What can we do with a hierarchy of coupled models? Example of South Atlantic coupled variability

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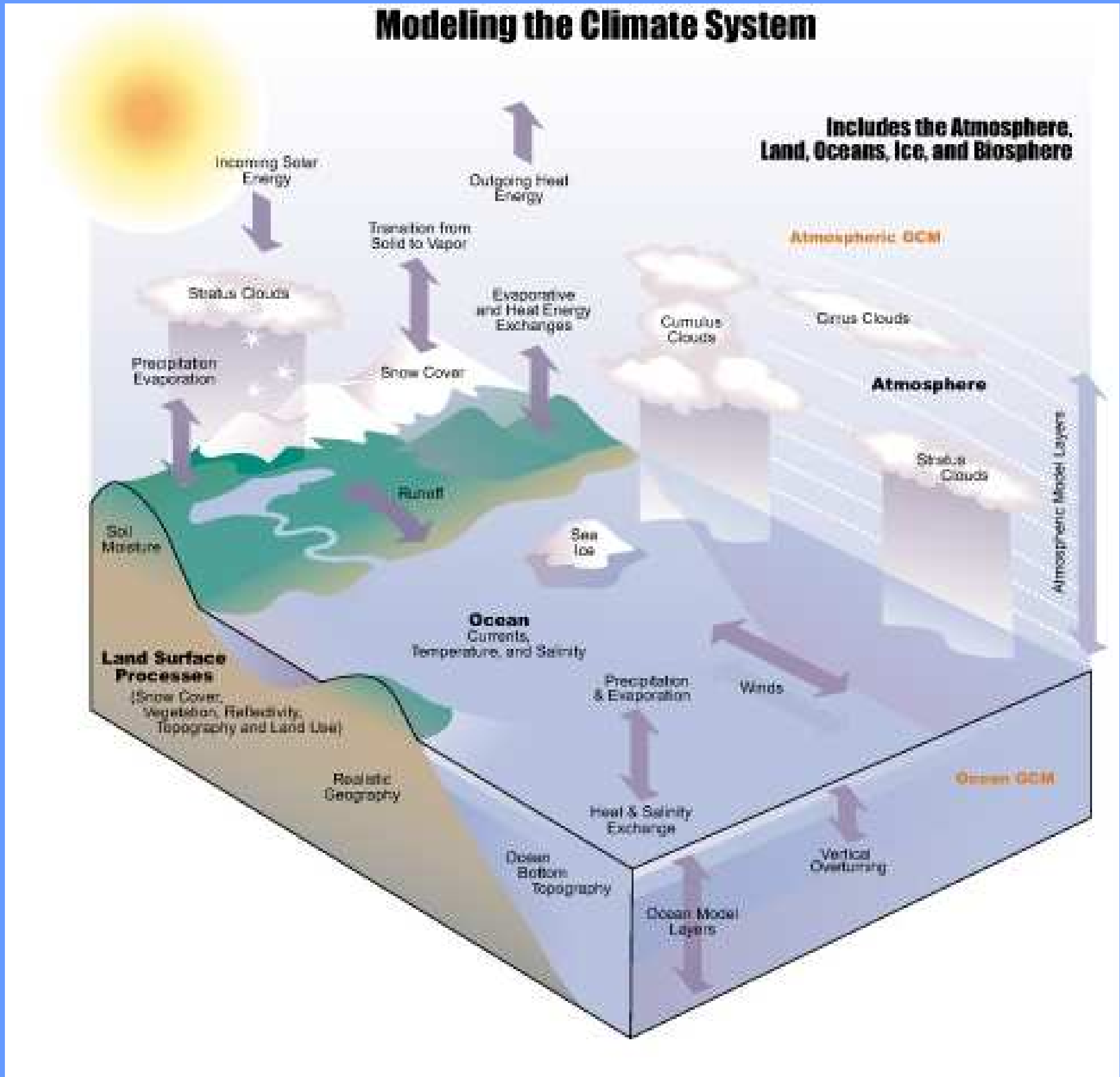
Modeling the Climate System
Includes the Atmosphere, Land, Oceans, Ice, and Biosphere
Incoming Solar Energy
Outgoing Heat Energy
Transition from Solid to Vapor
Evaporative and Heat Energy Exchanges
Atmospheric GCM
Stratus Clouds
Cumulus Clouds
Cirrus Clouds
Precipitation Evaporation
Snow Cover
Atmosphere
Stratus Clouds
Atmospheric Model Layers
Runoff
Soil Moisture
Sea Ice
Ocean
Currents, Temperature, and Salinity
Land Surface Processes
(Snow Cover, Vegetation, Reflectivity, Topography and Land Use)
Precipitation & Evaporation
Winds
Realistic Geography
Heat & Salinity Exchange
Ocean GCM
Ocean Bottom Topography
Vertical Overturning
Ocean Model Layers

Why use numerical models in climate research?

•Quantitative tests hypotheses on climate variability

•Prediction and projections of climate

Typically one wants to:

•Perform long or many runs (ensembles) for stable results

•Resolve as much processes as possible

•Explore parameter space

•Experiment on “what if” scenario’s

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Dimension		Ocean			
		0	1	2	3
Atmosphere	0	global EBM *Saltzman Models* pulse response models	global mixing models geochemical box models advection-diffusion models, ***HILDA***	thermohaline models (lat/z): wind-driven circulation models (lat/long) deep ocean models (lat/long)	OGCM
	1	EBM (lat) radiative-convective models (z)	–	ocean (lat/z) + EBM (lat) ***BERN2.5D***	–
	2	EBM (lat/long)	statistical dynamical atmosphere + diffusive ocean, ***MIT 2D***	ocean (lat/z) + statistical dynamical atmosphere (lat/long), ***CLIMBER2*** ocean (lat/z) + stat. dyn. atm. (lat/z), ***MOBIDIC***	OCGM + EBM (lat/long) ***UVIC*** OCGM + QG atm. ***ECBILT***
	3	AGCM + SST	ACGM + mixed layer	ACGM + slab ocean	**A/OGCM**

Knutti and Stocker 2003

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SPEEDO (SPEEDy-Ocean)

LBM LAND

LAND

SPEEDY

ATMOSPHERE

ICE

FOCEAN SEA

PRESCRIBED OCEAN

SLAB

THERMODYNAMIC OCEAN

G-MODEL MICOM

DYNAMIC OCEAN

SPEEDY (Molteni 2003):

Primitive equation atmosphere

T30 horizontal resolution

7 layers

simplified physics

Land Bucket Model:

grid point temperature, soil moisture
soil ice, snow, run off.

Slab Ocean Model:
passive slab, + anomalous Ekman currents, + anomalous wind mixing, + anomalous barotropic flow

G-MODEL: linear 1.5 layer shallow water model for tropical Pacific

MICOM:
isopycnic (constant density) coordinate primitive equation ocean model (Bleck et al. 1992)

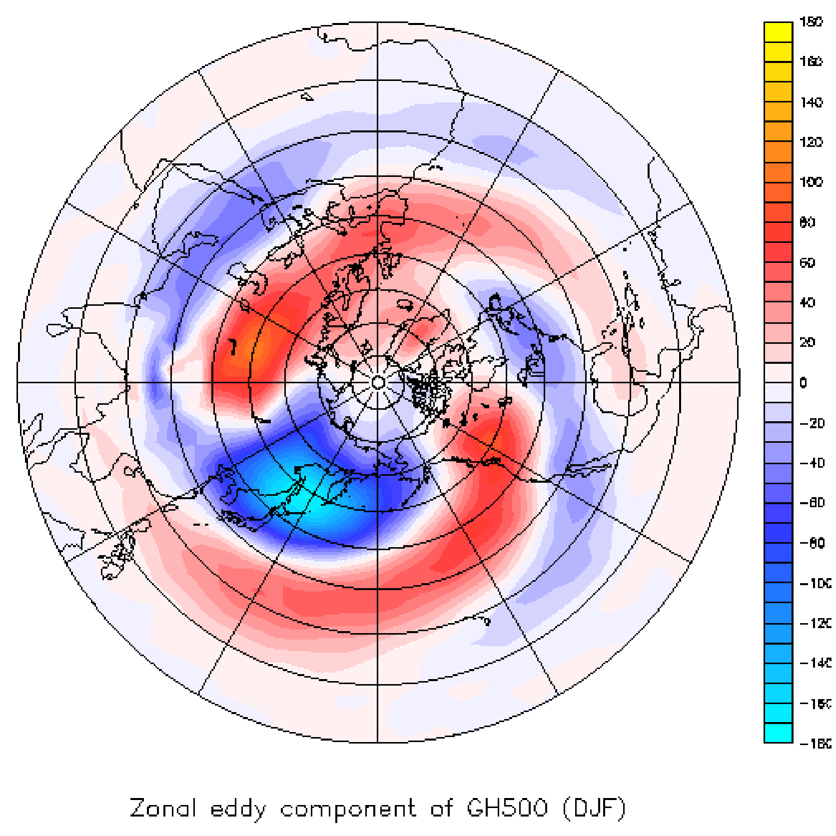
1 degree horizontal resolutiton

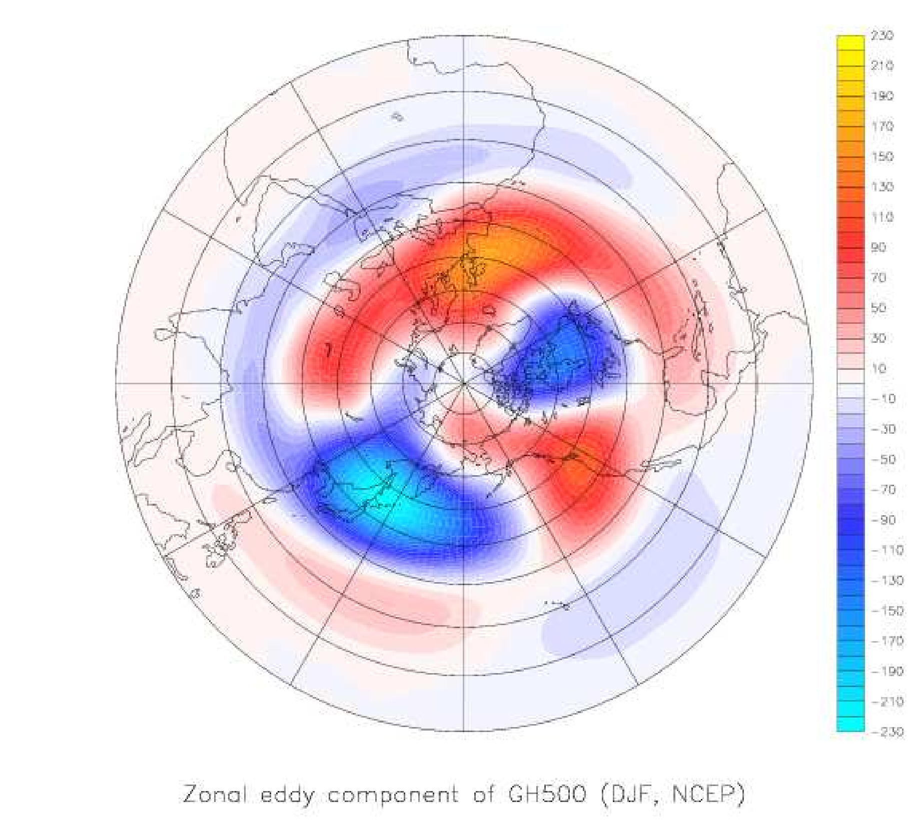
20 layers

IN ANY COMBINATION FOR DIFFERENT BASINS.

Hindcast with Speedy-LBM-SST (NCEP/Re, 1960-1991)

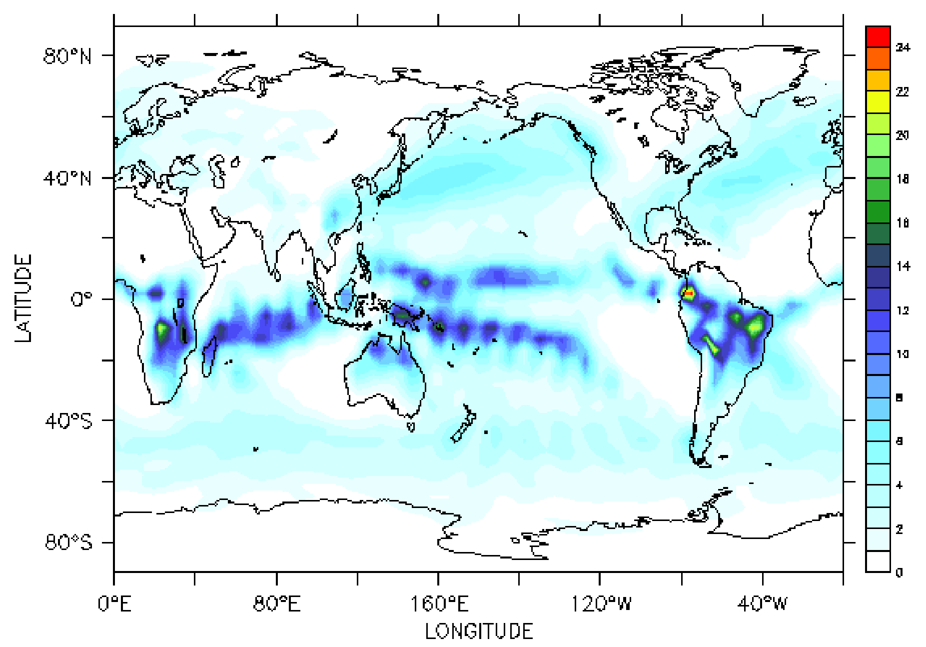
Stationary eddies at 500 hPa



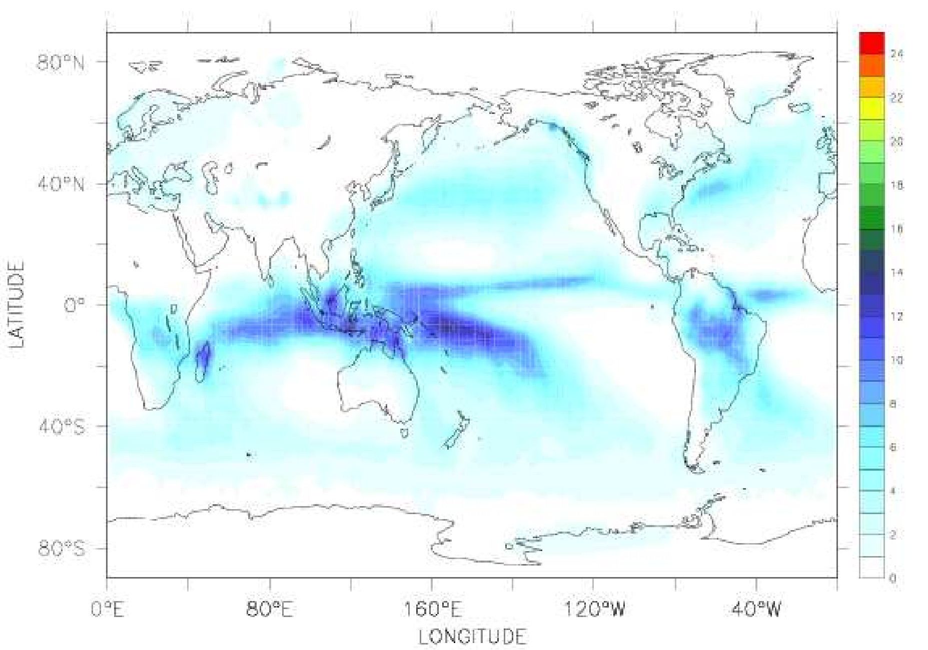


Hindcast with Speedy-LBM-SST (NCEP/Re, 1960-1991)

Annual mean precipitation



Precipitation (DJF)



Precipitation (DJF, CMAP)

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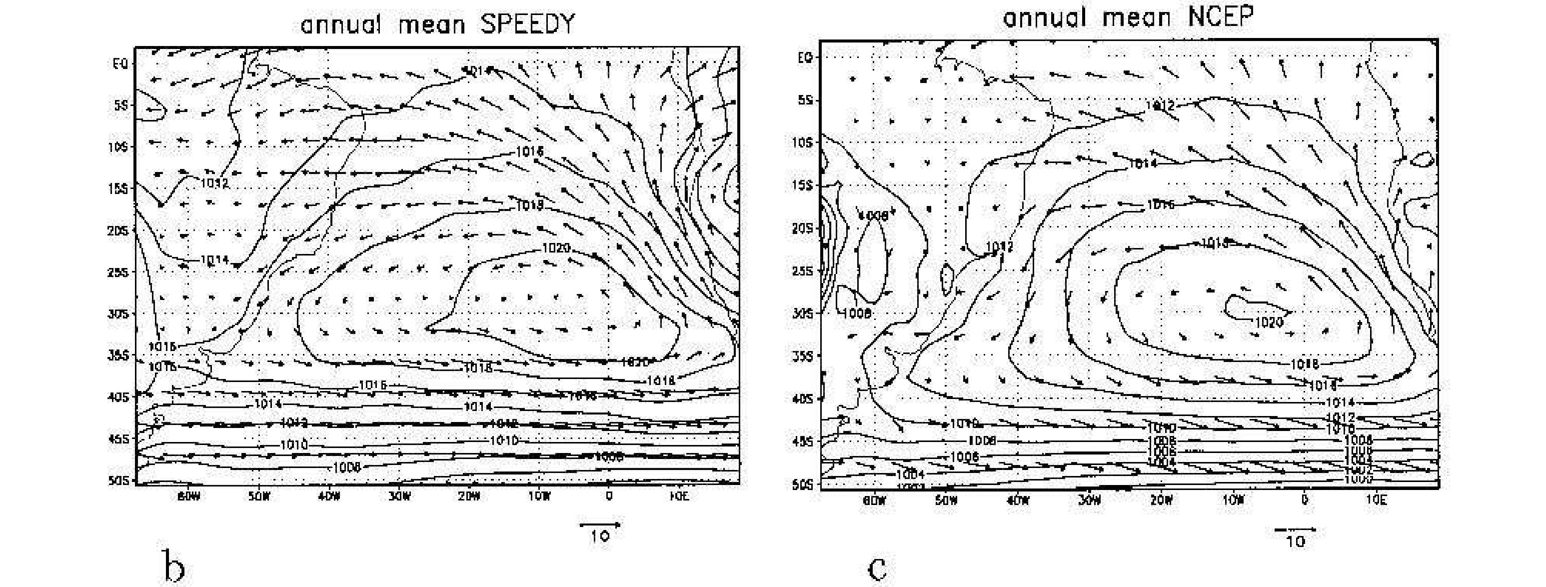
SPEEDO MEAN STATE NEAR SURFACE ATMOSPHERE



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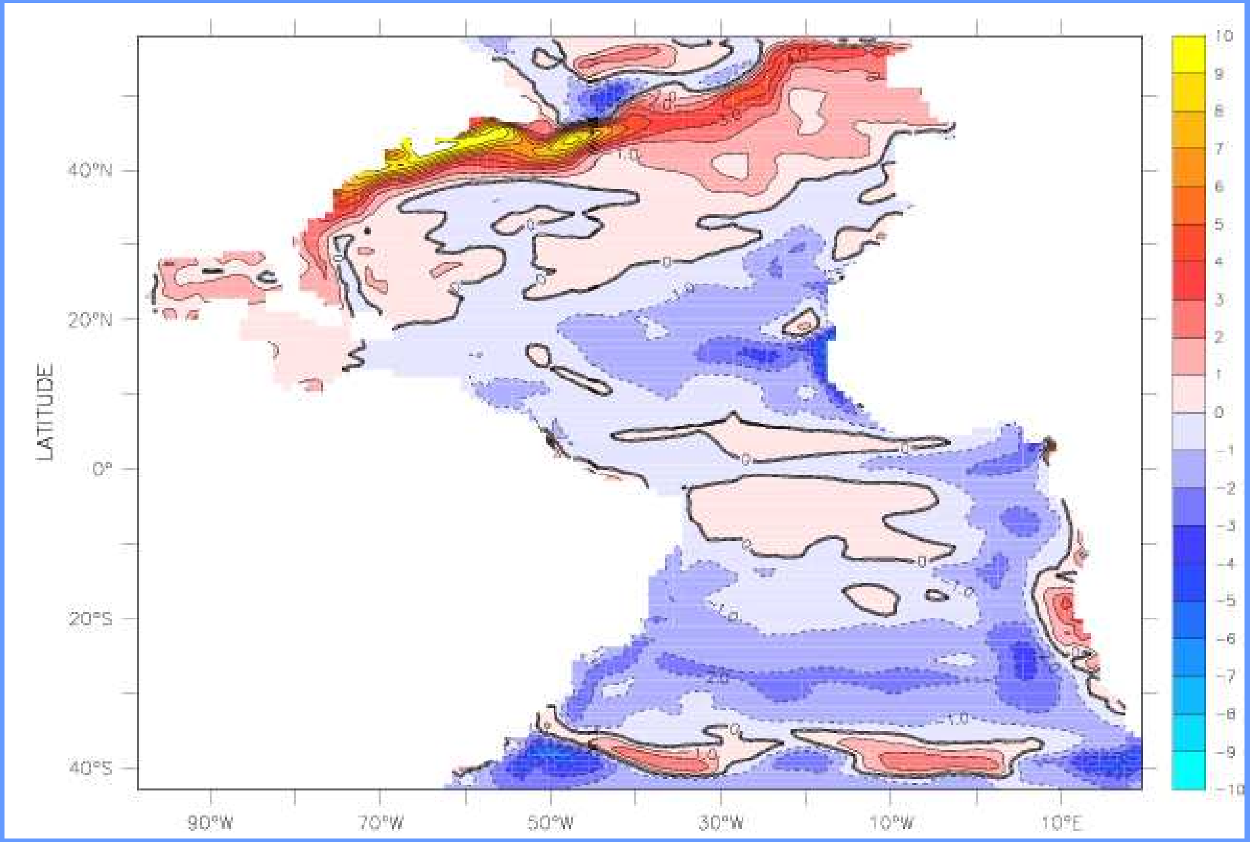
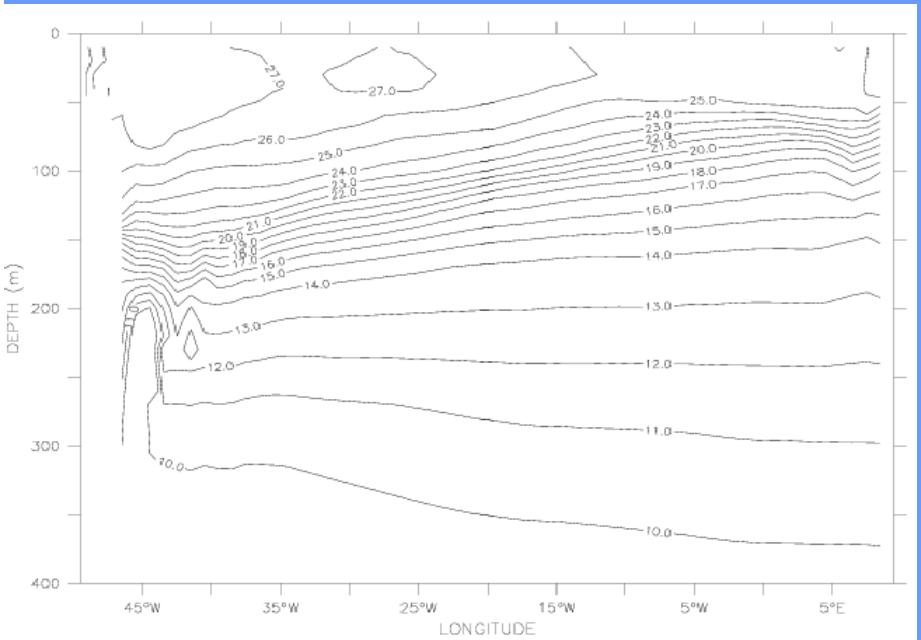
COUPLED SPEEDY-LBM-MICOM/ATLANTIC (rest prescribed SST climatology): SST error

1 degree MICOM, 20 layers
Note: wrong Gulf Stream separation (common for coarse res. ocean models)
Very good tropical Atlantic (very uncommon for coupled models)

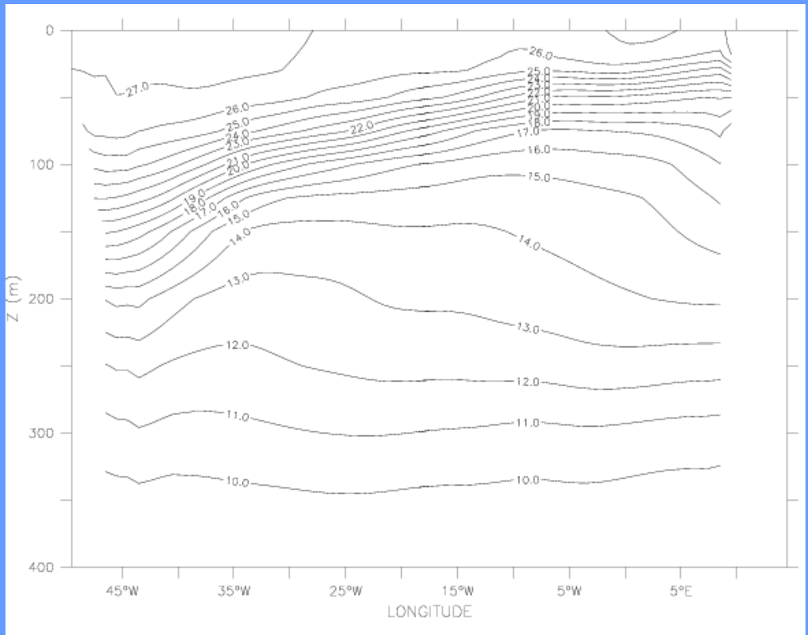


Results of coupled SPEEDY-LBM-MICOM/ATLANTIC (rest prescribed SST climatology): Thermocline in Tropical Atlantic

1 degree MICOM, 20 layers



Levitus 1998



EXAMPLE OF USE OF SPEEDO

MECHANISMS OF DOMINANT MODES OF VARIABILITY IN THE SOUTH ATLANTIC

Sterl and Hazeleger 2003, Clim Dyn
Haarsma, Campos, Hazeleger, Piola, Severijns, Molteni, JClim, 2004

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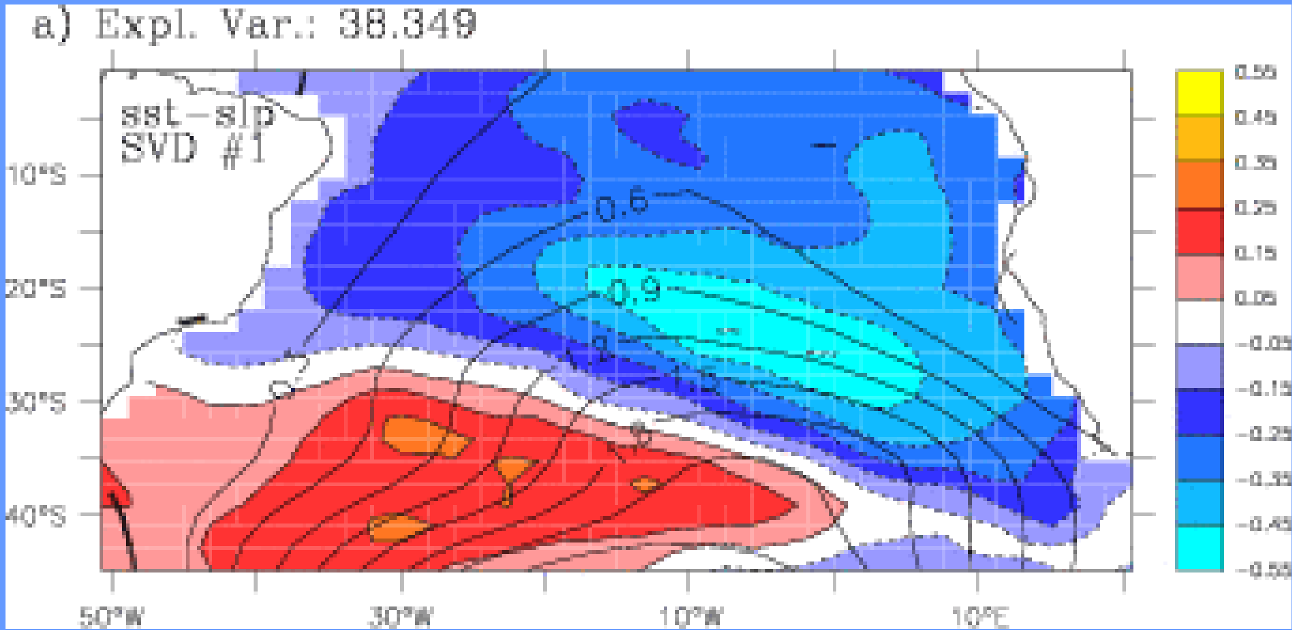
Dominant mode of South Atlantic coupled variability

(sea surface temperature and sea level pressure)



(Sterl and Hazeleger, 2003, from NCEP/REANALYSIS)

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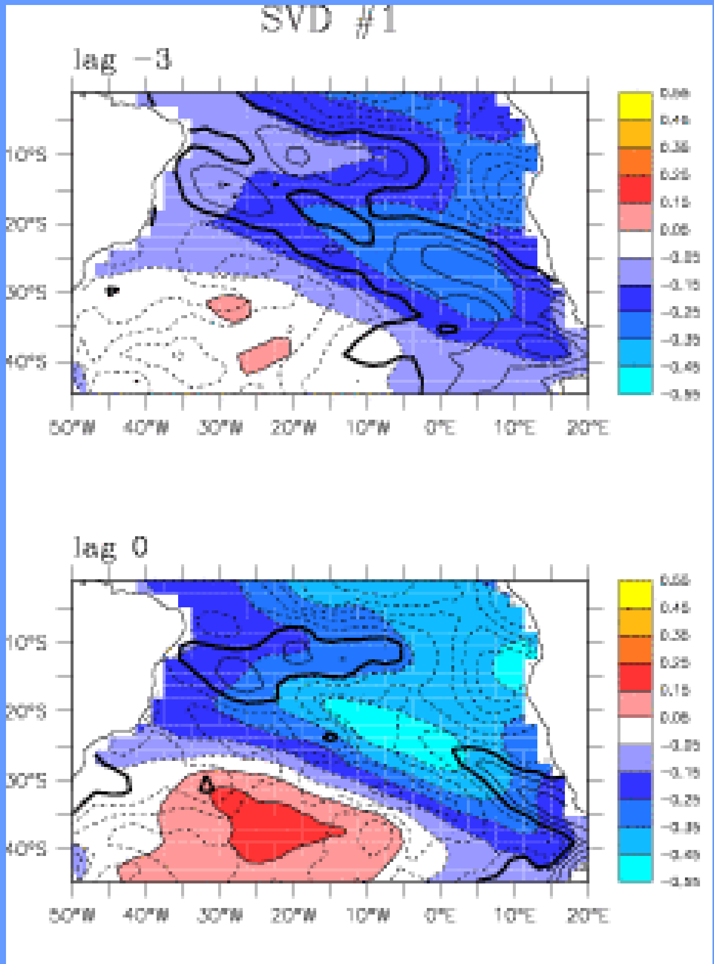
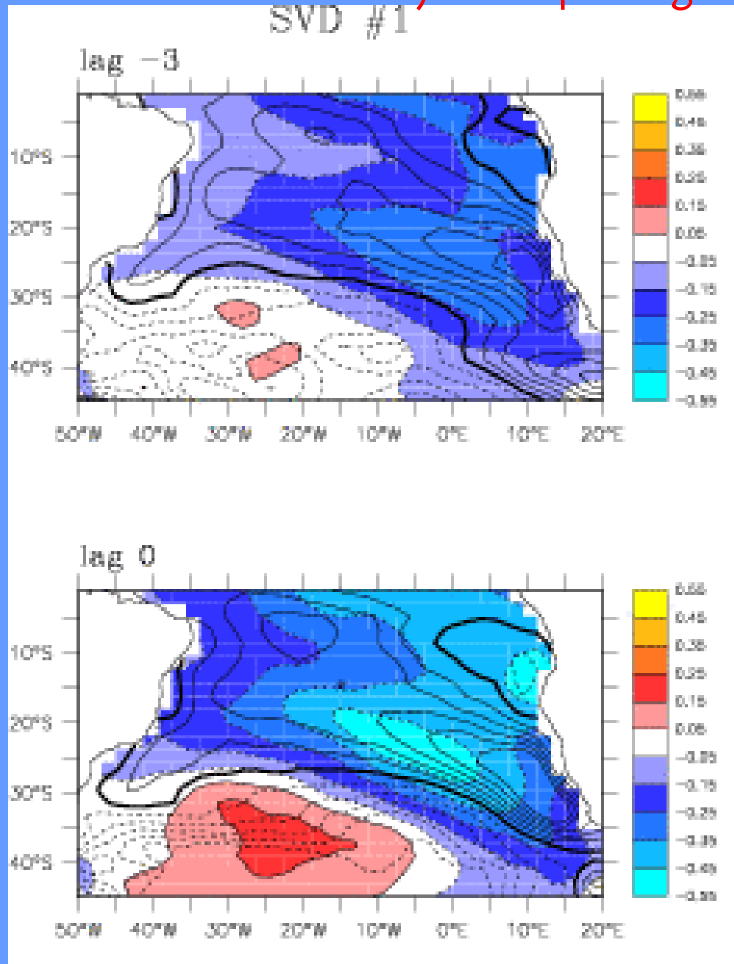
Dominant forcing mechanisms for SST variability
(Lagged regressions on SVDs of SST)

Latent heat flux



wind-induced mixed layer deepening



Estimates from NCEP/Reanalysis

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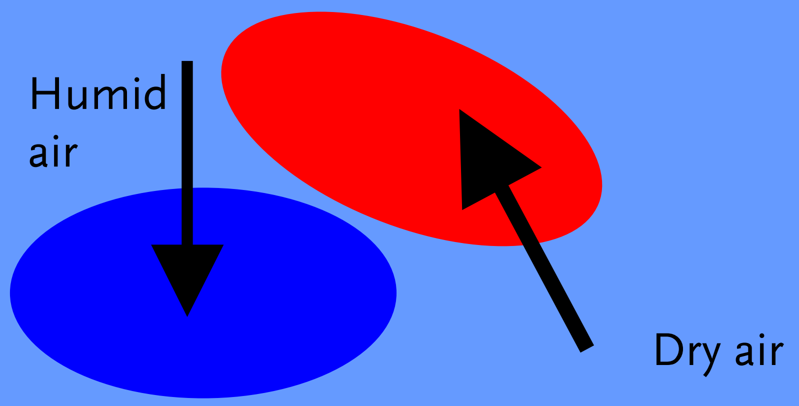
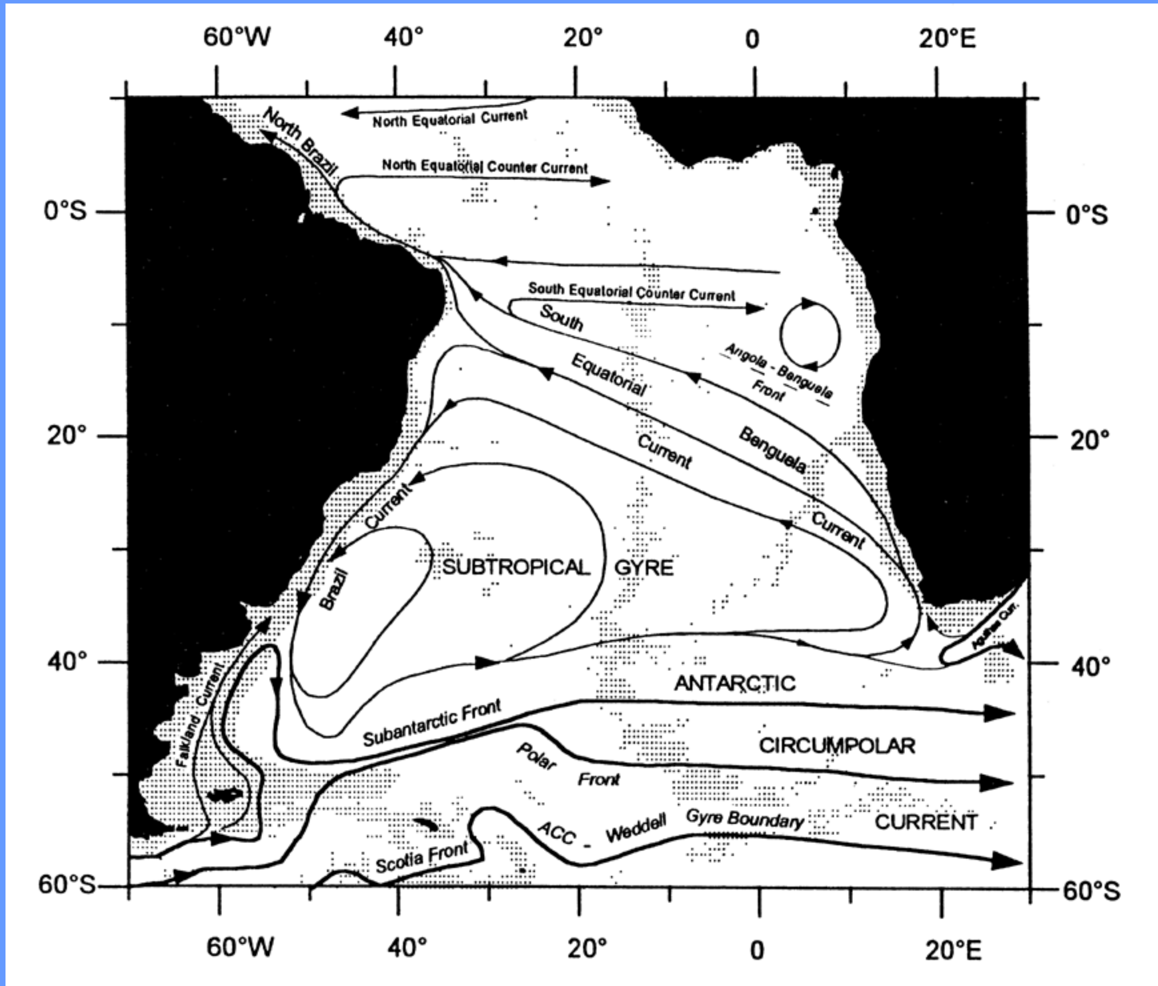
Dominant forcing mechanisms for SST variability

U' q forces anomaly: anomalous advection of dry air from the south generates northeastern pole through changes in evaporation. Anomalous advection of humid air from the north generates southwestern pole (+wind speed helps)



Once established, **U q'** damps the anomaly (higher SST enhances evaporation -> cools the anomaly and vice versa

What is the role of ocean dynamics?



Peterson and Stramma 1995

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TO STUDY ROLE OF OCEANIC PROCESSES:
USE HIERARCHY OF OCEAN MODELS COUPLED TO SPEEDY

SLAB MIXED LAYER

SLAB + ANOMALOUS EKMAN TRANSPORTS

SLAB + ANOMALOUS WIND-INDUCED MIXING

SLAB + ANOMALOUS BAROTROPIC FLOW

OCEAN GENERAL CIRCULATION MODEL: MICOM

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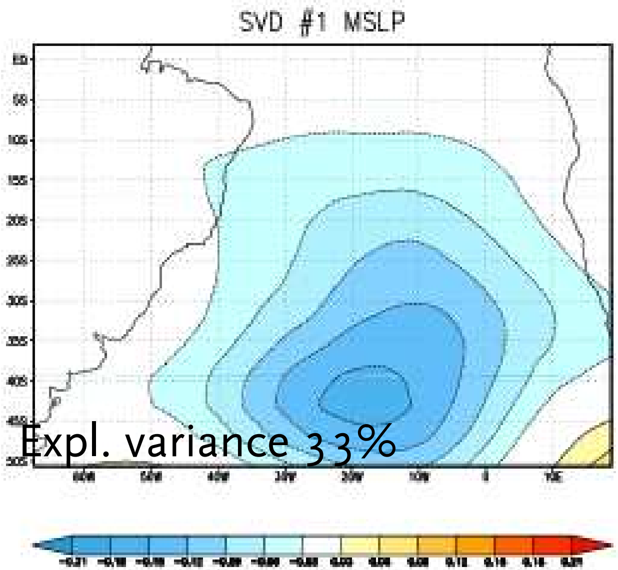
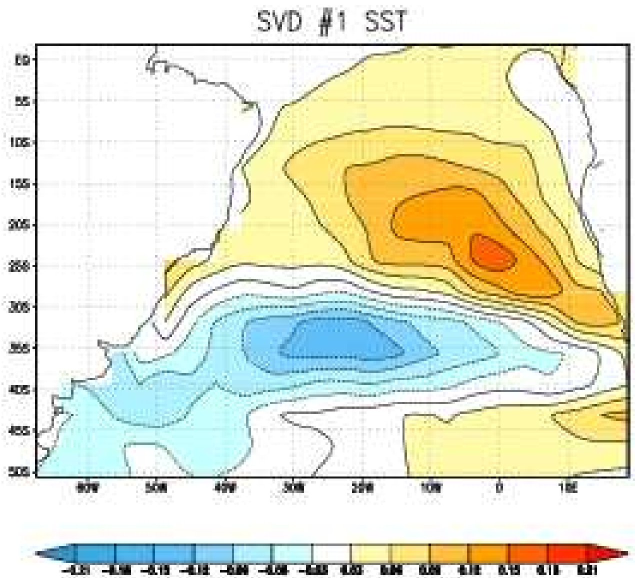
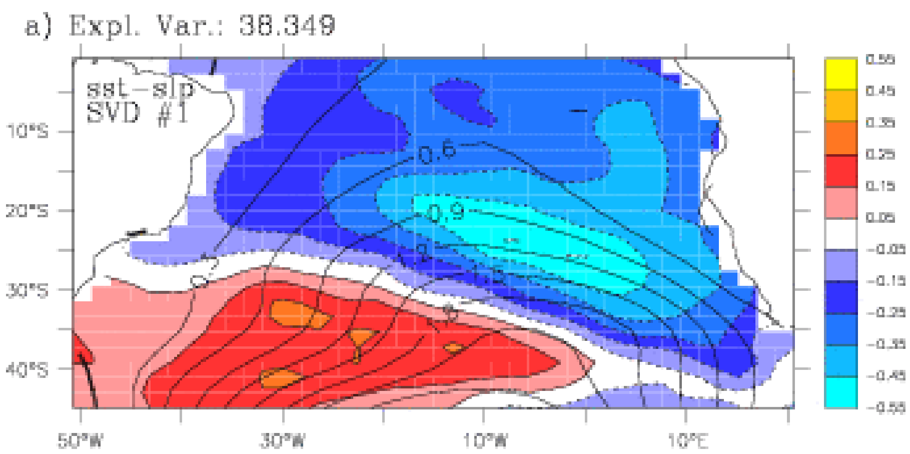
SPEEDO: MICOM-SPEEDY VARIABILITY







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SLAB MIXED LAYER

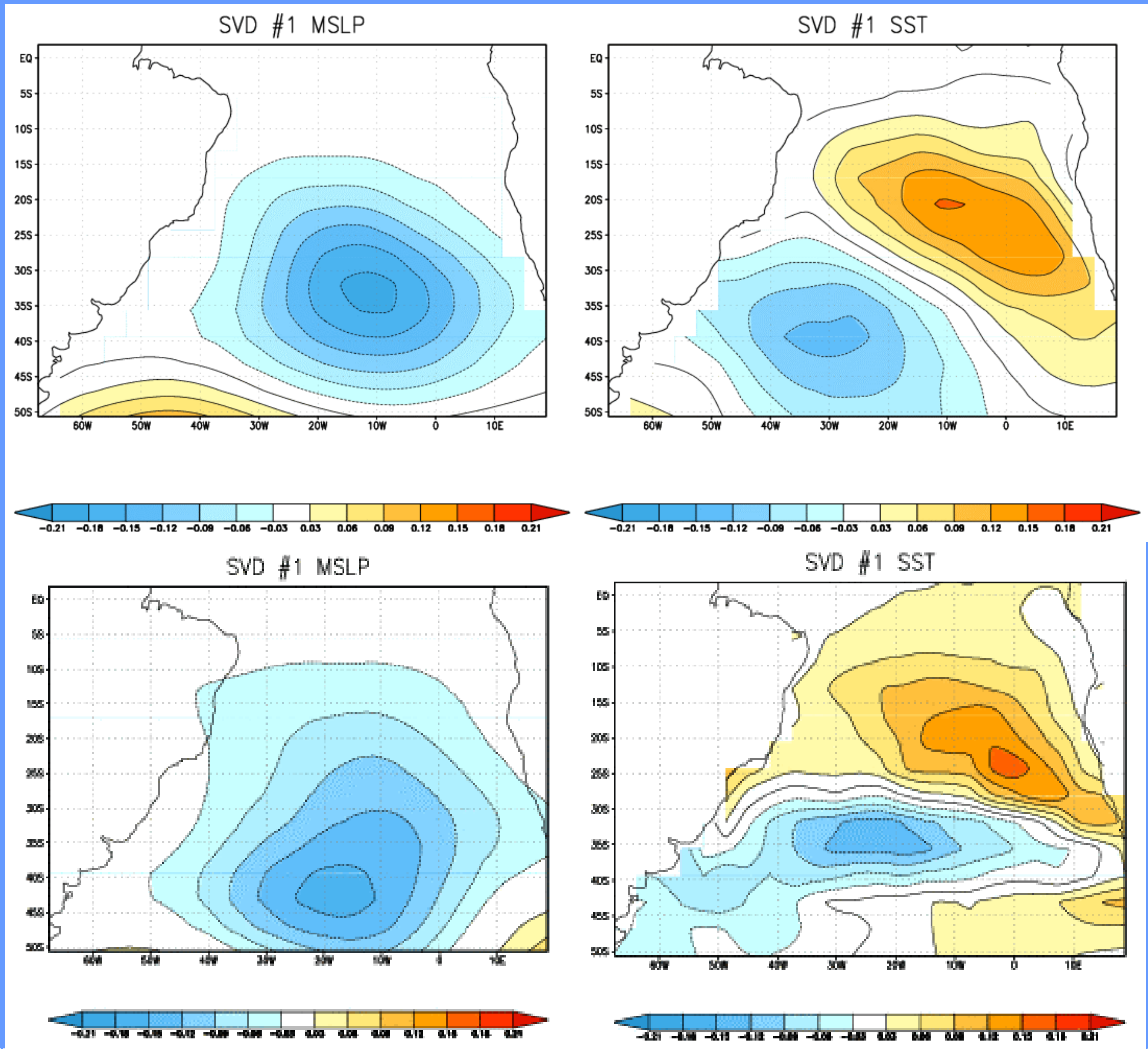
$$\partial T/\partial t = - Q/(h\rho_w c_p) + F$$

Q : surface heat flux

h : mixed layer depth

F: prescribed climatological heat flux from spin up of Speedy (represents oceanic heat transport, 'qflux')

Speedy-SLAB MIXED LAYER



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INCLUDE ANOMALOUS EKMAN TRANSPORT

$\partial T/\partial t = -(U'_e.\nabla T + w'_e\Delta T)/h - Q/(h\rho_w c_p) + F$

$$U_e = (U_e, V_e) = \frac{1}{\rho_w (f^2 + r^2)} (f\tau_y + r\tau_x, -f\tau_x + r\tau_y)$$

$$w_e = \nabla \cdot U_e$$

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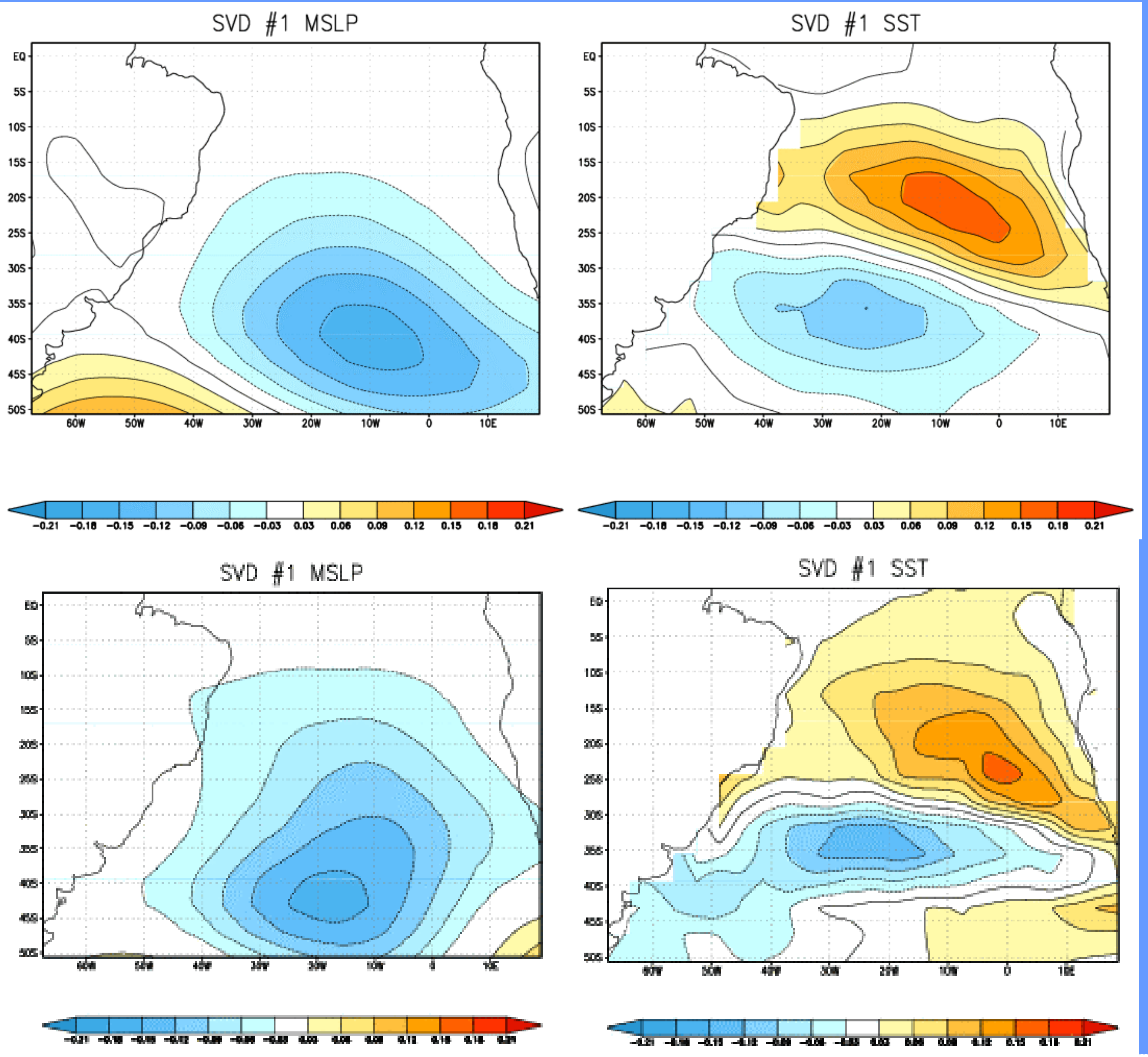
•••• Speedy-SLAB + EKMAN



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INCLUDE ANOMALOUS WIND-INDUCED MIXING

$$\partial T/\partial t = -(U'_e.\nabla T + w'_e \Delta T)/h -$$

$$- (\alpha\, u_*^3)'/h$$

$$Q/(h\rho_w c_p) + F$$

($\alpha = 10\ Ks^2m^{-2}$)

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•••• Speedy-SLAB + EKMAN+MIX

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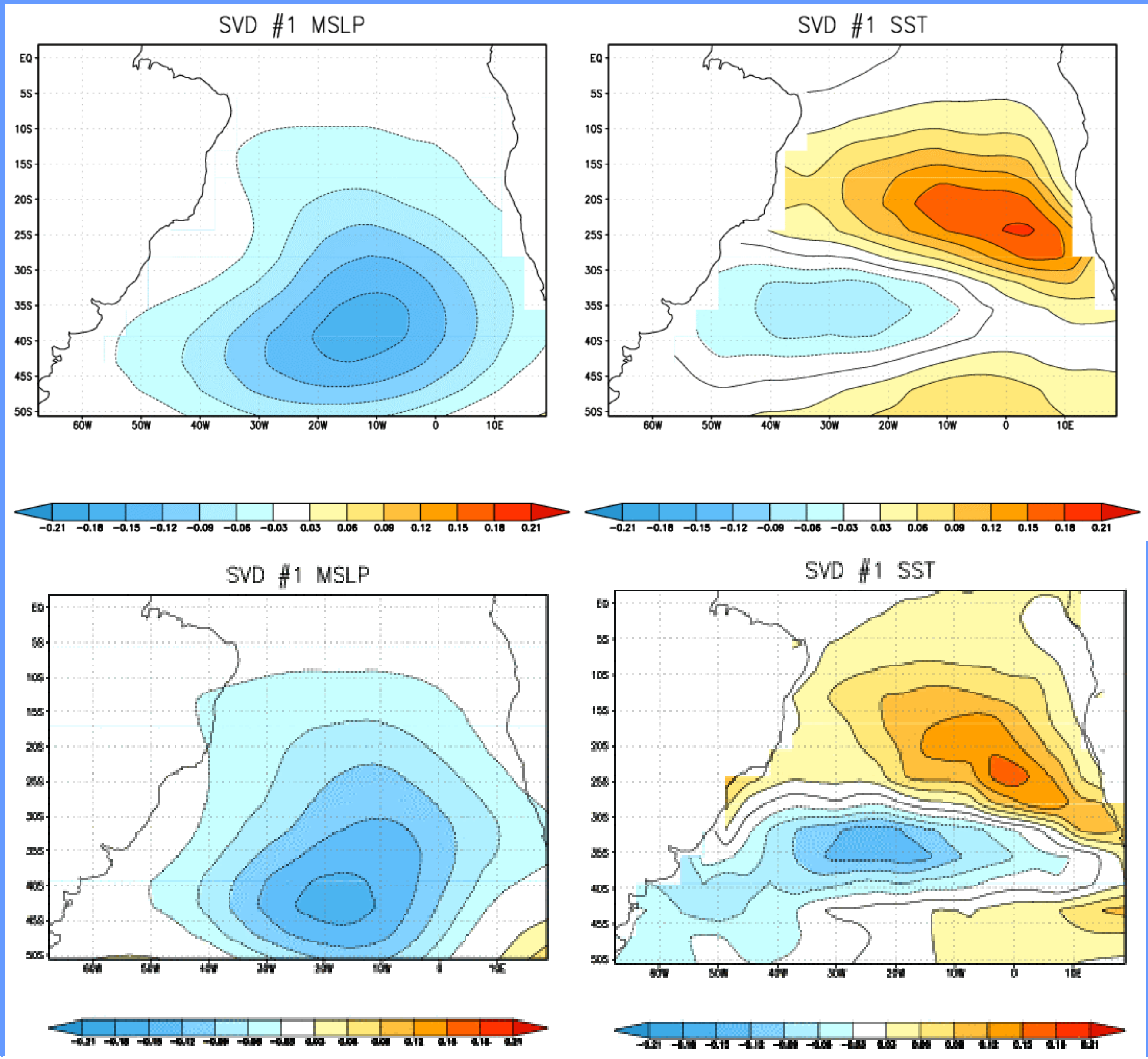

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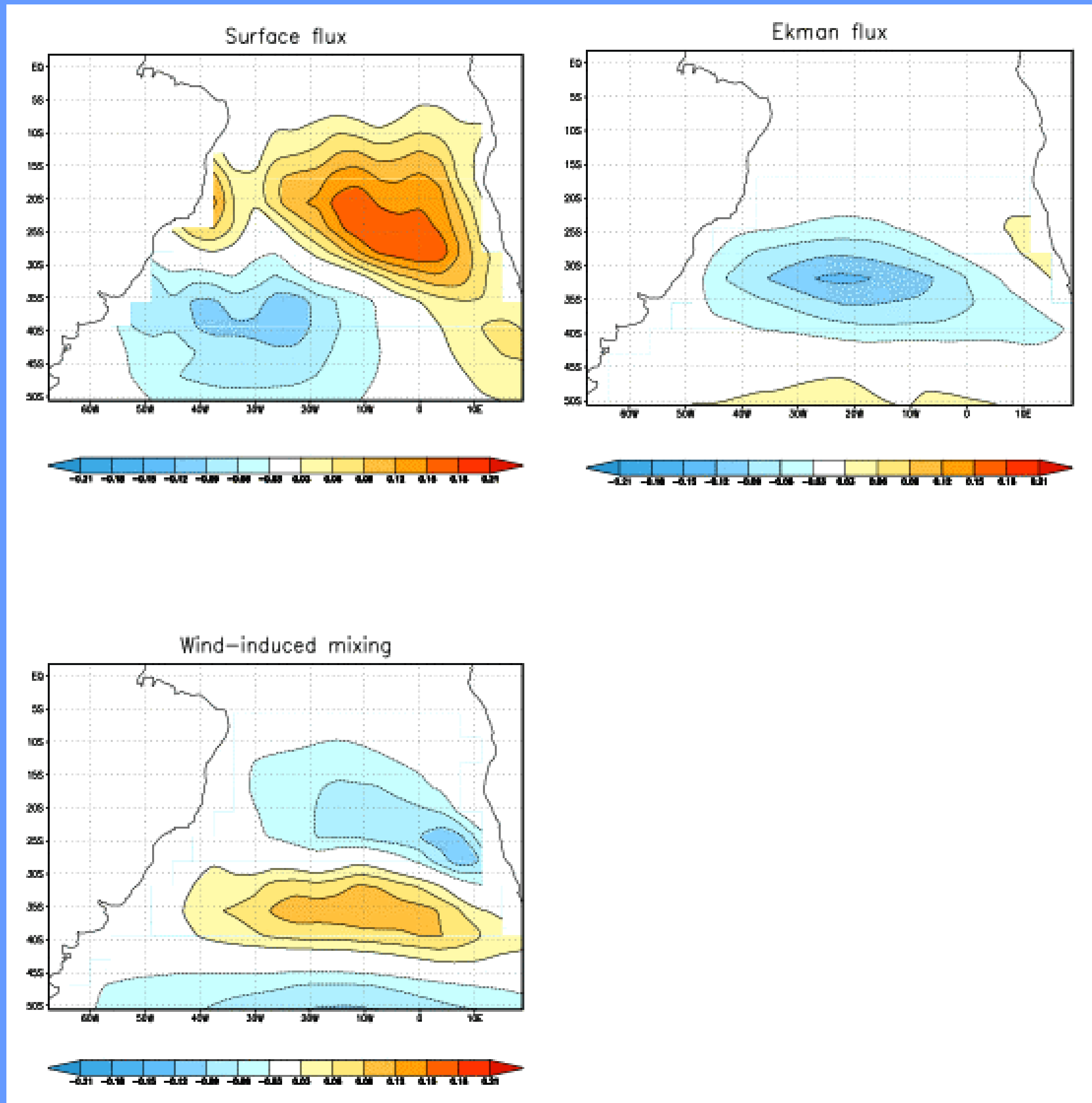
…. REGRESSION ANALYSIS OF SST BUDGET



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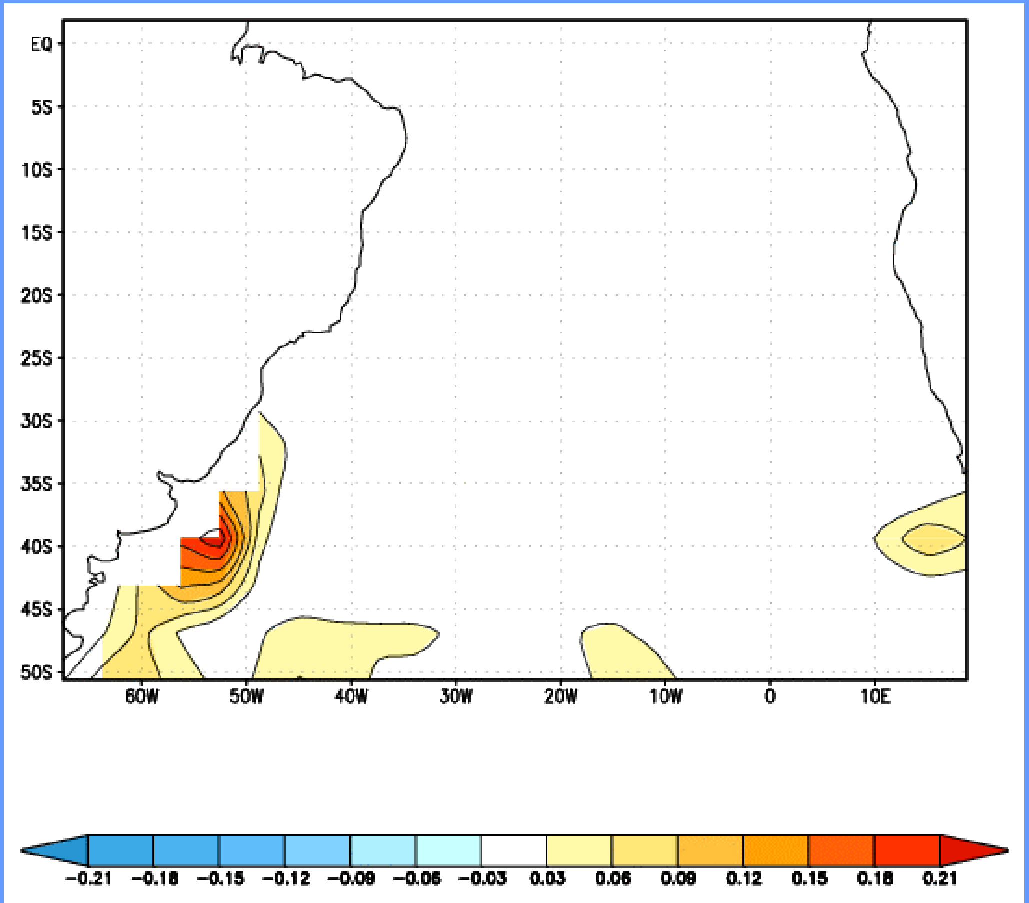
Effect of barotropic velocities on SST (using Sverdrup balance and linear friction)



Time variability
(spectra of principal compoonent of SST SVD)

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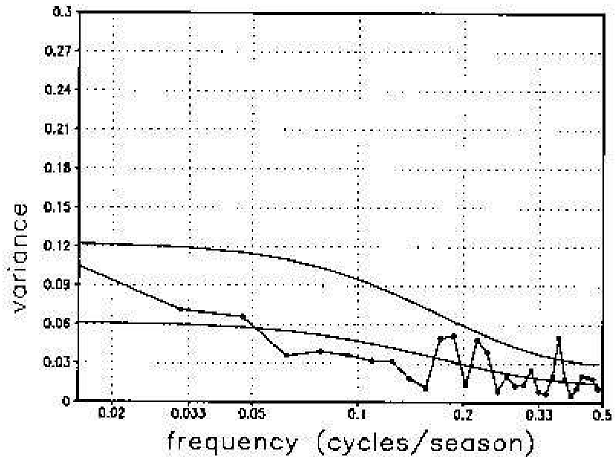
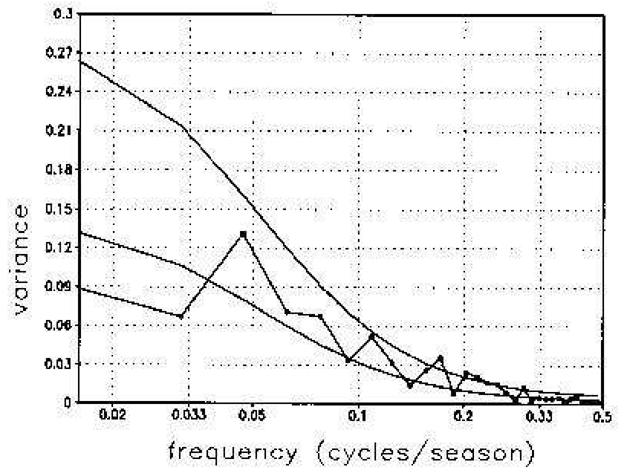


Speedy-MICOM



Speedy-Slab+Ekman+wind mixing

Too strong coupling between surface air temperature and SST in absence of ocean dynamics
-> reddening of spectrum in Speedy-slab

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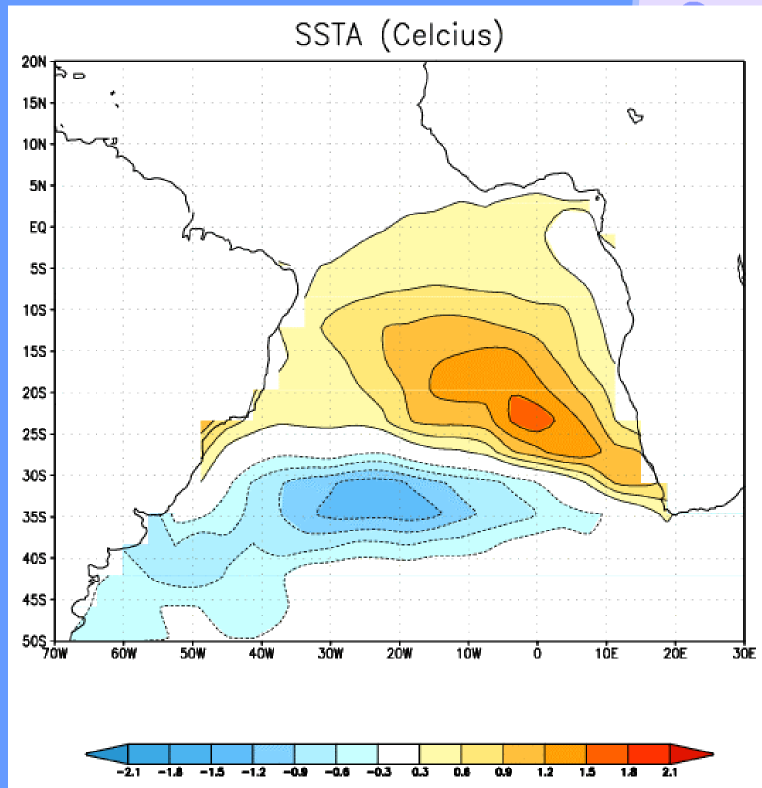
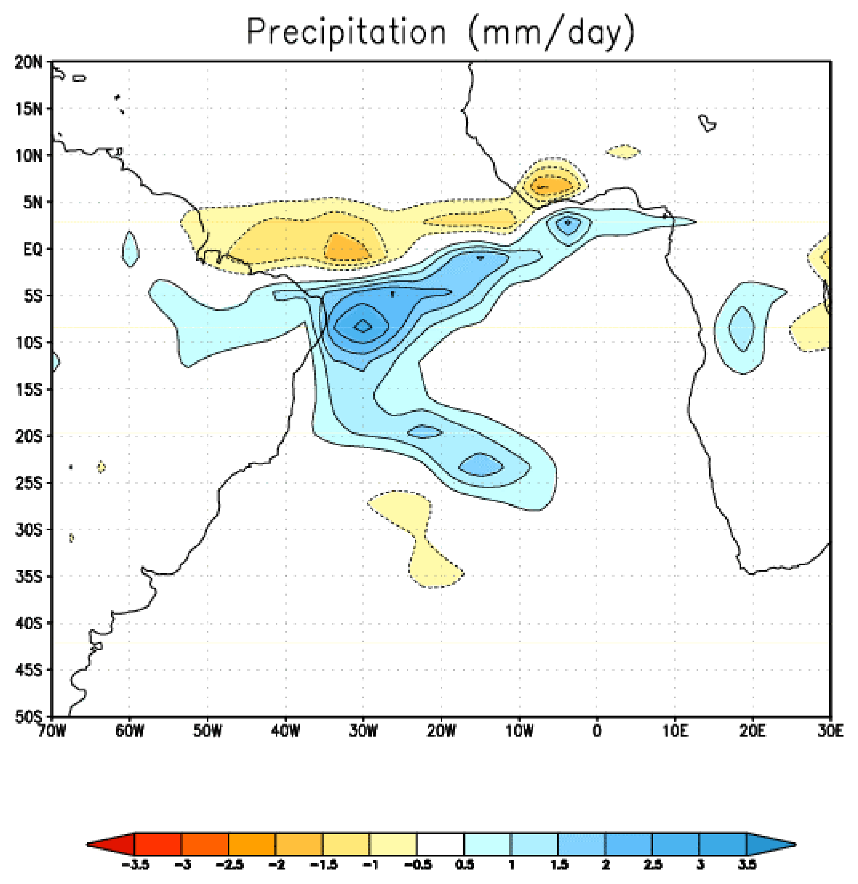
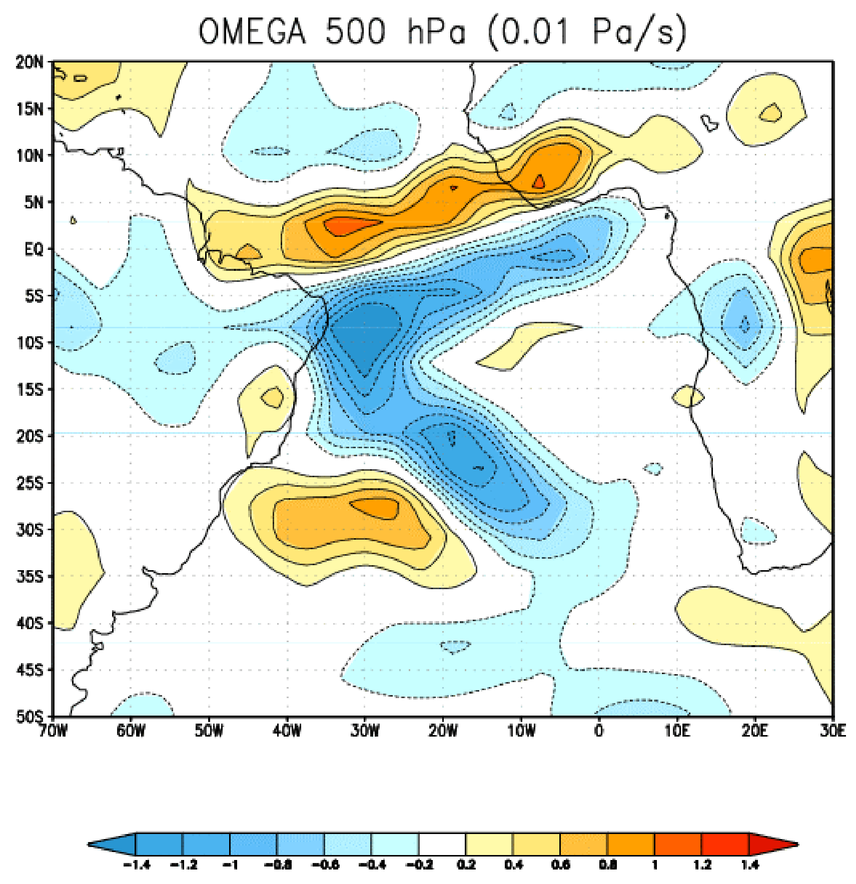
What is the remote effect of the Dipole mode??

Take the Speedy atmosphere model and prescribe climatological SST + anomalous SST pattern associated with dominant South Atlantic SST variability



•••• Shift ITCZ, SACZ





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North Atlantic Response to South Atlantic Variability

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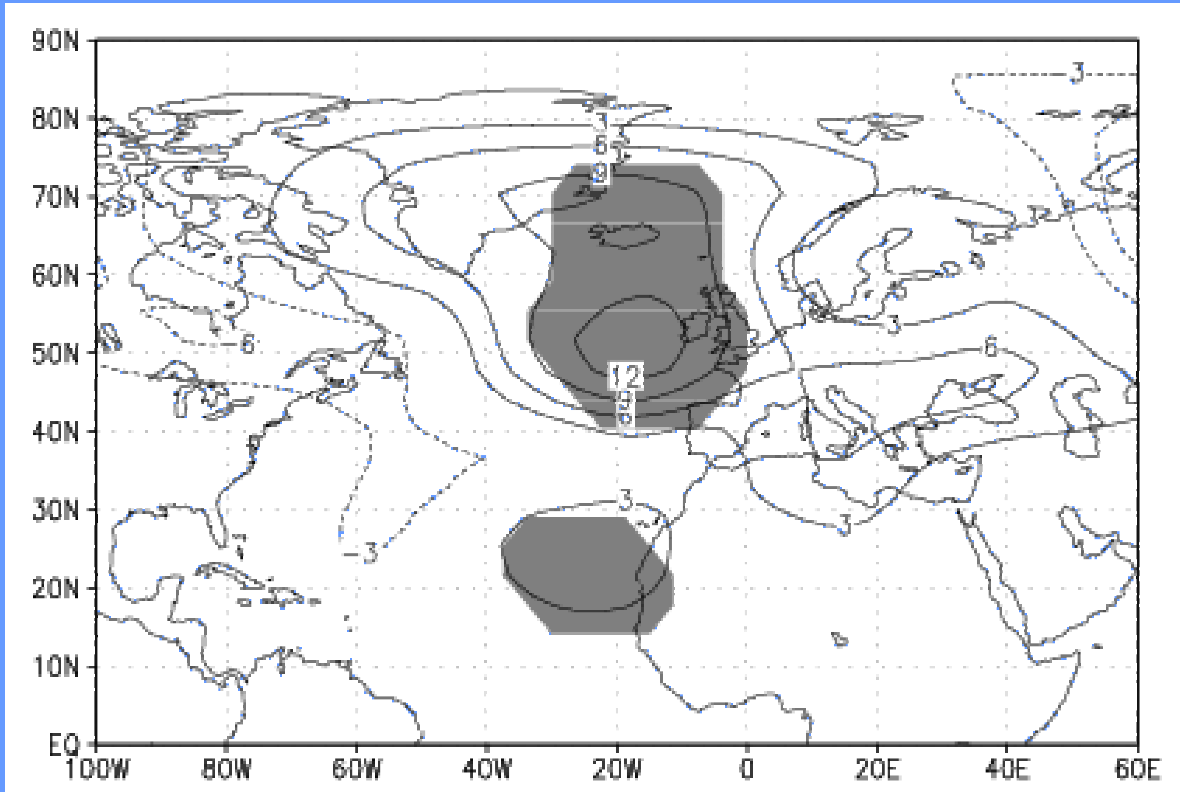

RESPONSE IN VARIABILITY (standard deviations of GH500), NOT IN THE MEAN.

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.... Conclusions

SPEEDO simulates pattern of coupled South Atlantic variability very well

Hierarchy of models is succesfully used to find that:
Latent heat fluxes, Ekman transport and wind mixing contribute to the generation of the pattern. Ocean dynamics are not very important for this mode

South Atlantic SST variability affects tropical circulation and perhaps even more..

No preferred time scale found, while data shows 12-14 yr Variability (comes from Pacific?)

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