The Impacts of Altered Sea Surface Temperature Gradients on Indian Ocean Atmospheric Circulation in Warmer Climate

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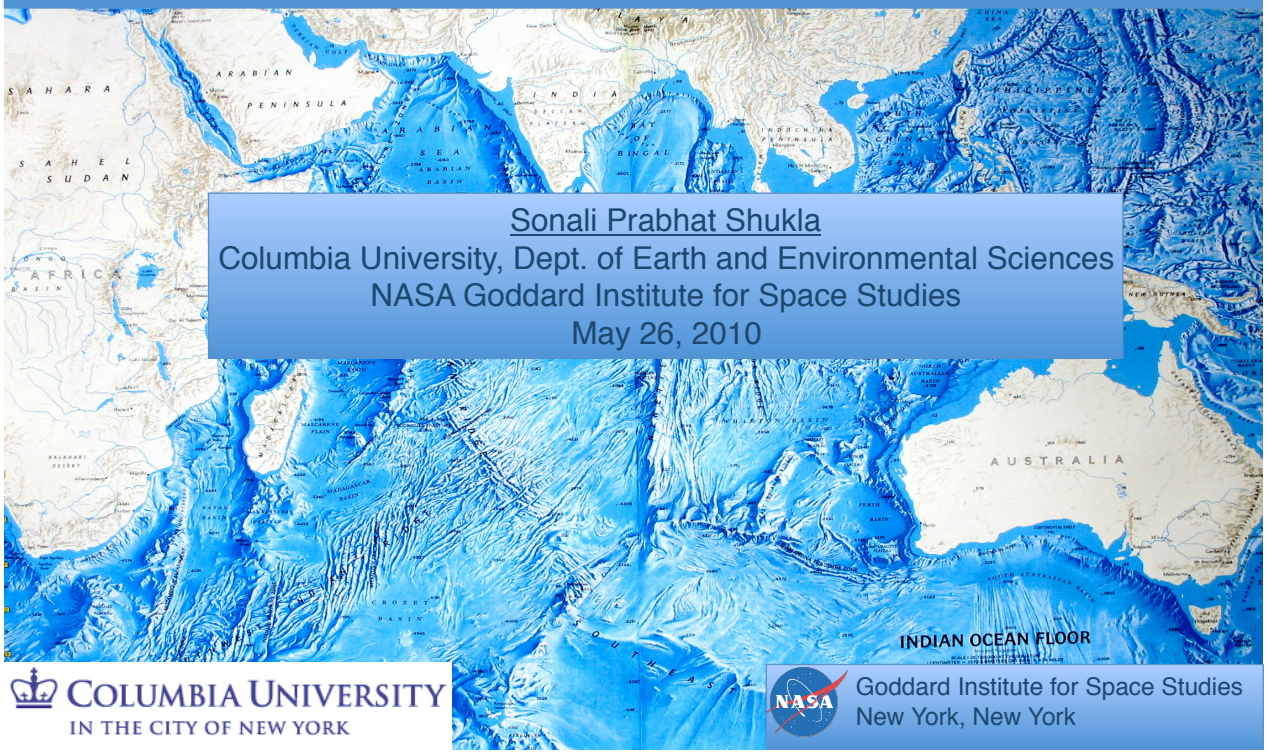
May 26, 2010



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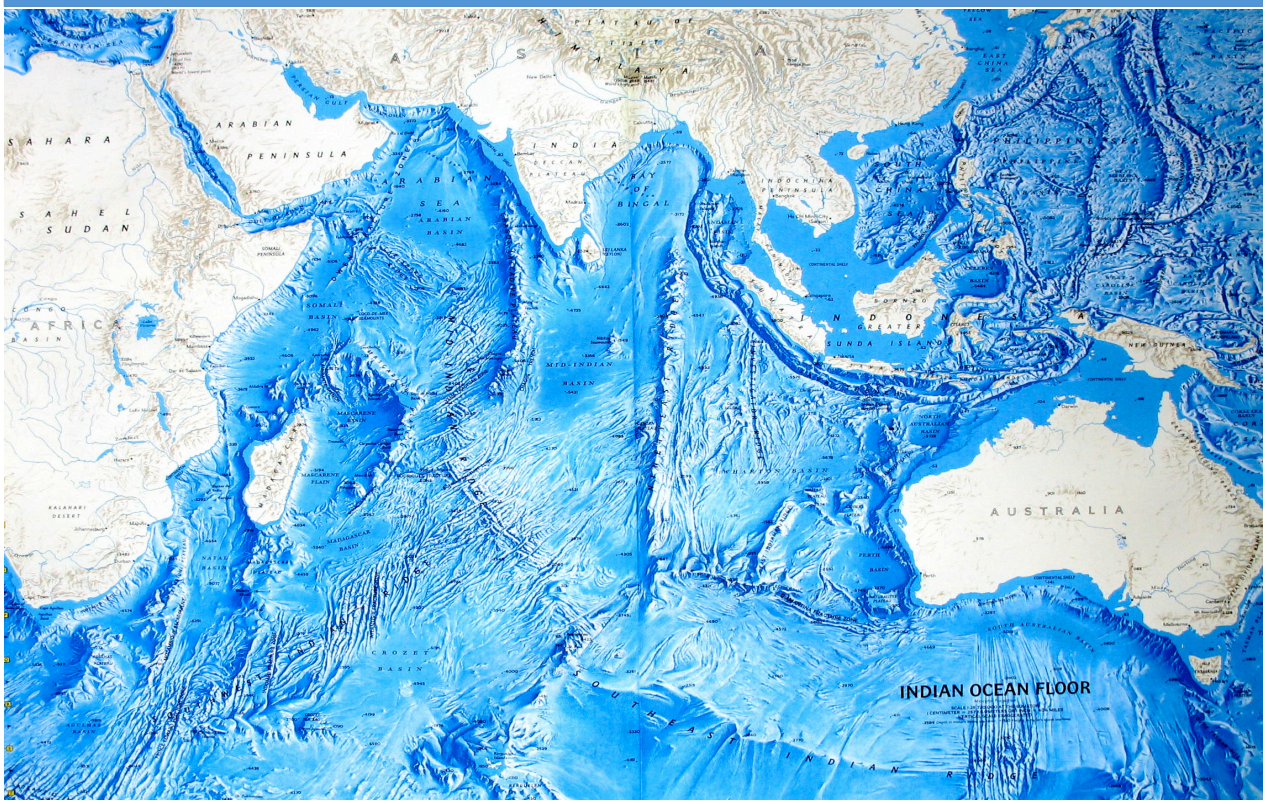
Broader Relevance for Indian Ocean Region



Overview of Project Evolution

I. Why Altered Sea Surface Temperature Gradients?

   a) Perspective from the Warm Pliocene Period

   b) Current State of Indian Ocean Research

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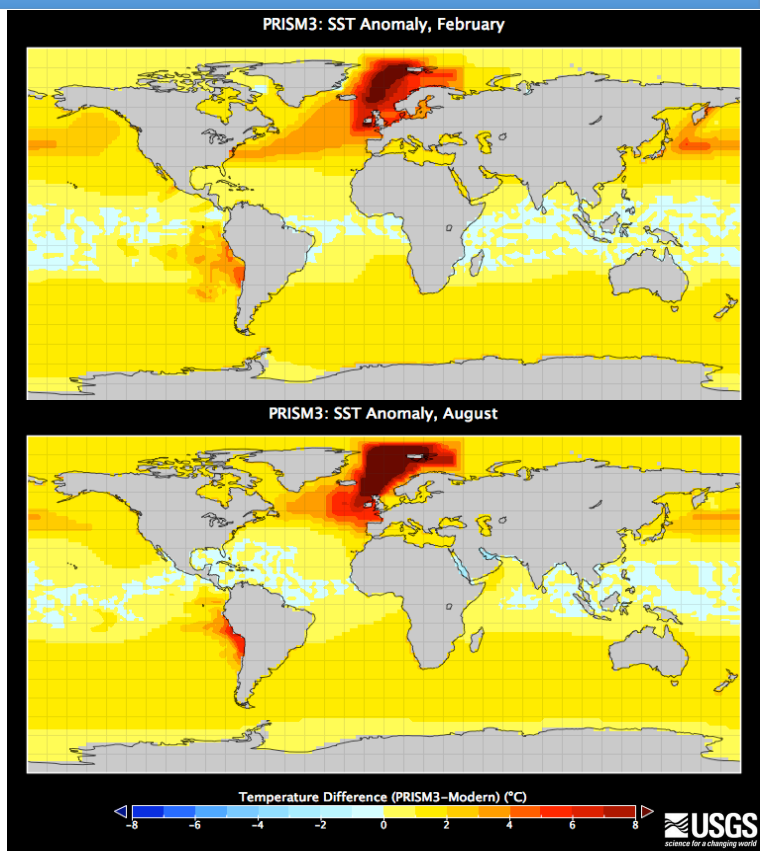
III. Proposed Methodology

IV. Preliminary Results and Implications

V. Schedule of Project Completion

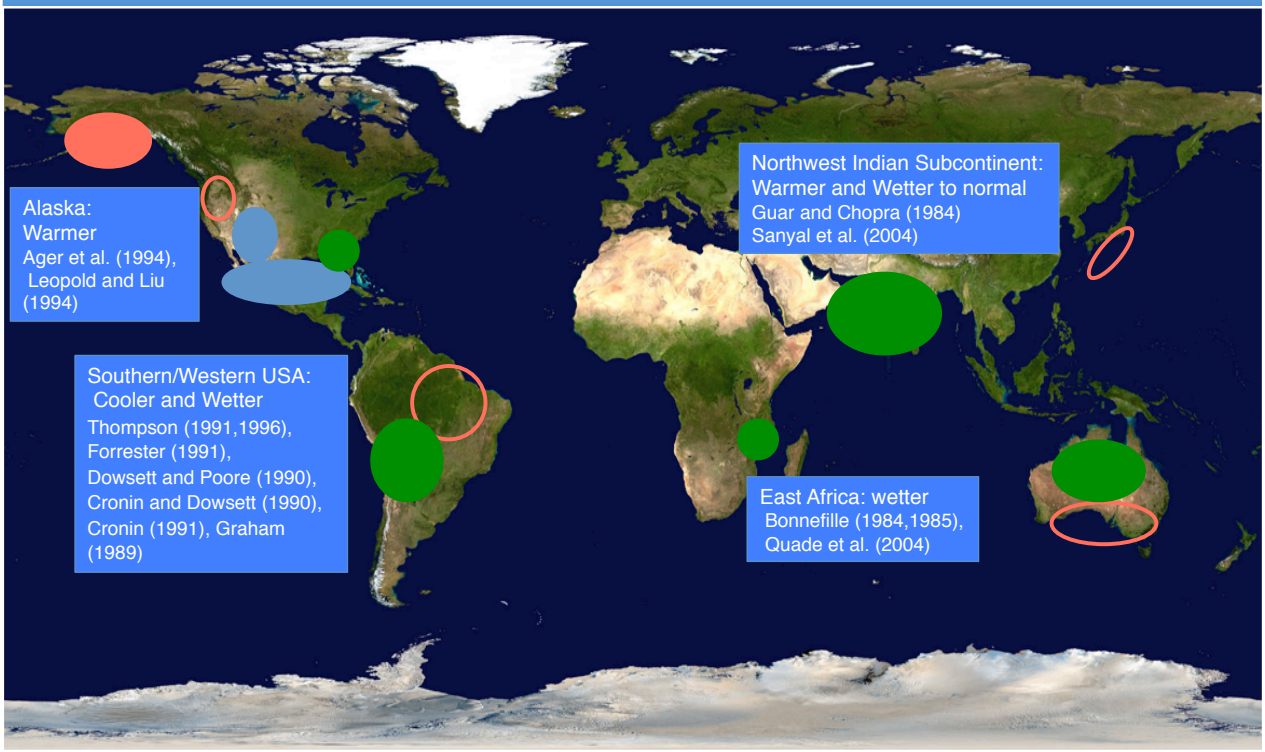
Ia Altered SST Gradients: The Warm Pliocene

Warm Pliocene: Decreased Meridional SST gradients impact atmospheric teleconnections



Ia

The Warm Pliocene Regional Climates



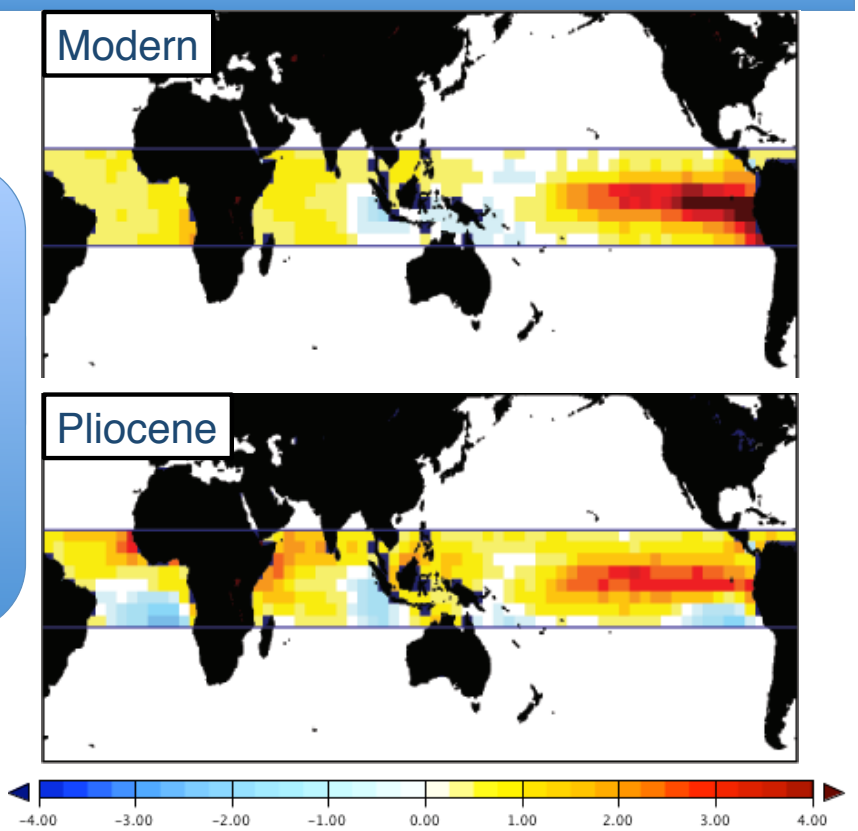
Cool and Wet Warm and Dry Warm and Wet

Ia

Altered SST Gradients: The Warm Pliocene

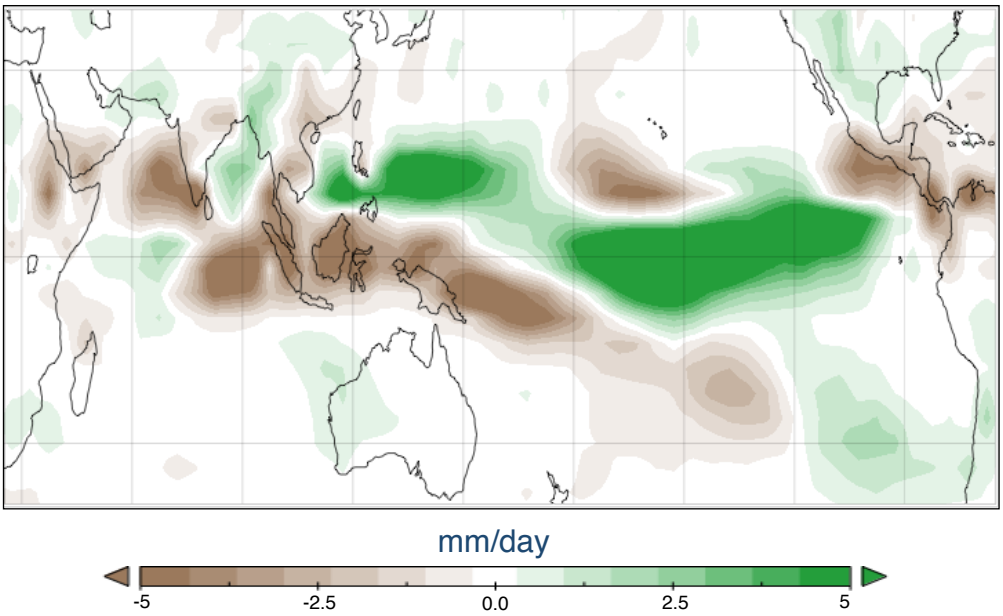
Pliocene Regional Climates Resembled 1997/98 El Niño/Indian Ocean Dipole Event.

GCM Simulations Do Not Reproduce Pliocene Regional Climates If Tropical SST Gradients Are Excluded



Ia Impact of an IOD/El Padre in the Warm Pliocene

Modern El Padre JJA Averaged Precipitation



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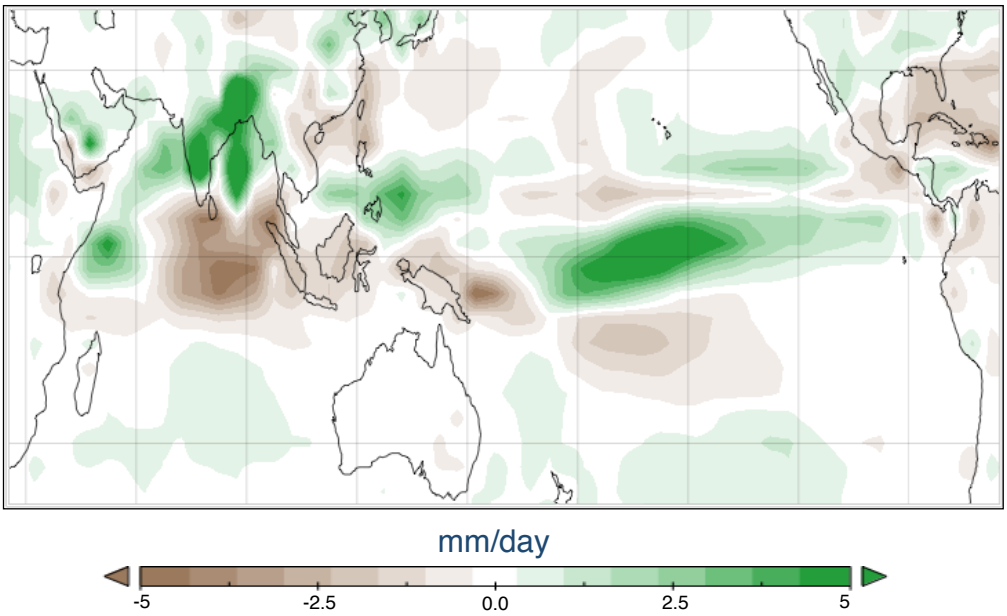
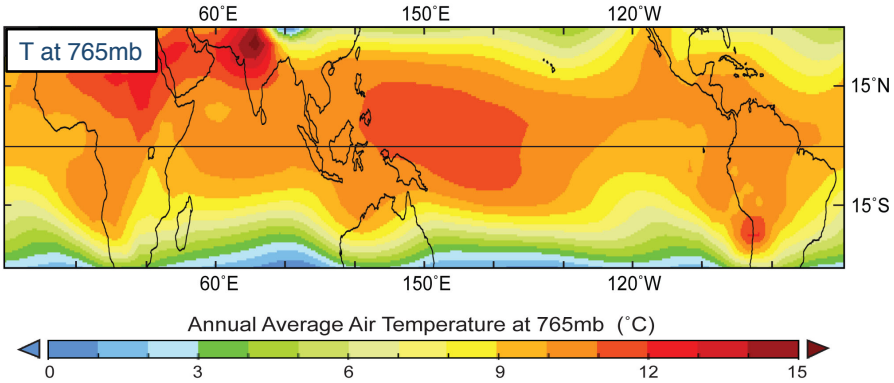
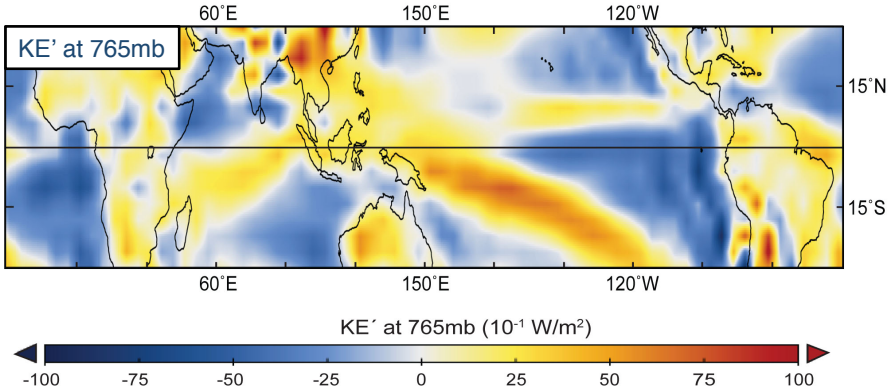


Ia Using KE' to Assess IOD-Produced Zonal Overturning





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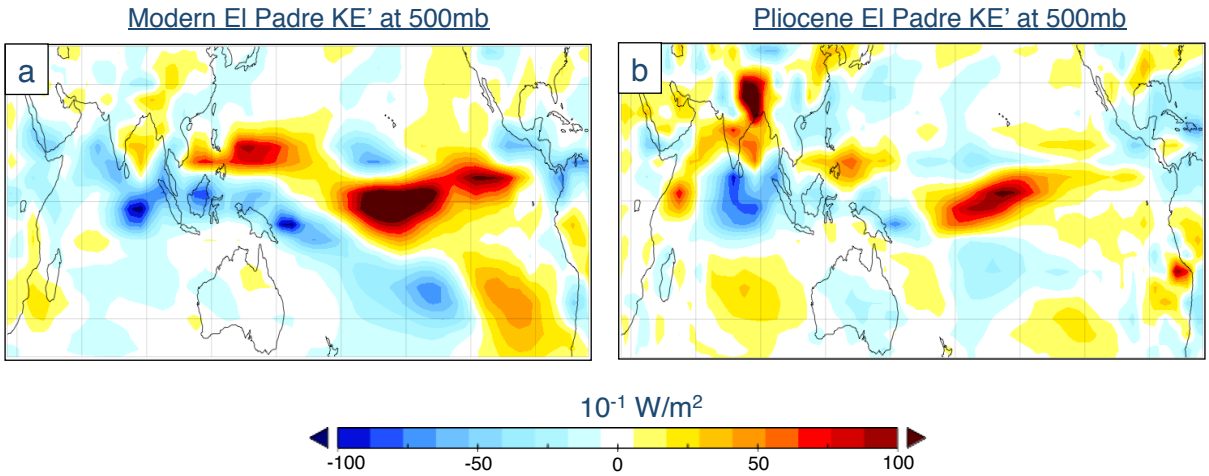
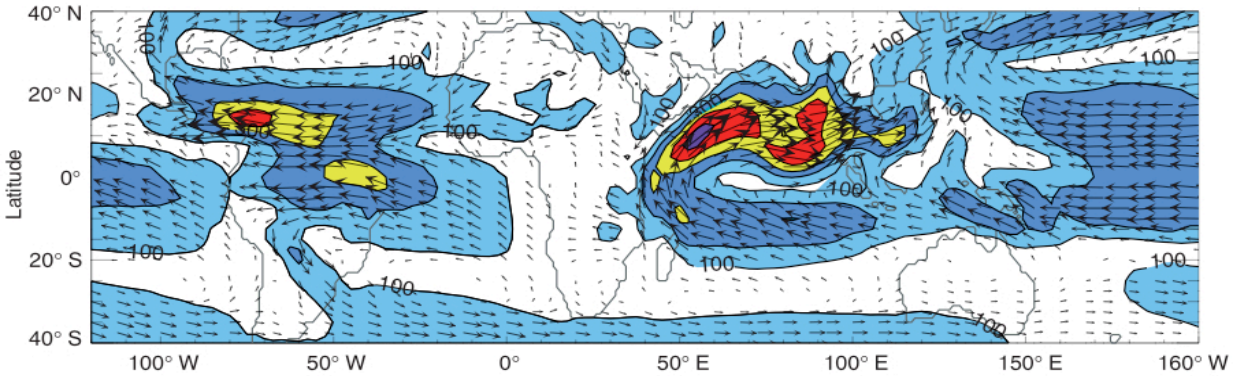


Ia Perspective from the Warm Pliocene

Both IOD and El Padre features are consistent with Warm Pliocene patterns of temperature and precipitation. This raised the question of whether or not they are characteristic of warmer climates in general.

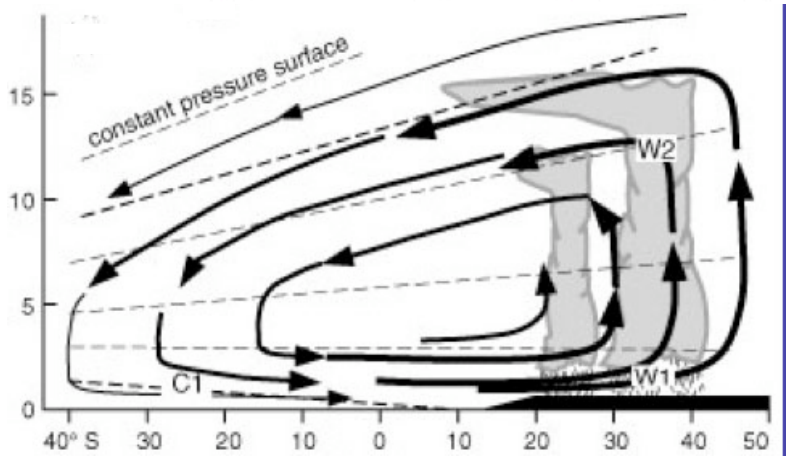
The IOD modifies the Indian Ocean region atmospheric circulation, decreasing the influence of the Pacific on the monsoon.

Ia Indian Ocean Monsoon Circulation



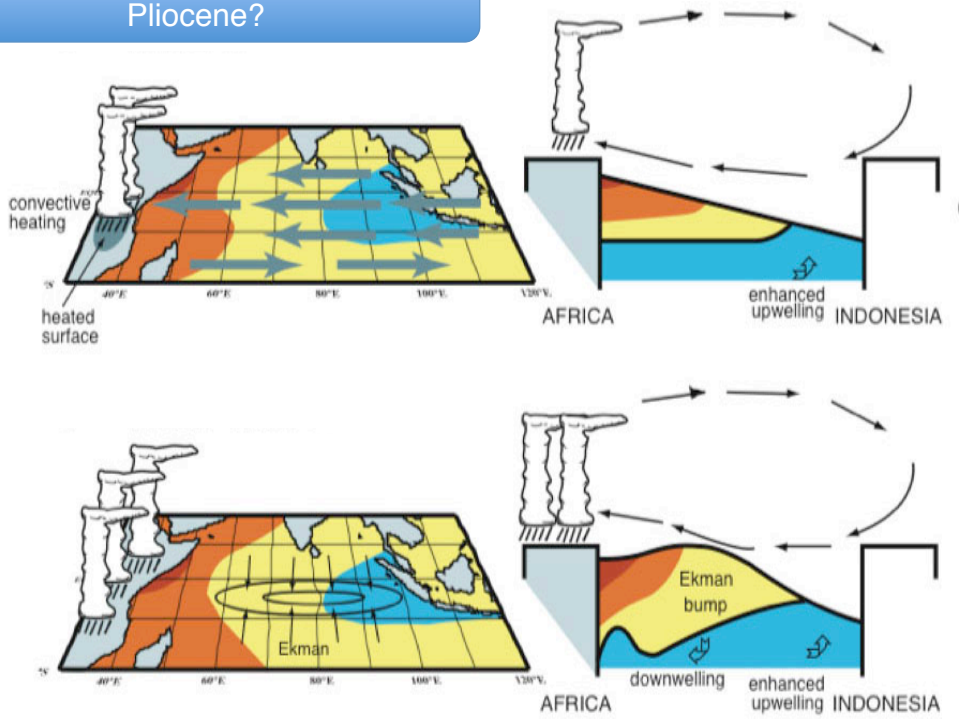
3 x 10^2 kg ms^{-1}

How does this change during the warm Pliocene?



Ia What Happens During an IOD Event?

How does this manifest in the warm Pliocene?

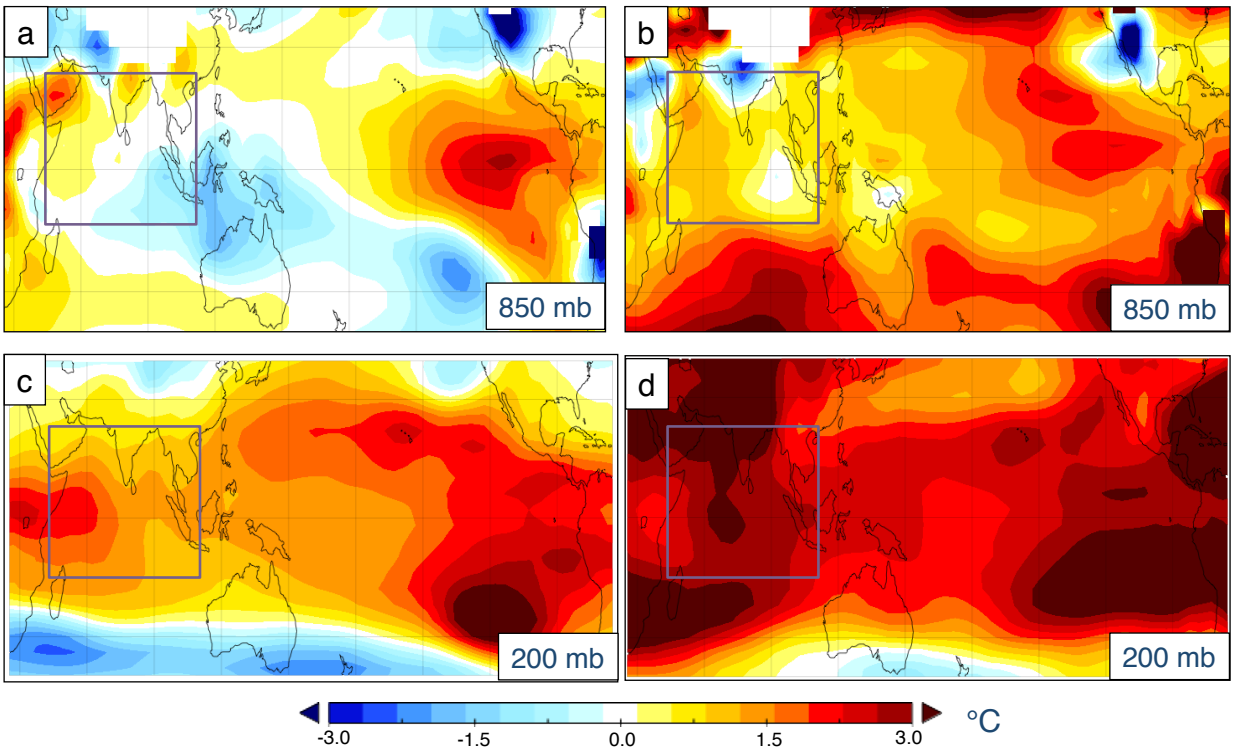


Webster et al., 1999

Ia Pliocene Monsoon Components

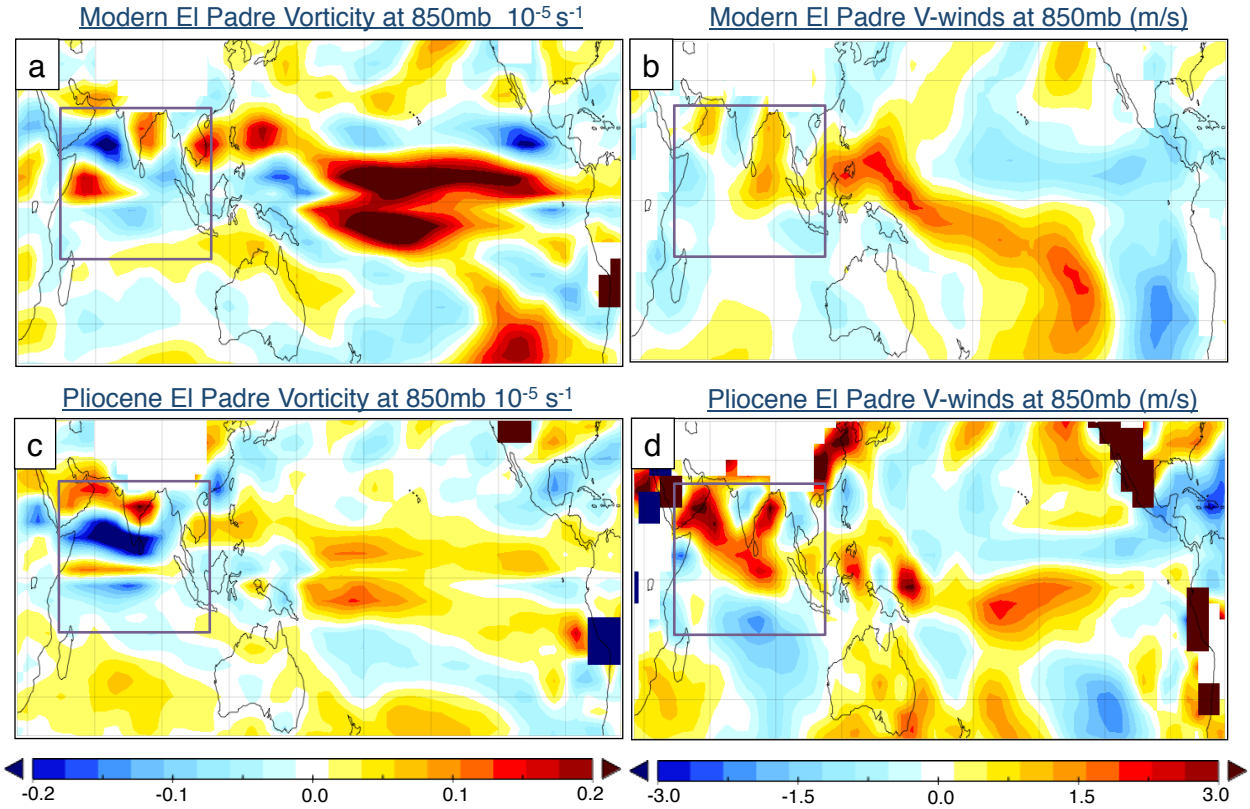
Modern El Padre Temperatures (˚C)

Pliocene El Padre Temperatures (˚C)



Ia

Pliocene Monsoon Components



Ia

Pliocene Monsoon Components

Monsoon Intensity Index (Webster and Yang, 1992):

$U_{850mb} - U_{200mb}$= MI, Averaged over 0˚ - 20˚N and 40˚E to 110˚E

Measurement of shearing and thermal difference that drives the greater monsoon circulation

Simulation	MI Index	Percent of Modern Control
Modern Control	18.7	--
Modern El Padre	13.0	70%
Pliocene El Padre	17.7	95%

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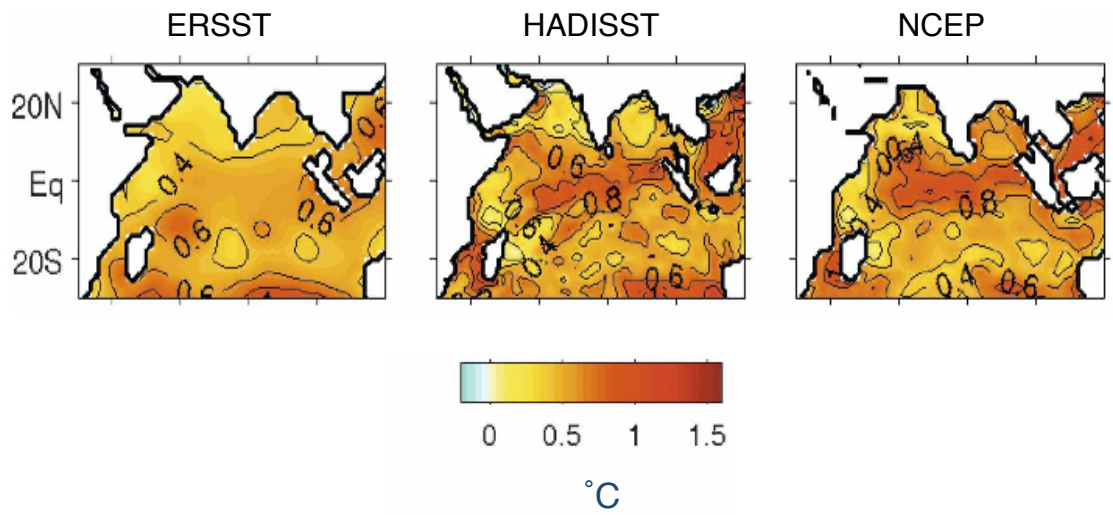
Ib Modern Indian Ocean Warming Trends

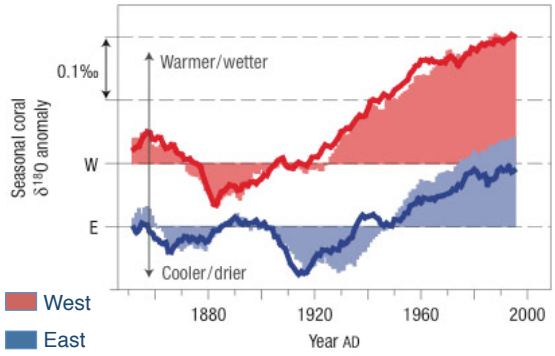
SST Trend for 1960-1999



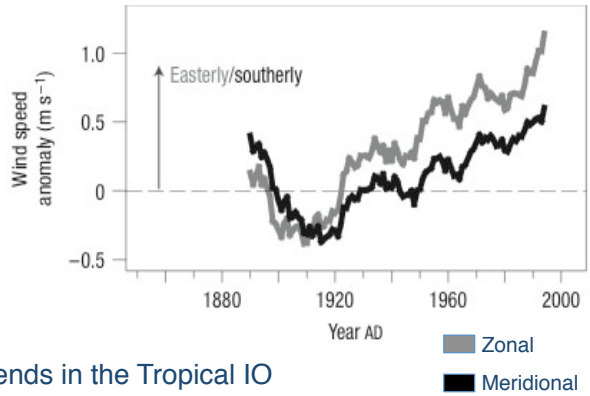
Alory and Meyers, 2009

Ib Modern Indian Ocean Warming Trends

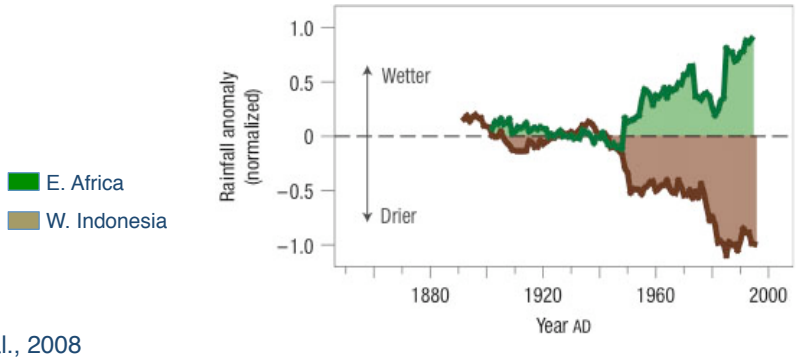
a) Coral Trends in the Tropical IO



b) Wind Trends in the Tropical IO



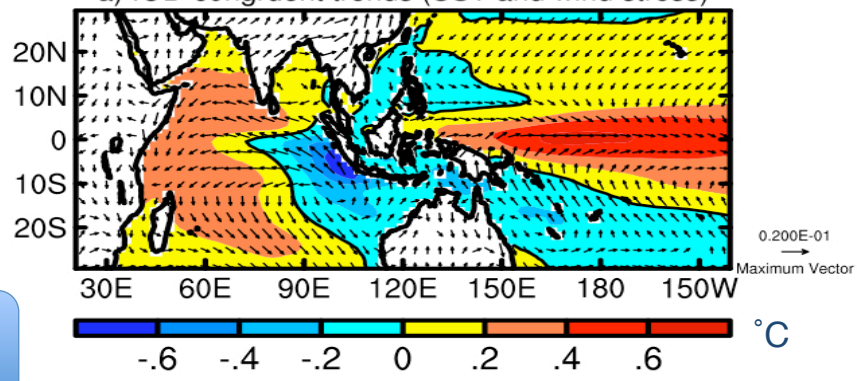
b) Rainfall Trends in the Tropical IO



Abram et al., 2008

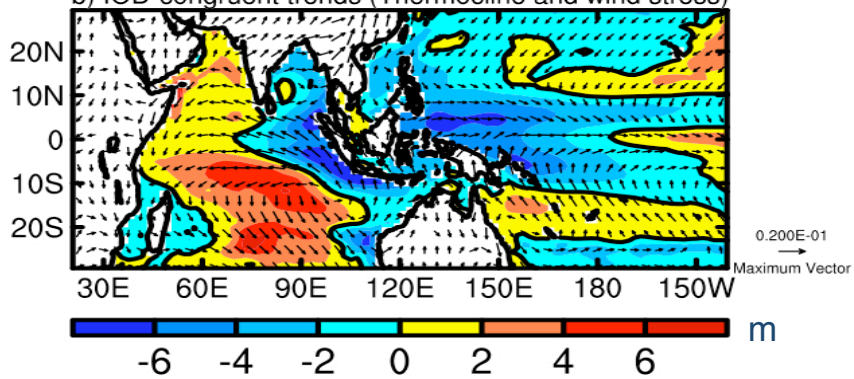
Ib Coupled Model Warming Trends

a) IOD-congruent trends (SST and wind stress)



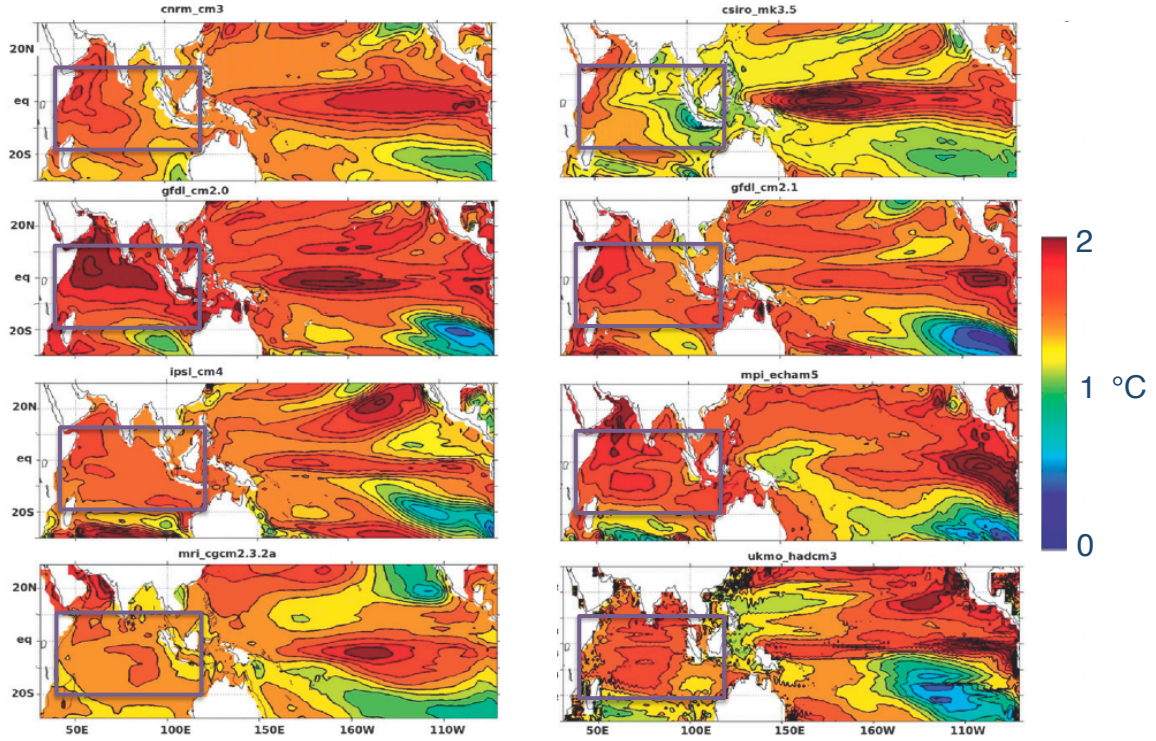
Indian Ocean Dipole-like Preconditioning in 20th Century simulations

b) IOD-congruent trends (Thermocline and wind stress)



Cai et al., 2009

Ib Coupled Model Warming Trends



Ihara et al., 2009

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II General Projection for the Greater Indian Ocean

The Indian Ocean's dominant monsoon flow will strengthen with global warming, facilitated by a new zonal overturning circulation associated with IOD-like preconditioning

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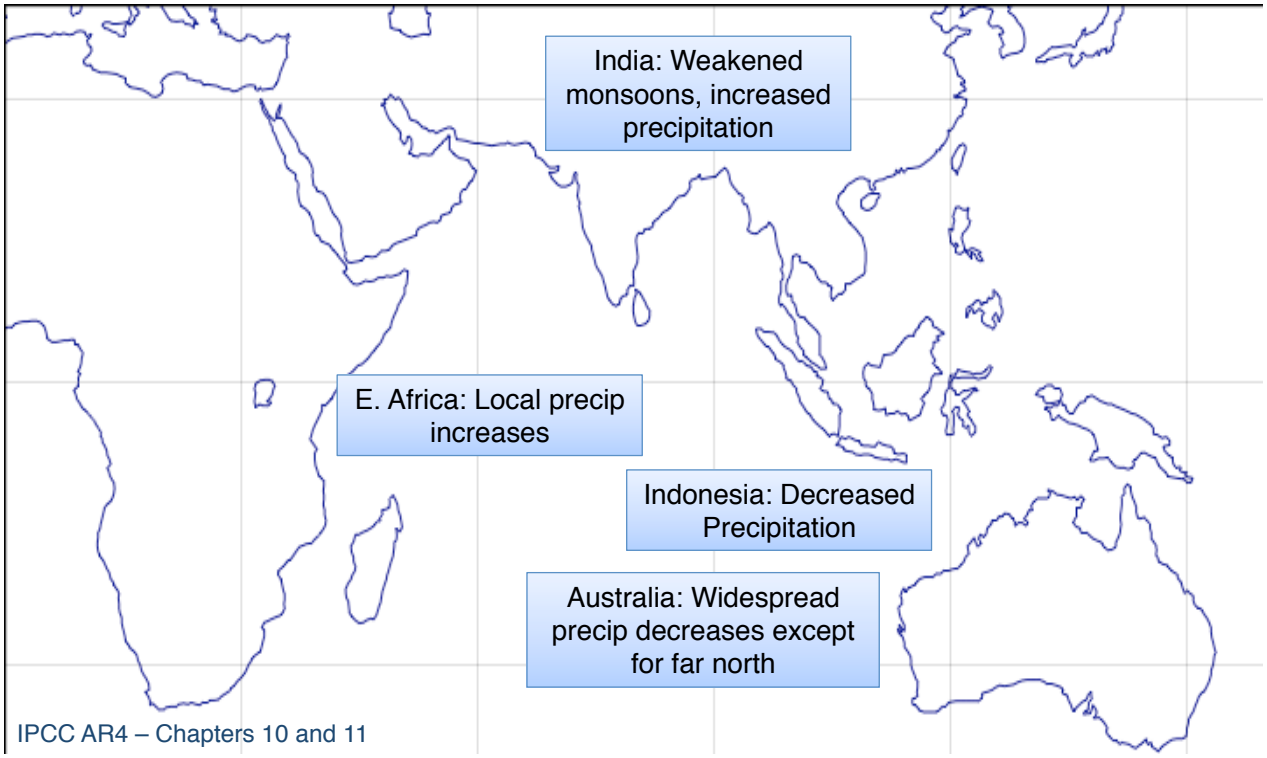
Concurrently, rainfall will increase (decrease) in the western/ central (eastern) IO

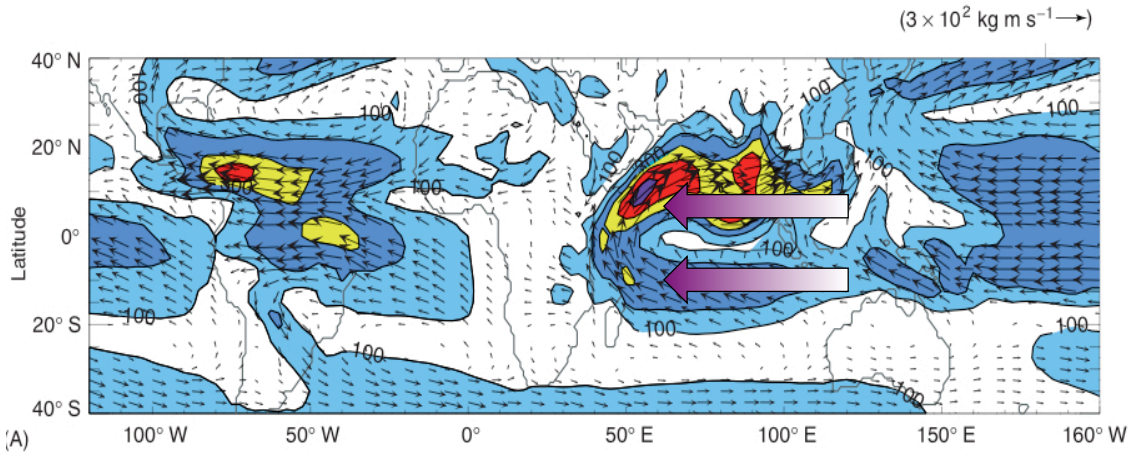
II General Projection for the Greater Indian Ocean

Regional Projections for Landmasses Surrounding the Indian Ocean Basin



III Evaluating Monsoon's Components

Easterly Winds and the Monsoon Circulation



III Evaluating Monsoon's Components

The Dominant Monsoonal Circulation of the Indian Ocean

Driving Monsoon Pressure Gradient Forces:

$$\Delta \ln p(z_1) = \frac{g}{R} z_1 \left(\frac{1}{\overline{T}_c} - \frac{1}{\overline{T}_w} \right) - \Delta \ln p(0)$$

Establishes thermally direct meridional monsoon circulation

Contribution of Moisture:

$$B_q = \int_{P_t}^{P_s} q \nabla dz$$

Moisture convergence enhances monsoon

Atmospheric Flow Field:

$$f\hat{k} \times \overline{V} + \alpha \overline{V} = -\frac{1}{\rho} \frac{\partial p}{\partial y}$$

Mean Wind response to monsoon pressure/temperature changes

III GISS Model Simulations

Completed Simulations

Simulation	Model 3 4°x 5°	Model E 2° x 2.5°
IOD/El Padre	✓	✓
Pliocene IOD/El Padre	✓	★
El Padre Only		✓
IOD Only		✓
IOD/El Padre $4xCO_2$	★	✓
Annually Varying SSTs		✓

✓= Performed Simulation
★= Simulation To Be Performed

III GISS Model Simulations

Proposed Model Comparison Simulations

Simulation	Model 3 4°x 5°	Model E 2° x 2.5°	Model 3 2° x 2.5°
IOD/El Padre	✓	✓	★
Pliocene IOD/El Padre	✓	★	★
El Padre Only		✓	
IOD Only		✓	
IOD/El Padre $4xCO_2$	★	✓	★
Annually Varying SSTs		✓	

✓= Performed Simulation
★= Simulation To Be Performed

GISS Model Simulations

Proposed Coupled Ocean Simulations

Simulation	Model EH 2° x 2.5°
Transient CO_2	★
Equilibrium $4xCO_2$	★

✓= Performed Simulation
★= Simulation To Be Performed

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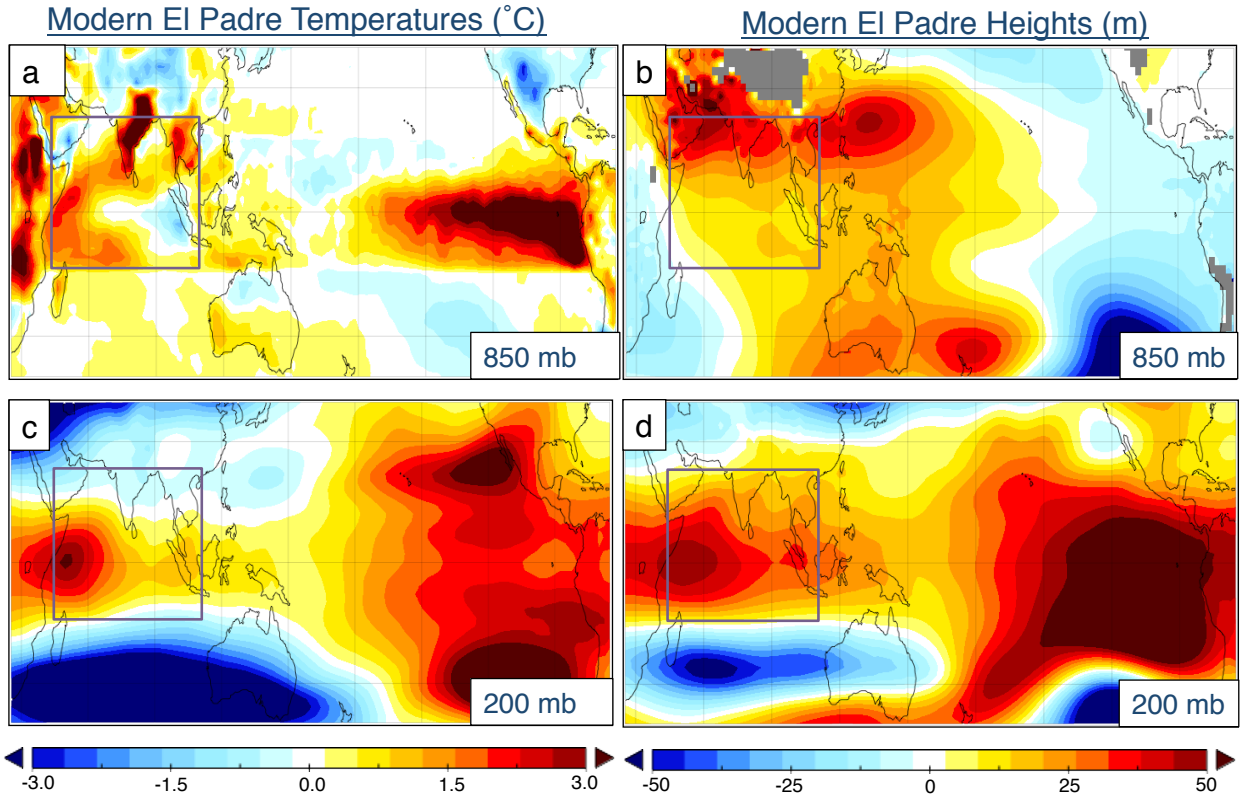
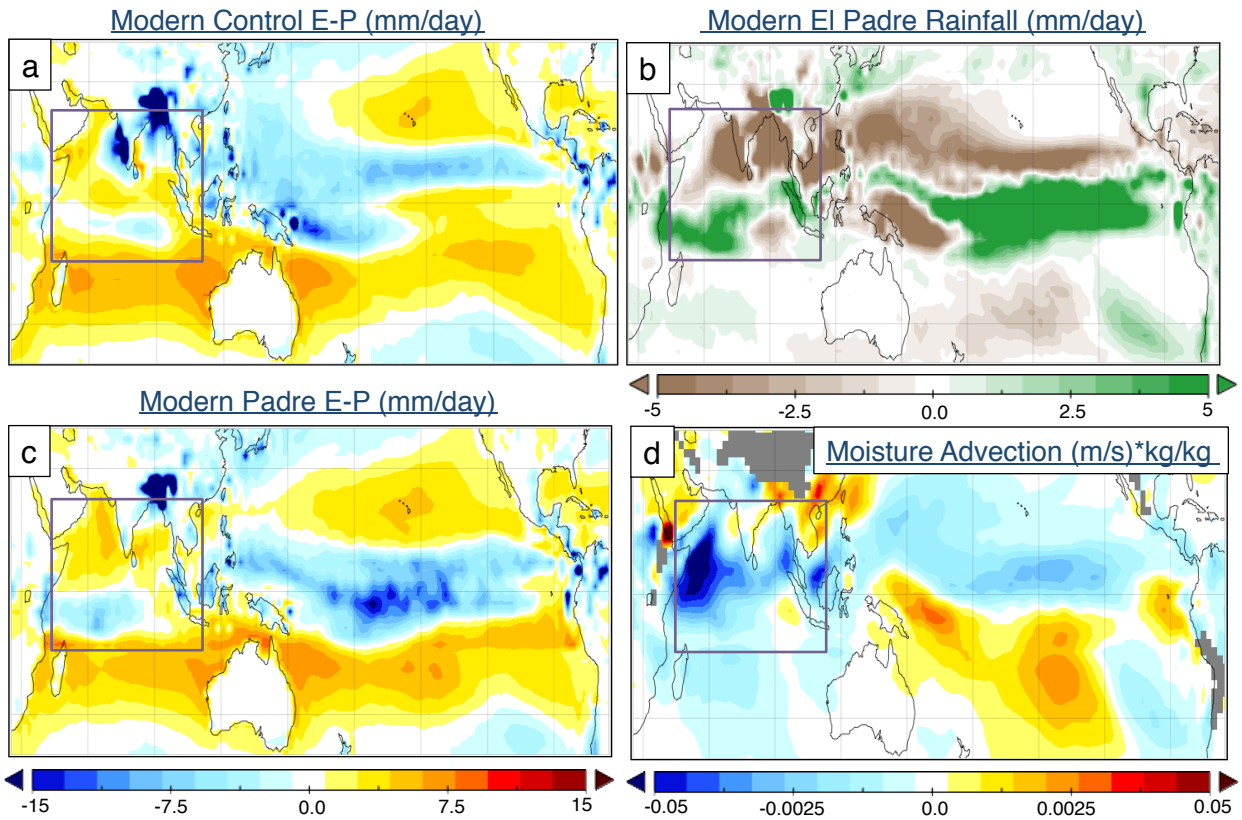
IV Preliminary Results: Modern El Padre



IV Preliminary Results: Modern El Padre



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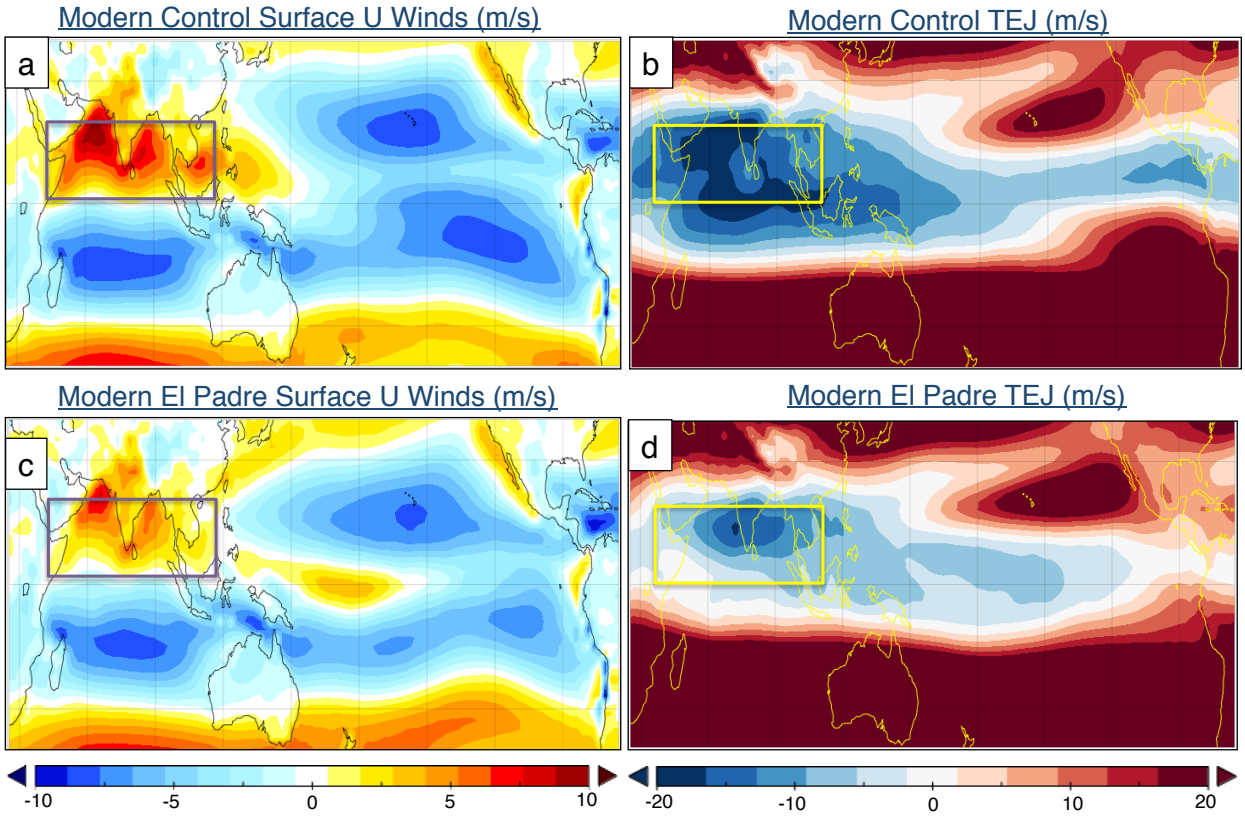


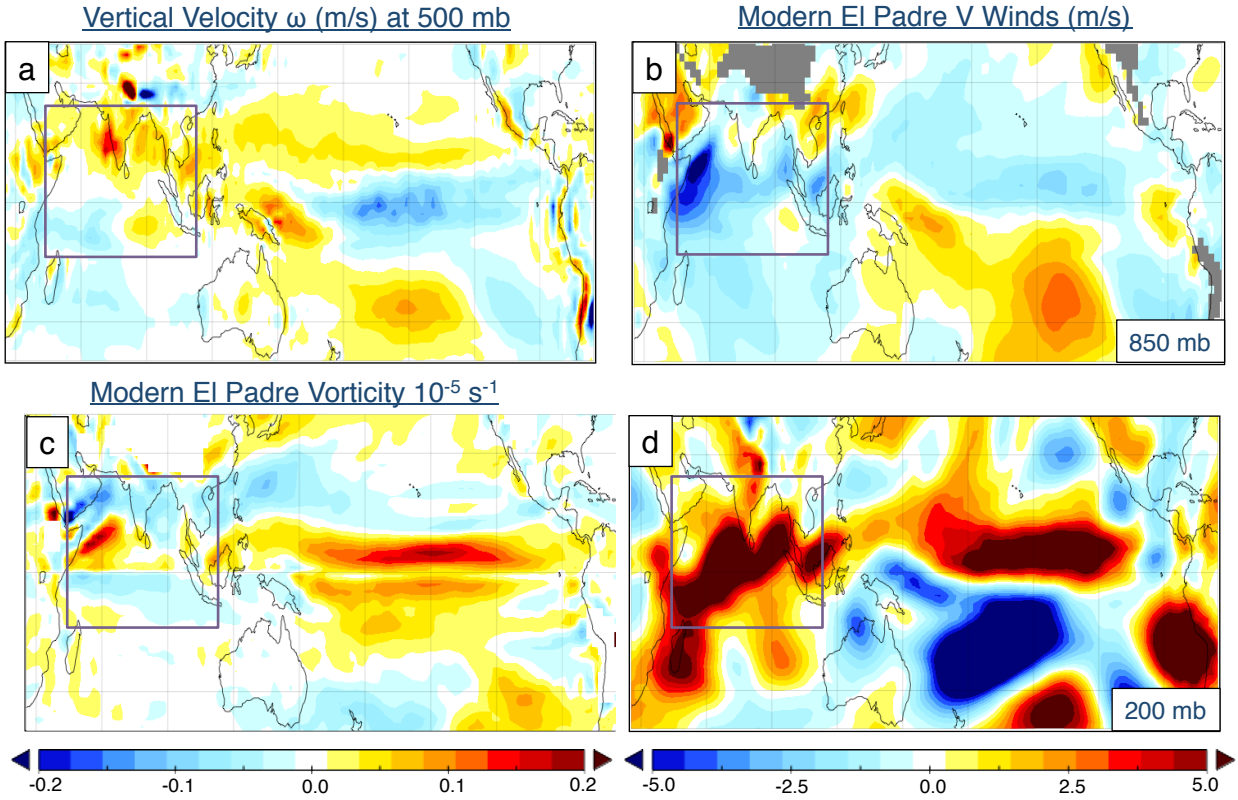
IV Preliminary Results: Modern El Padre

Modern El Padre MI Index = 10.6 m/s

↓

48% of Modern Control MI Index

Preliminary Results: Modern El Padre



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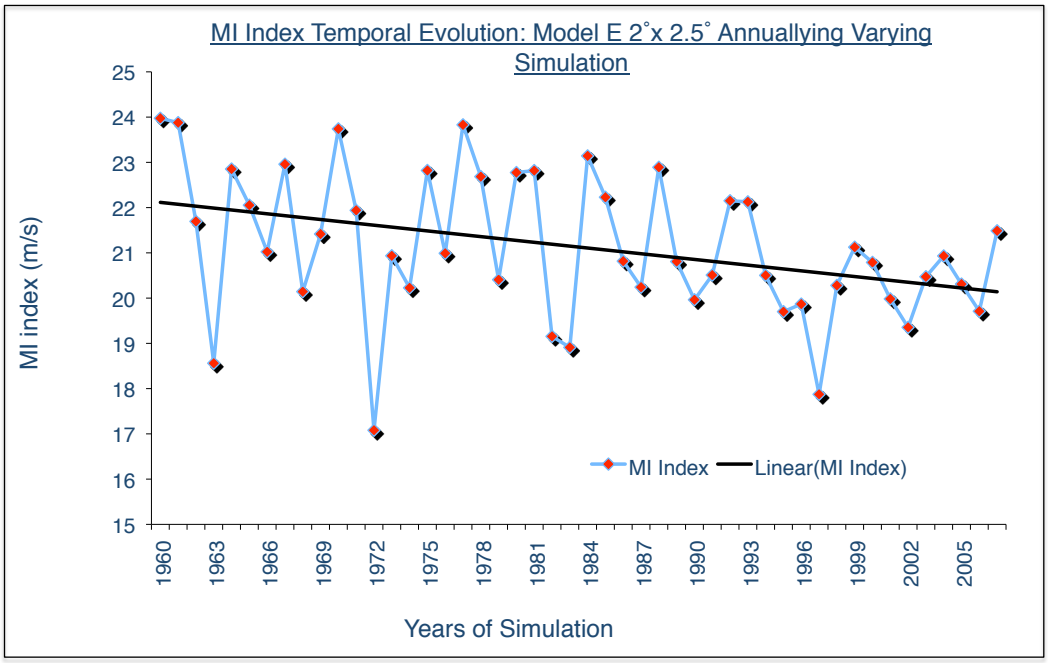
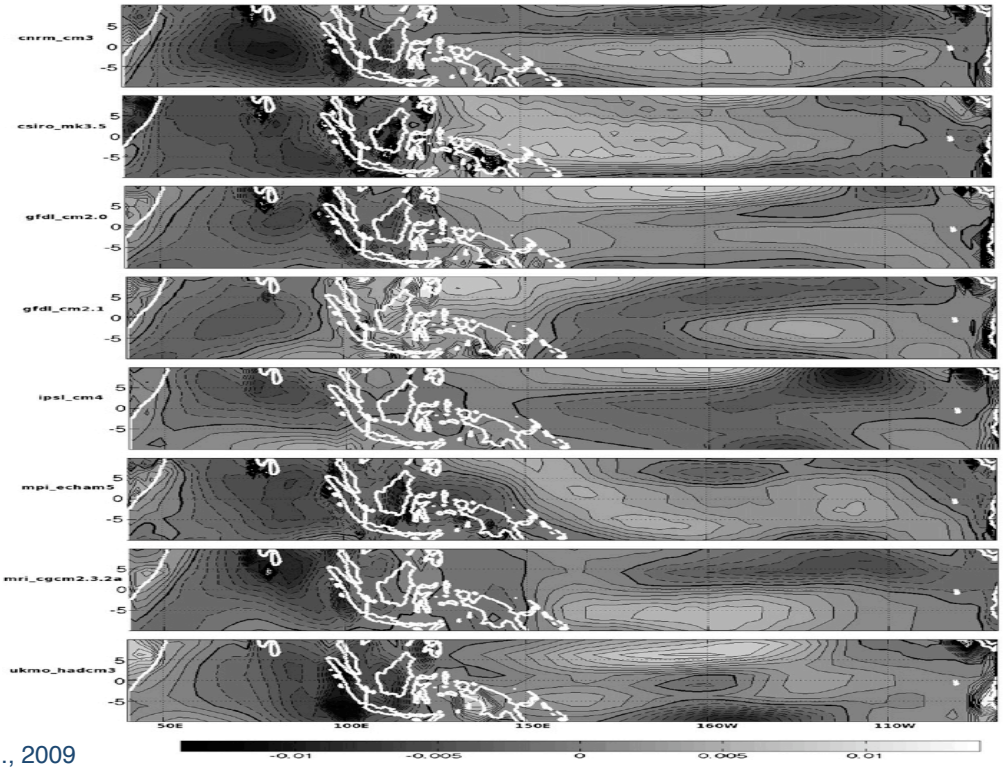
Chapter	Timeframe	Description
Chapter 1	Shukla et al., 2009 *Paleoceanography*	Impact of a Permanent El Niño (El Padre) and Indian Ocean Dipole in Warm Pliocene Climates
Chapter 2	Shukla et al., submitted 2010 *Climate Dynamics*	Teleconnections in a Warmer Climates: Perspective from the Pliocene
Chapter 3	Summer/Fall/Winter 2010 Finish Simulations and Carry on Analysis	The Impact of Altered SST Gradients on General Indian Ocean Atmospheric Circulation
Chapter 4	Winter 2010, Spring/ Summer 2011 Finish Coupled Model	GISS Intermodel Comparison of Simulating the IO regional circulation

IV Preliminary Results and Implications



Indian Ocean Research and Outstanding Questions

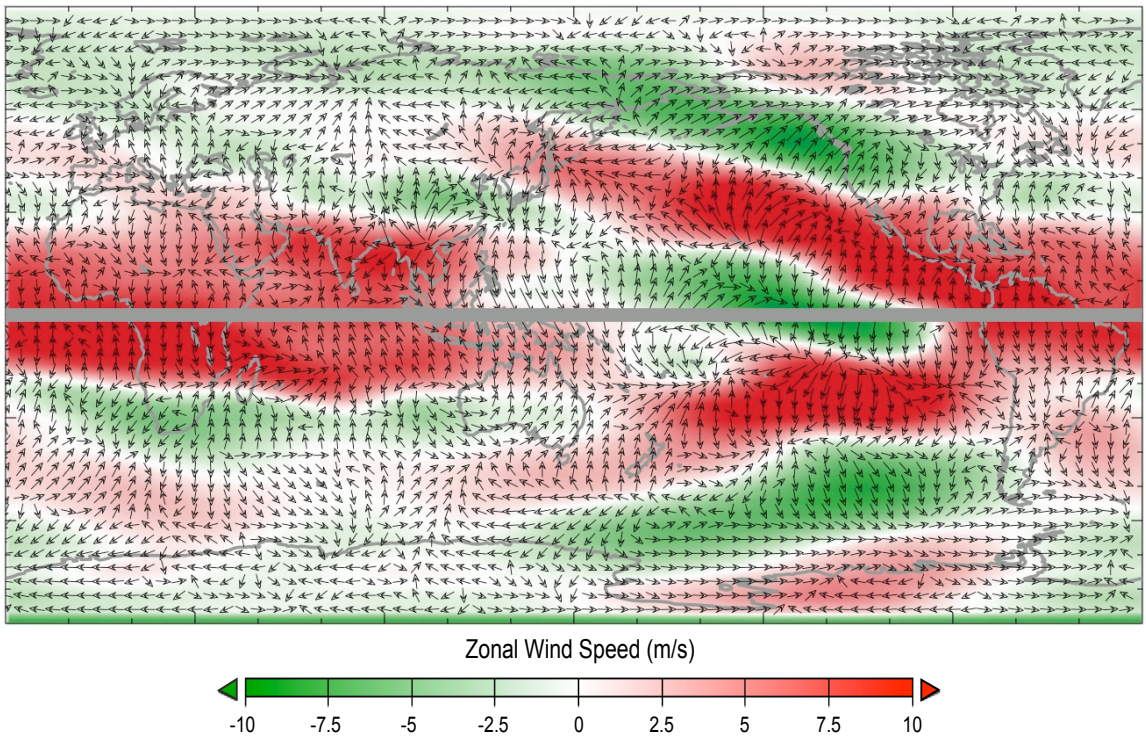
Indian Ocean Warming Trends and Future Projections



Ihara et al., 2009

Perspective from the Warm Pliocene

Modern El Padre – Modern Control Wave Activity Flux (10^{-4} m^2/s^2)



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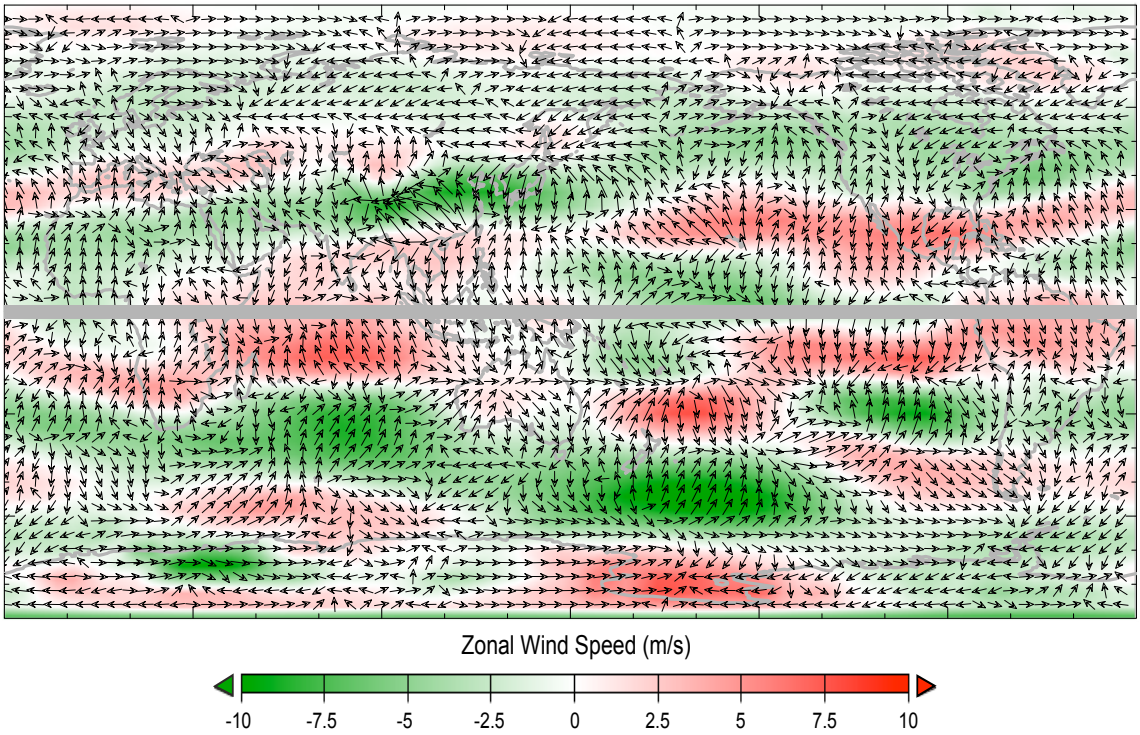
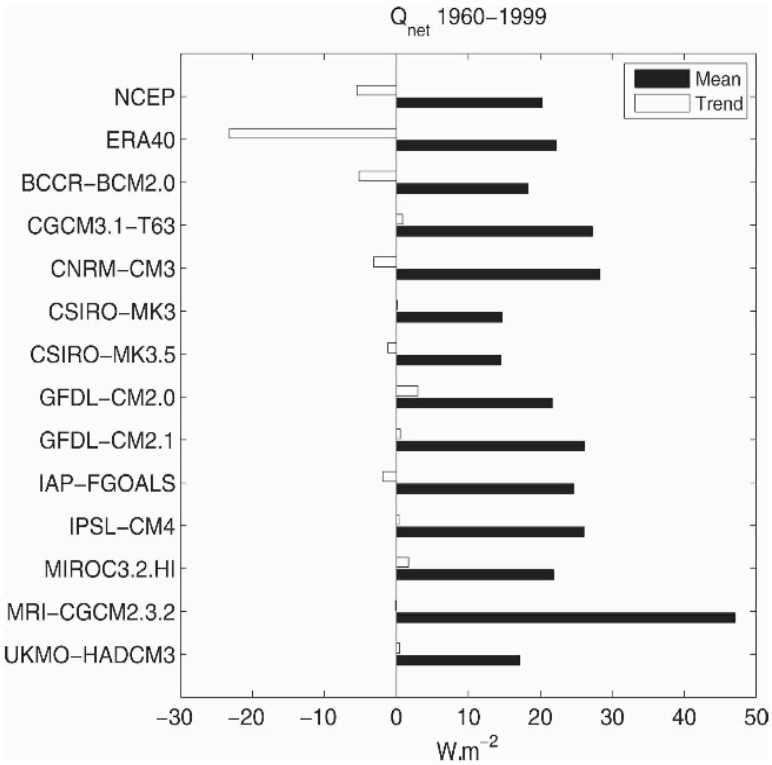


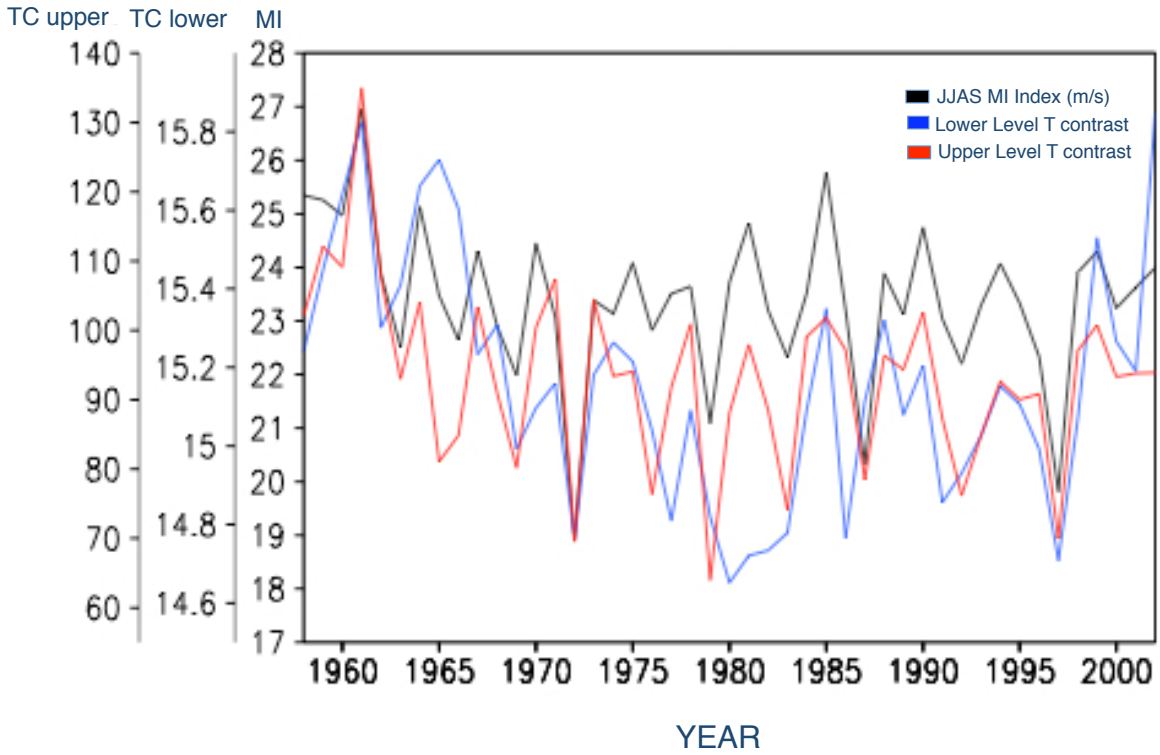
Ib Indian Ocean Warming Trends

Net Downward Heat Flux averaged from 9˚S to 6˚N



Alory and Meyers, 2009

Ib Indian Ocean Warming Trends and Future Projections



Sun et al., 2010