 0 to 1. Perfect score: 0.

Heidke skill score: *Measures the fraction of correct forecasts after eliminating those forecasts which would be correct due purely to random chance.*

Range: -1 to 1. 0 indicates no skill. Perfect score: 1.

Pierce's skill score: *Measures how well did the forecast separate the "yes" events from the "no" events. Range: -1 to 1. 0 indicates no skill. Perfect score: 1.*

Gilbert's skill score: *Measures the fraction of observed and/or forecast events that were correctly predicted and adjusted for hits associated with random chance.*

Range:-1/3 to 1. 0 indicates no skill. Perfect score: 1.

Yule's Q (Odds ratio skill score): *Measures the improvement of the forecast over random chance. Range: -1 to 0. 0 indicates no skill. Perfect score: 1.*

Results

Temperature and Rainfall

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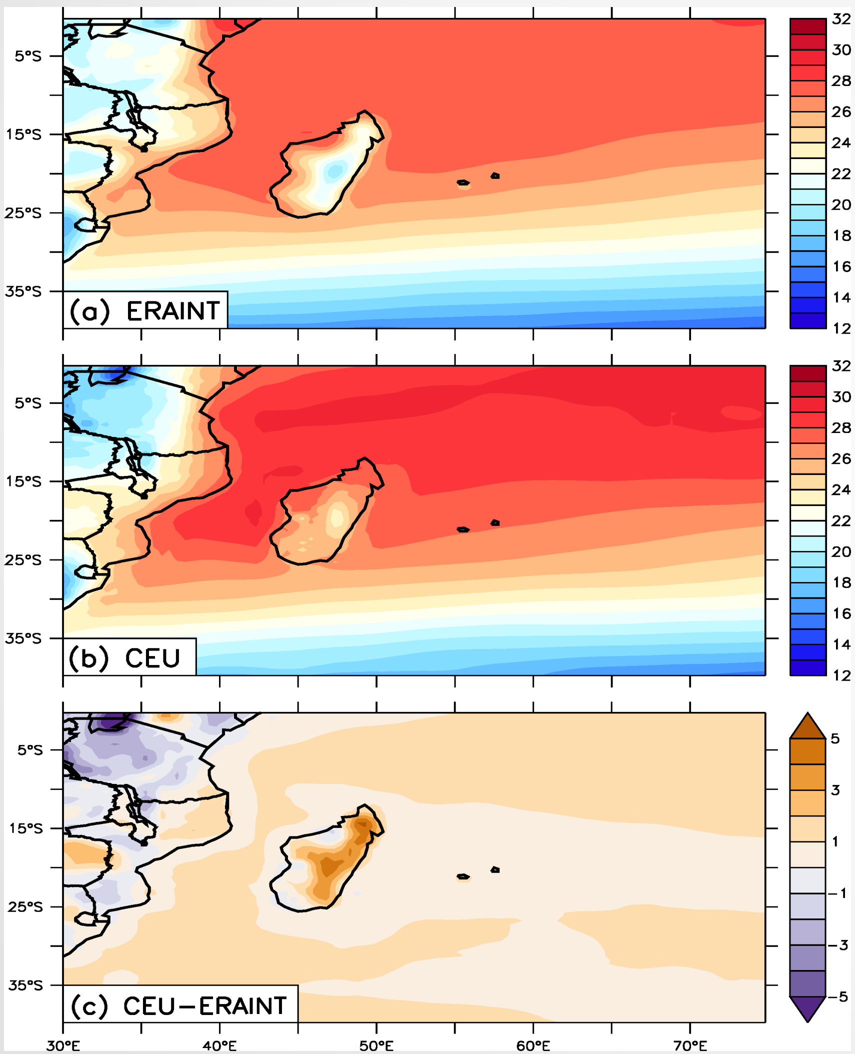
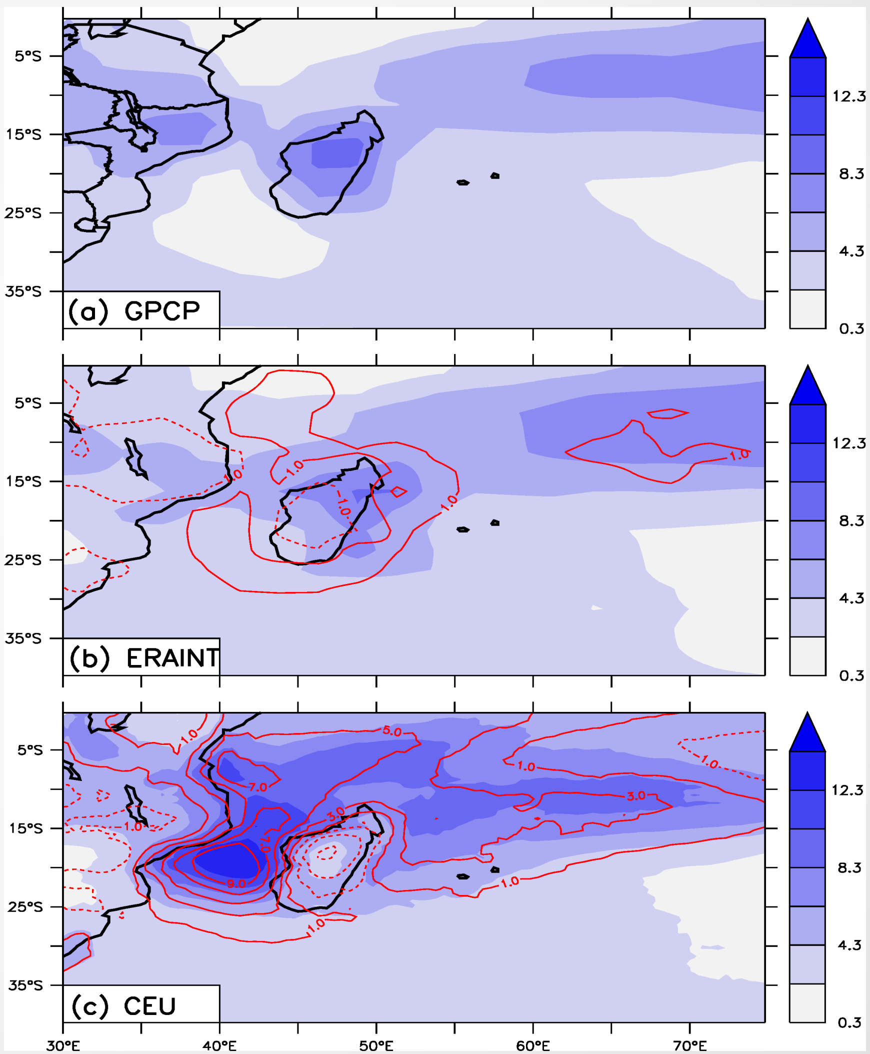
Surface Temperature in °C



Rainfall in mm/day



Vorticity and Wind

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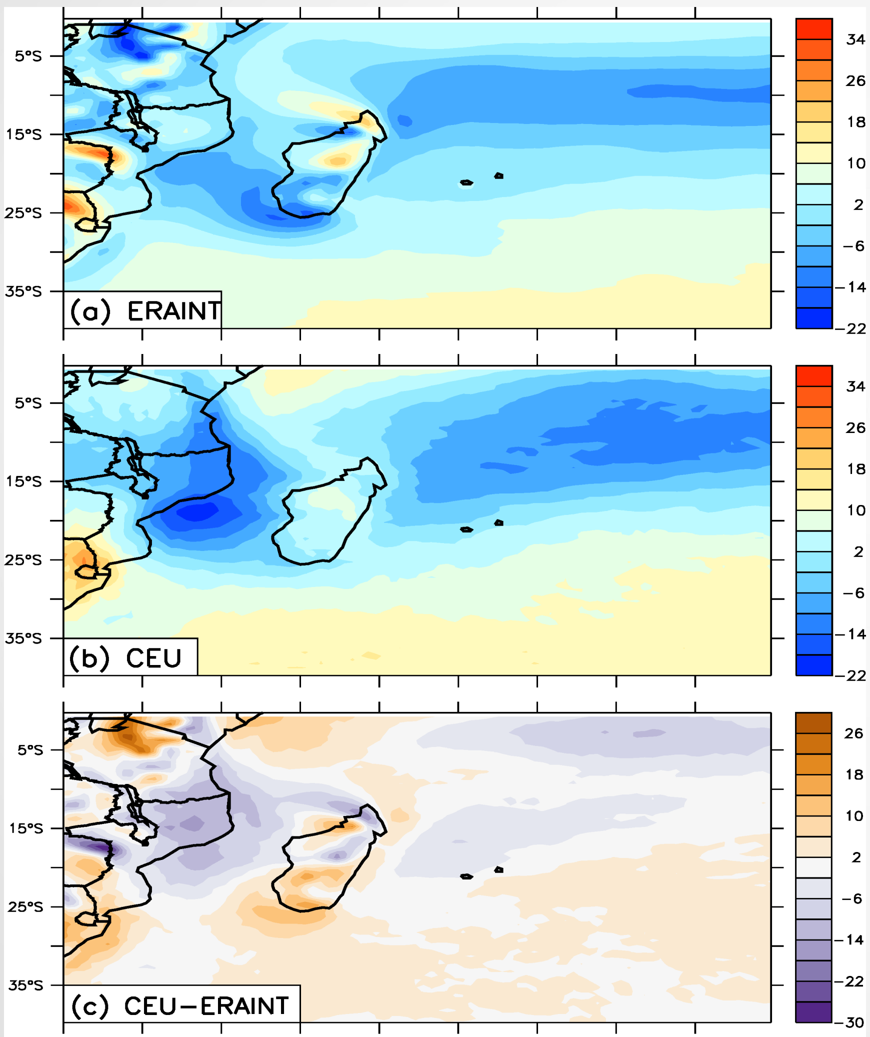
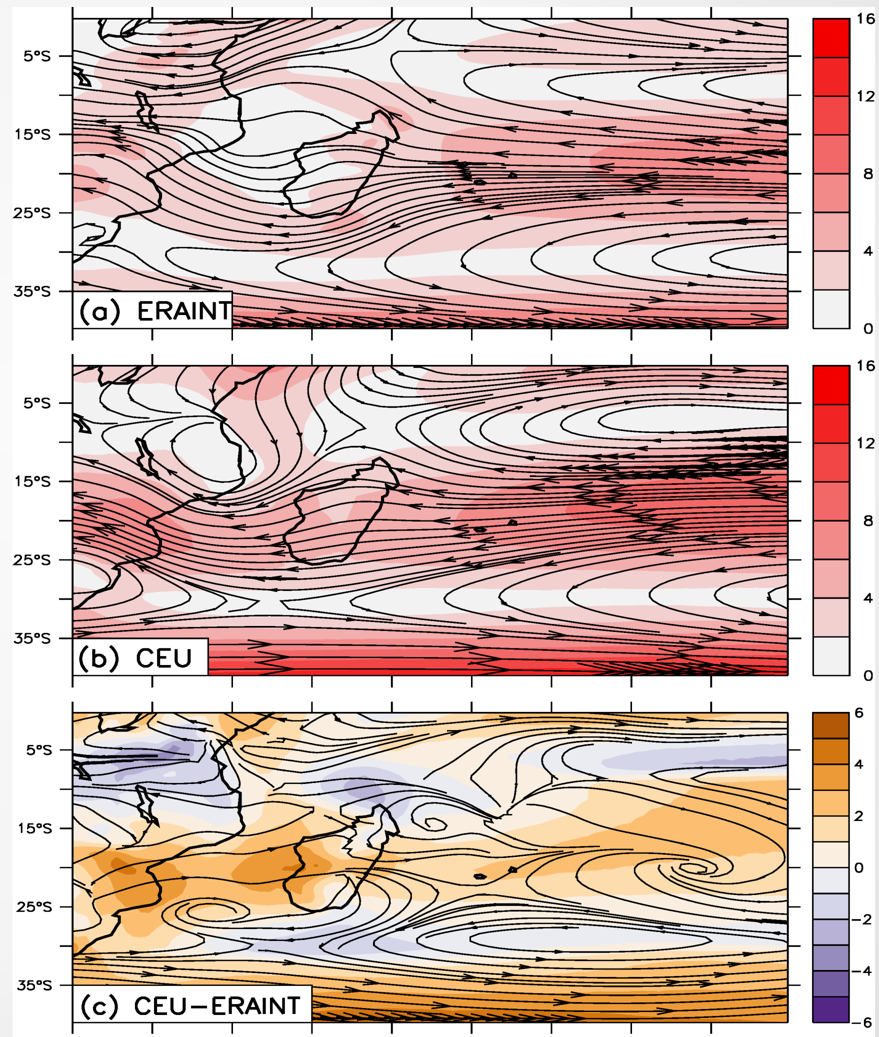
850 hPa Vorticity in $10^{6}s^{-1}$



850 hPa wind in m/s



MSLP and Zonal Wind

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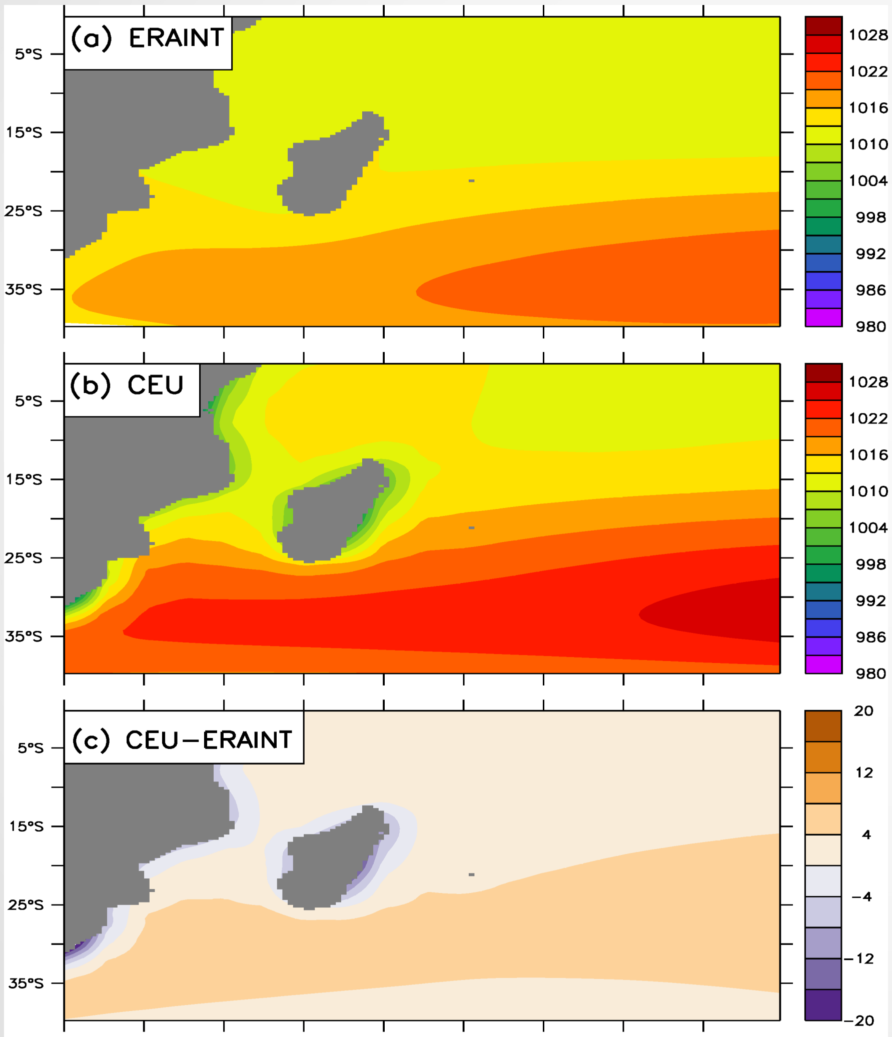
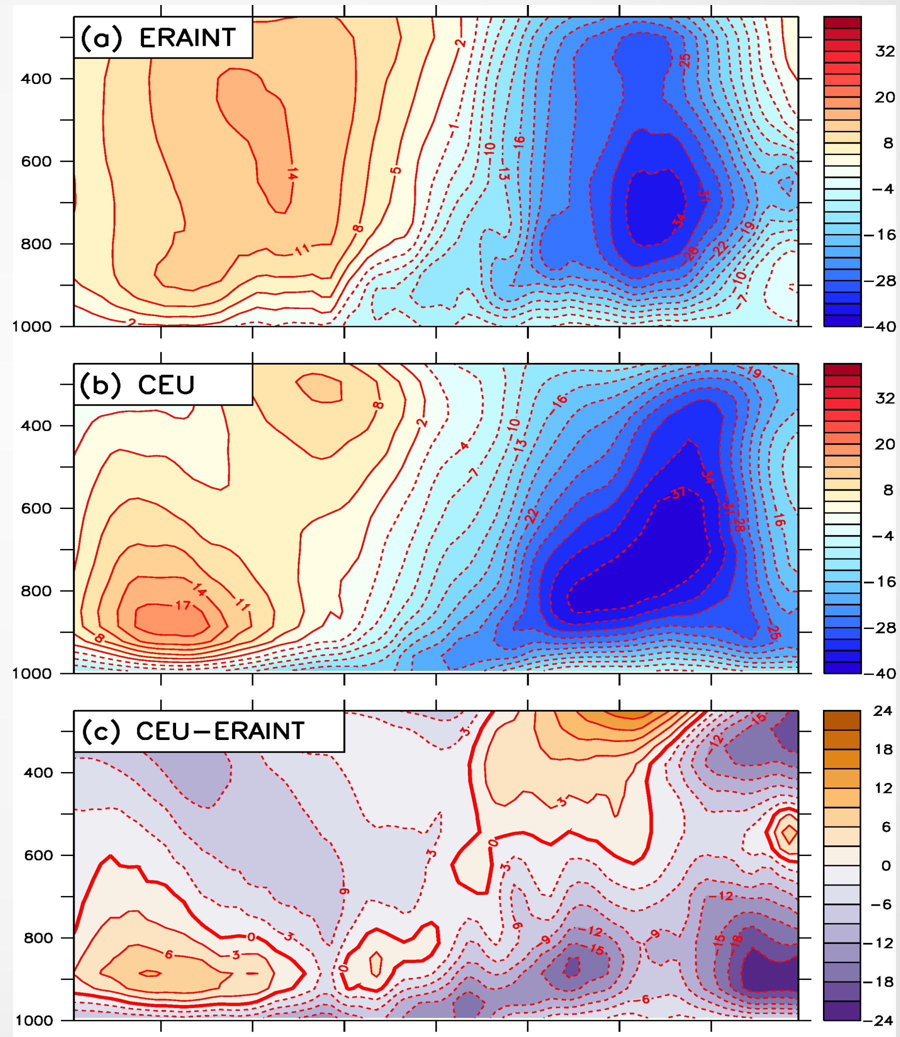
Mean Sea Level Pressure in hPa



Zonal Averaged Wind in 10^3Pa/s



Simulated TC Structure

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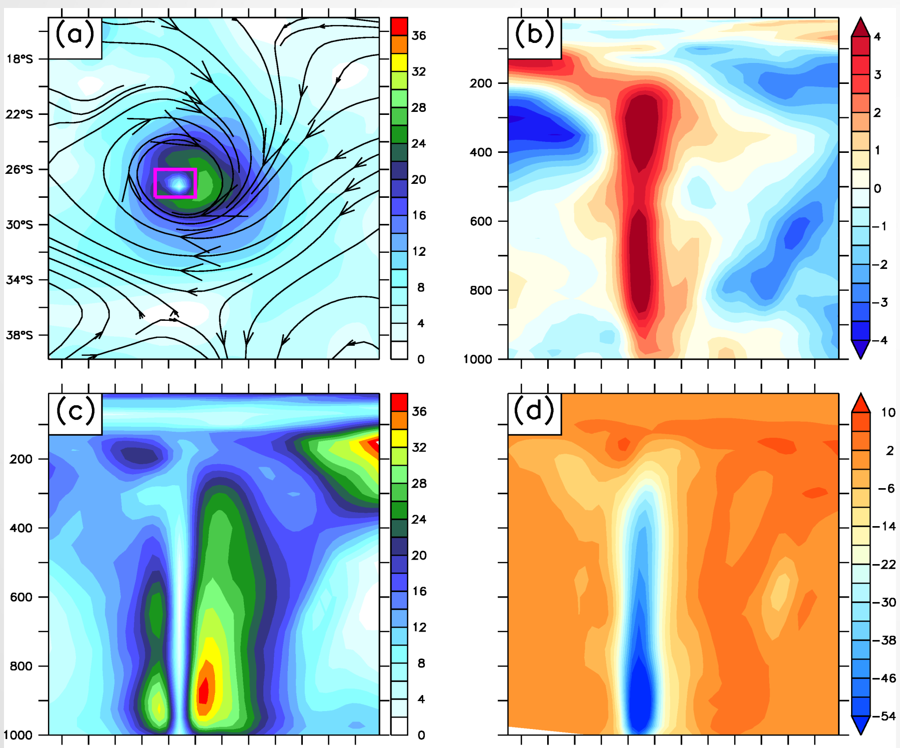
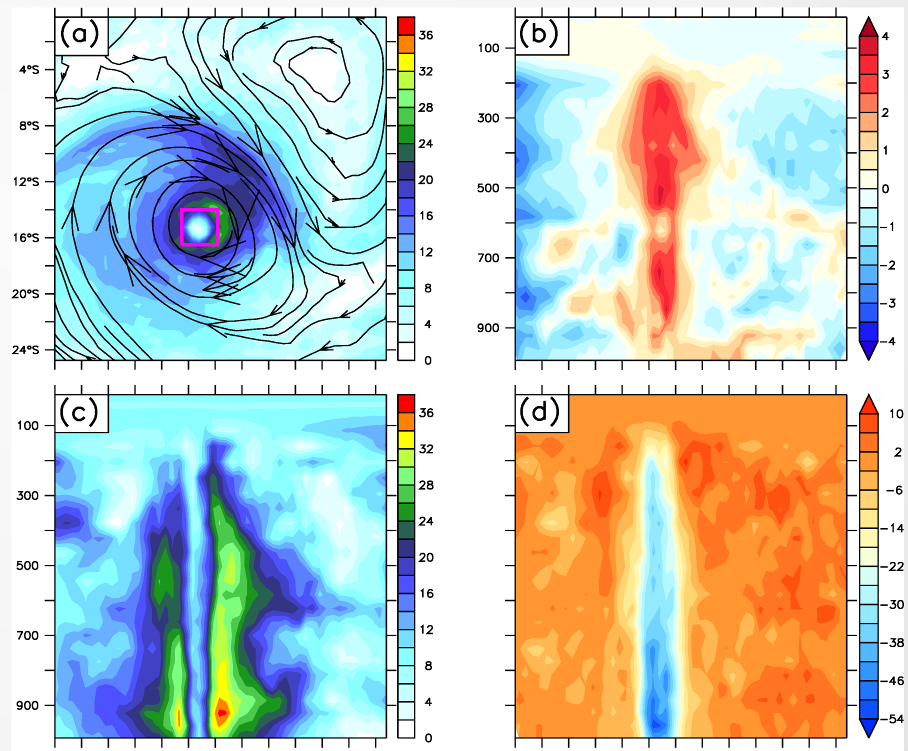
ERA-Interim



CAM-EULAG



TC Hary

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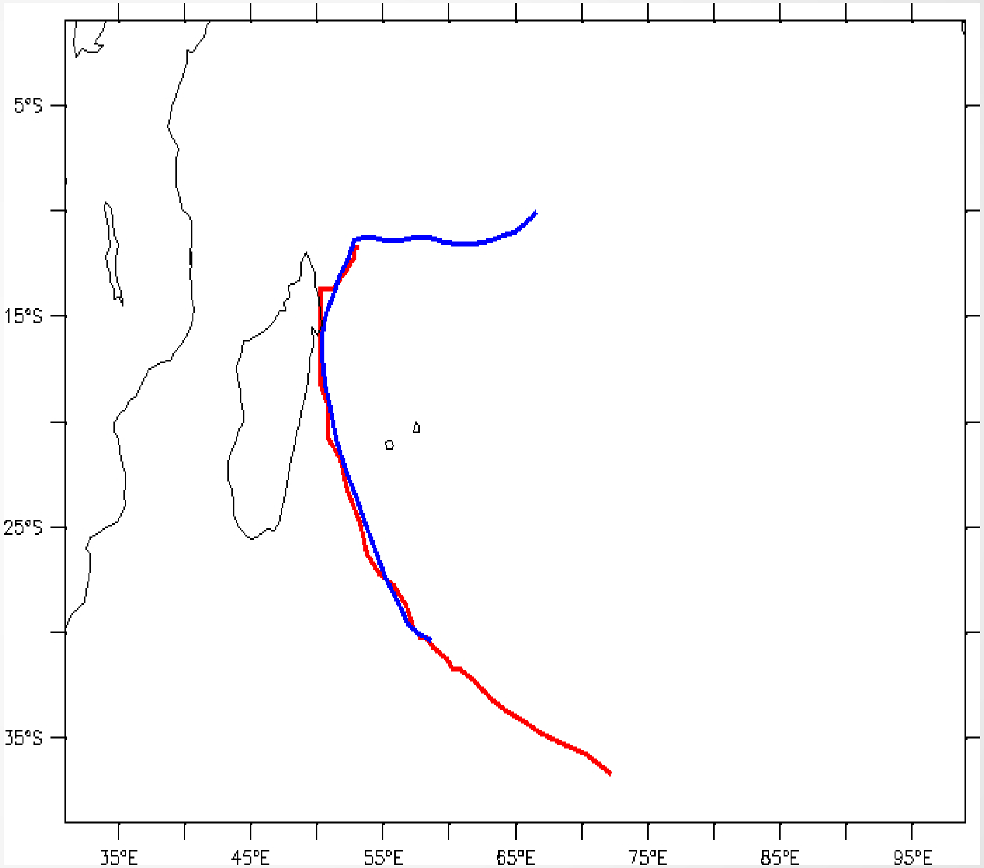
- Cyclogenesis: 8th March 2002
- TC on 10th of March
- Peak MSW 39 m/s
- Transitioned into Extra-Tropical TC on 17 March



ACE

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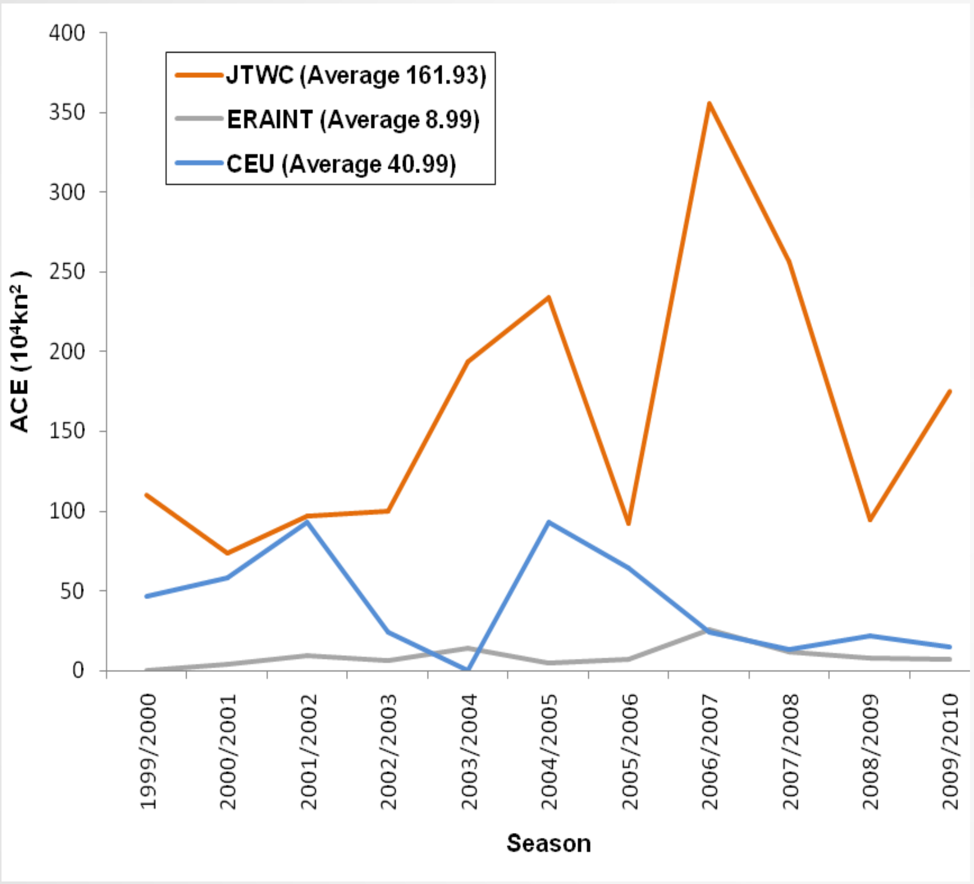

- ACE is an integrated measure of TC activity which combines intensity and duration (Bell et al., 2000).
- ACE = $10^{-4} \sum v_{max}^2$
- ERAINT Correlates better (ρ = 0.5) with JTWC in comparison to CAM-EULAG (ρ = -0.43) on the Interannual Variability of ACE

Wind-Pressure

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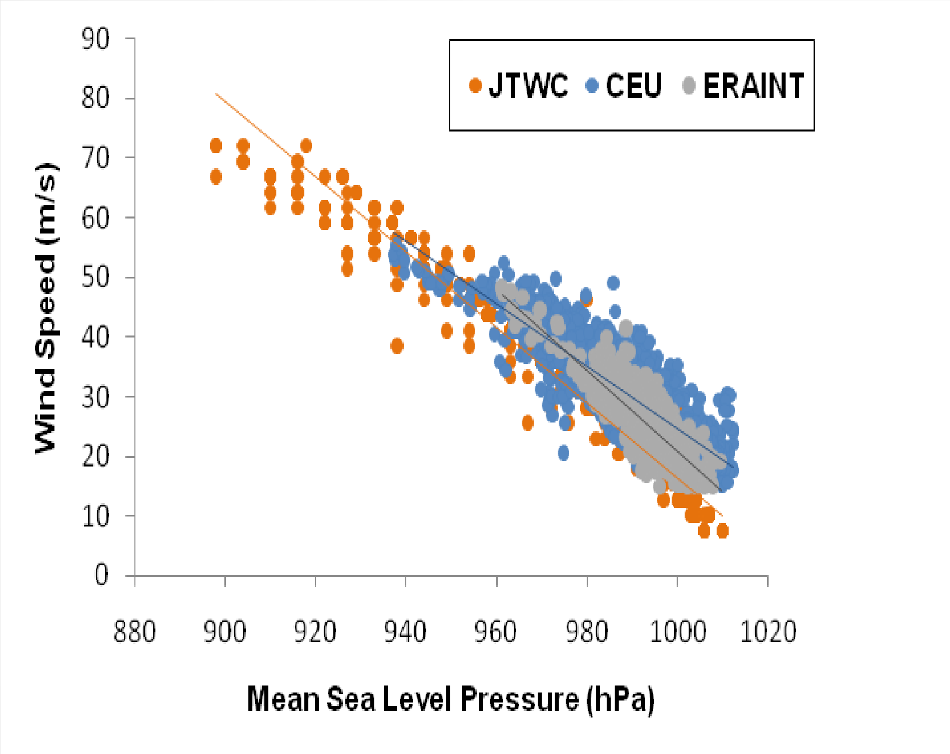

- JTWC wind-pressure relationship exhibits a strong linear relationship with a R^2 value of 0.98.
- ERAINT and CEU showed linearly regressed R^2 values of 0.76 and 0.74 respectively
- Both CEU and ERAINT struggle to produce overall spread as in JTWC.

TC Genesis and Tracks

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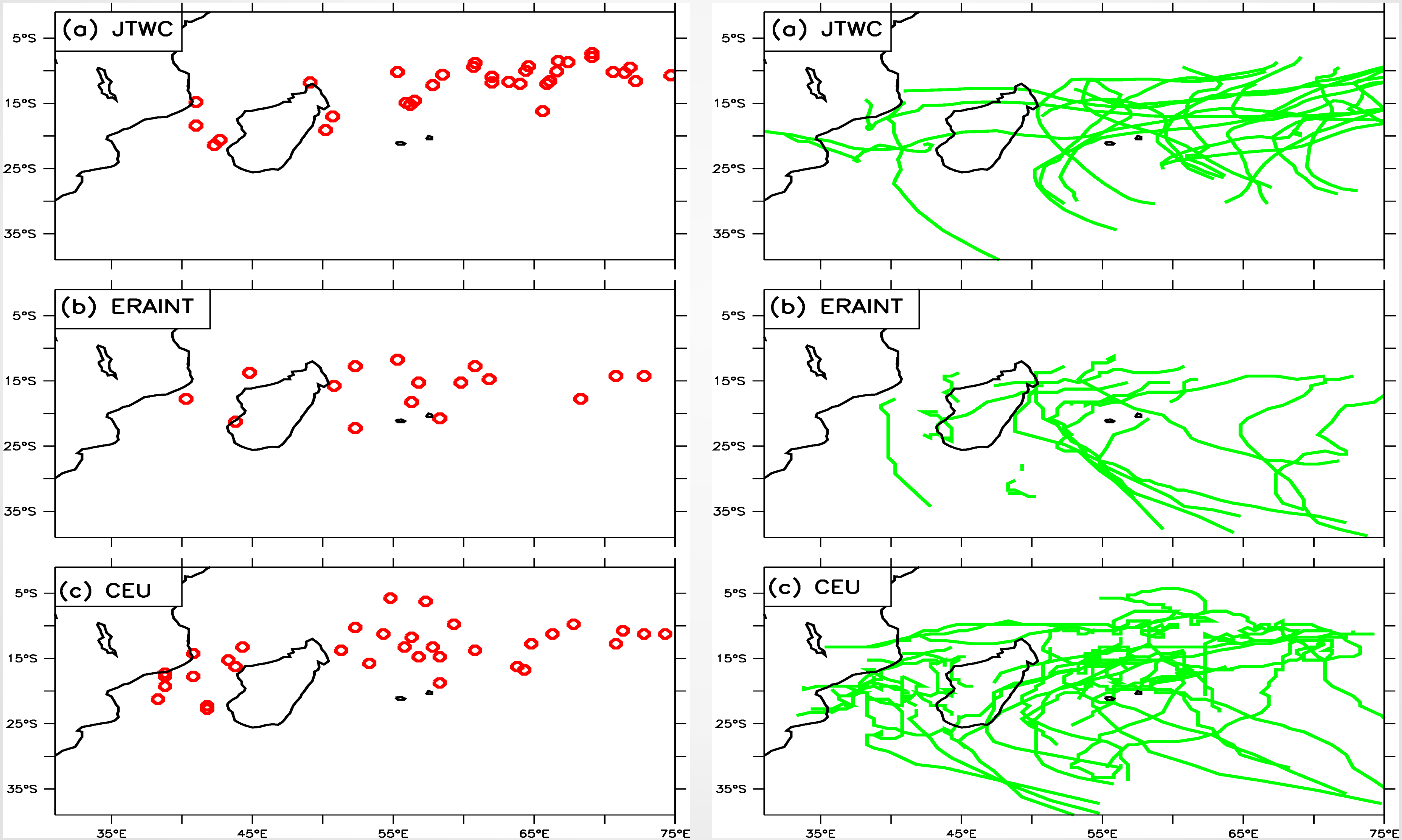

Monthly Variation of TCs

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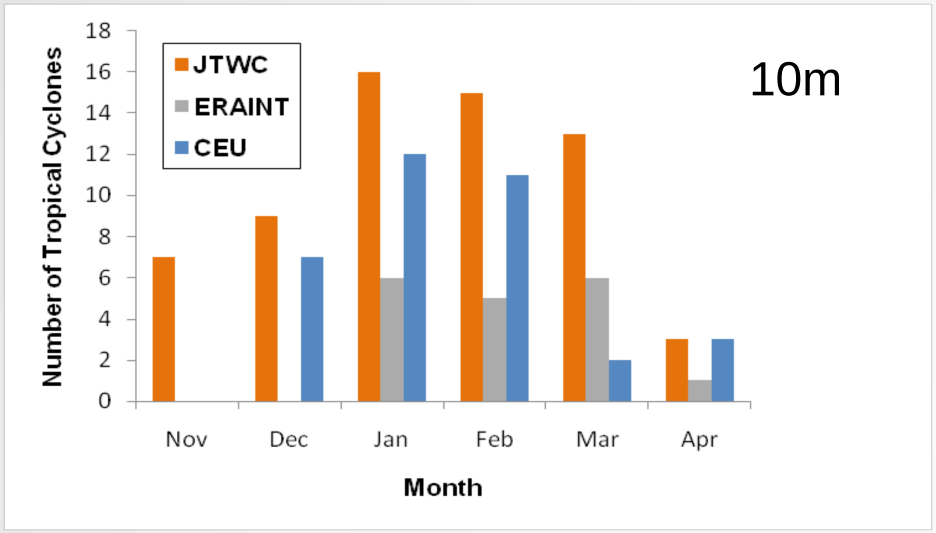
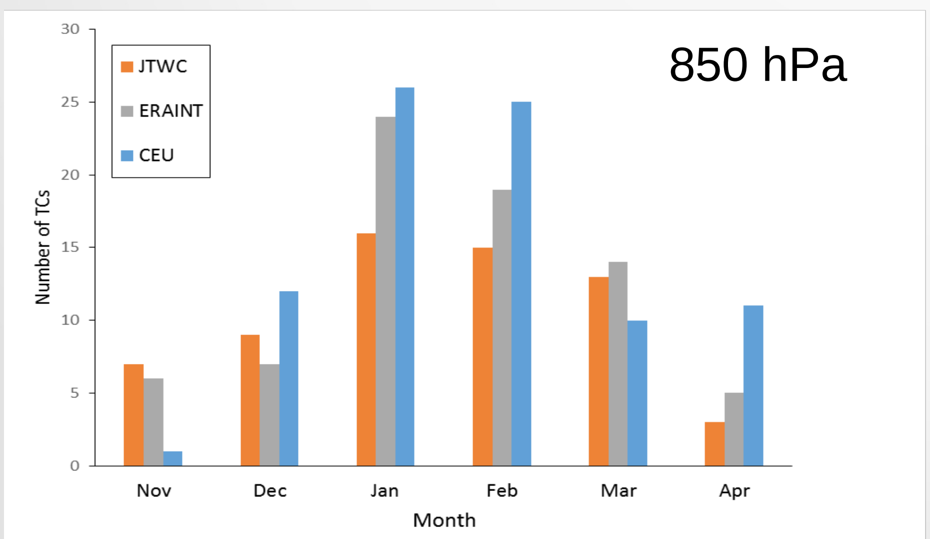
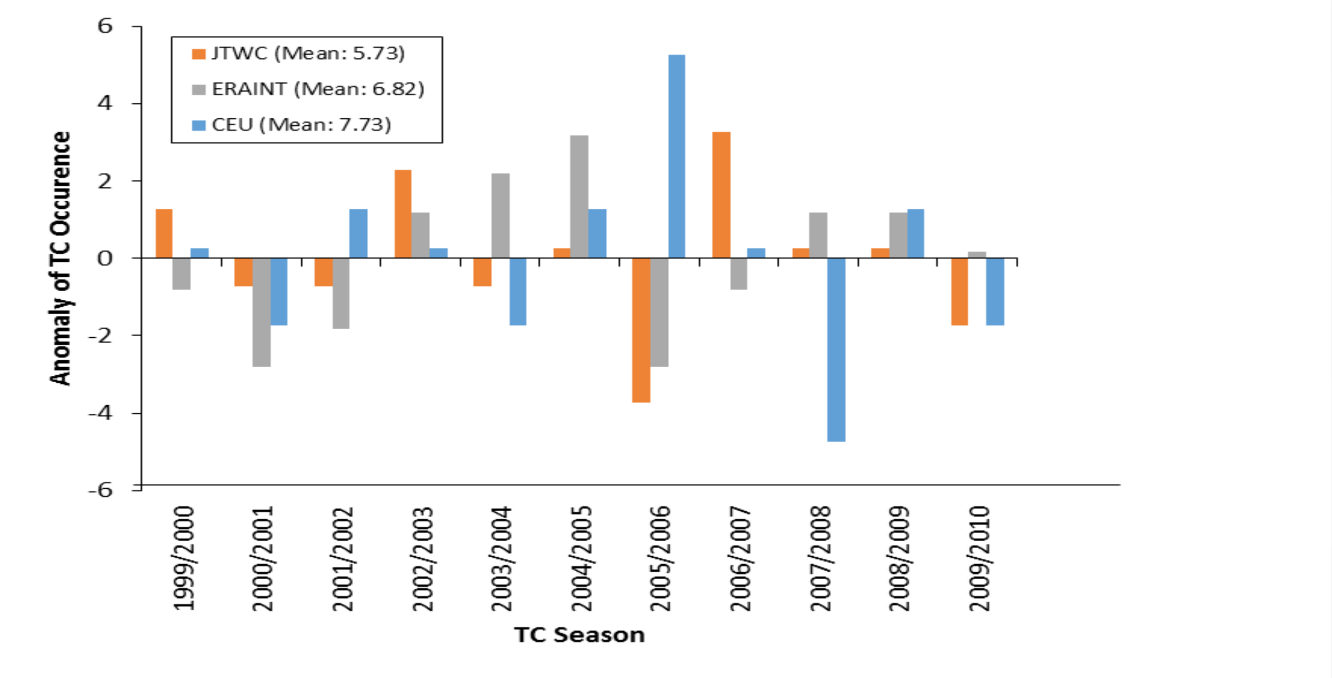




- For CEU, a good number of TCs in January and February formed over the MC which is consistent with the models vorticity bias over that area.
- Of the total CEU TCs that formed over the channel (i.e. 12), 6 (50%) formed in January, 3 (~25 %) in February and 3 in other months.
- Mavume et al. (2009) analysed TC data for 27 years (1980-2007) and showed that the majority of MC TCs (60%) formed in January and February.

Interannual Variability



Phase Synchronisation

$$\eta = \left(\frac{n'}{n}\right) \times 100\%$$

- ERAINT showed better agreement (η ~ 54%) in comparison to CEU (η = 36%) with regards to the TC anomaly patterns in the observation

	H	*F*	FAR	PC	HSS	PSS	GSS	Q
CEU	0.33	0.60	0.60	0.36	-0.26	-0.27	-0.12	-0.50
ERAINT	0.43	0.25	0.25	0.55	0.15	0.18	0.08	0.38

Conclusions

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- This study investigated the skill of a GCM with grid stretching (CEU) in simulating the characteristics of Tropical Cyclones (TCs) over the SWIO (South West Indian Ocean). The simulation was conducted over a period of 11-years (1999-2010) for the SWIO TC Season (November-April).

- In general, CEU showed good agreement with ERAINT in simulating climatic features over the SWIO for the study period but had a notable discrepancy over the Mozambique Channel (MC) due to the strong cyclonic features present in the CEU simulation over the region.

- The model and reanalysis produced well the distribtion of spatial tracks of TCs over the SWIO but the model overestimated the number of TCs over the MC. CEU (ERAINT) overestimated (underestimated) TC genesis directly over the basin as well as for the MC. However they both showed some skill in showing the spatial distribution of genesis locations.

Conclusions

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- ERAINT adequately reproduced the dynamical structure of an observed TC which consists of warm core and a well defined eye in the centre of the storm. However, the reanalysis exhibited a larger eye (~100 km) in comparison to a typical TC eye (32-64 km). A comparible storm was also simulated by CEU but with more detail in comparison to ERAINT.

- CEU showed better agreement with observation in comparison to ERAINT on the intensity of TCs. However, even at 0.5°x0.5°, CEU struggled to produce storms with stronger wind speeds as well as minimum MSLP centres deeper than 940 hPa.

- Both CEU and ERAINT reproduced well the monthly variation of TCs although TCs were overestimated for CEU during the peak months (i.e. January and February) in comparison to the observation.

- The model performed poorly in simulating the interannual variability of SWIO TCs. It captured some of the anomaly trends with an *H* score of 0.33 and a FAR of 0.60 in relation to the observation. ERAINT scored an *H* value of 0.43 which showed some skill.

Thank You !

Questions ?

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