Tropical Atlantic simulation in CCSM4: An update

Ernesto Muñoz
New Mexico Consortium at Los Alamos

Semyon Grodsky
University of Maryland at College Park

Wilbert Weijer (LANL) and others

In preparation for CCSM4 Special Issue

Outline

- Motivation and Background
- Diagnostics
- Foci:
  - Intra-Americas Sea and Tropical North Atlantic
  - Tropical South Atlantic and the Benguela region
- Summary

Why the Atlantic?

- Community has made significant improvements in the understanding of model simulations related to the Atlantic Ocean
- Know less compared to the Pacific inter-annual dynamics

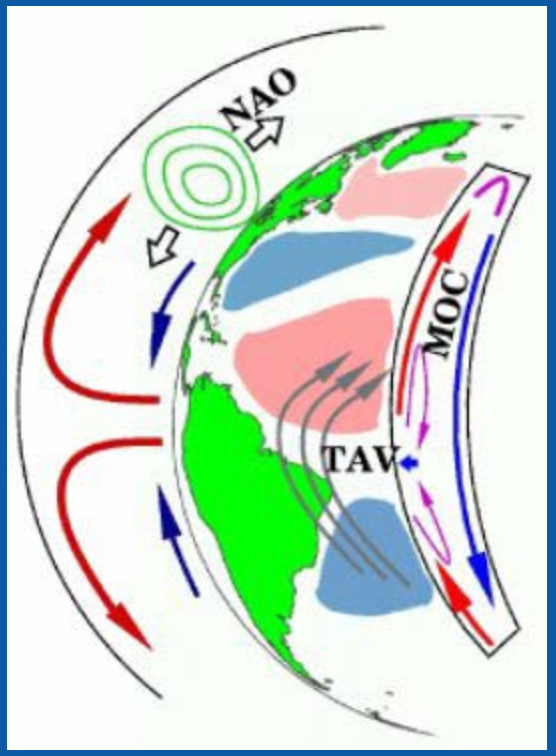
Objective:

- Identify the improvements in simulating the Atlantic mean and variability
- Study processes controlling the upper ocean heat budget from CCSM4

Goal:

- Contribute to the base of knowledge regarding the status of Atlantic simulation

Atlantic CLIVAR (Hurrell, Visbeck et al. 2006, J Clim)



Source: Atlantic CLIVAR

- North Atlantic Oscillation (NAO)
- Tropical Atlantic Variability (TAV)
- Meridional Overturning Circulation (MOC)

The Intra-Americas Sea (IAS):
Gulf of Mexico and Caribbean Sea

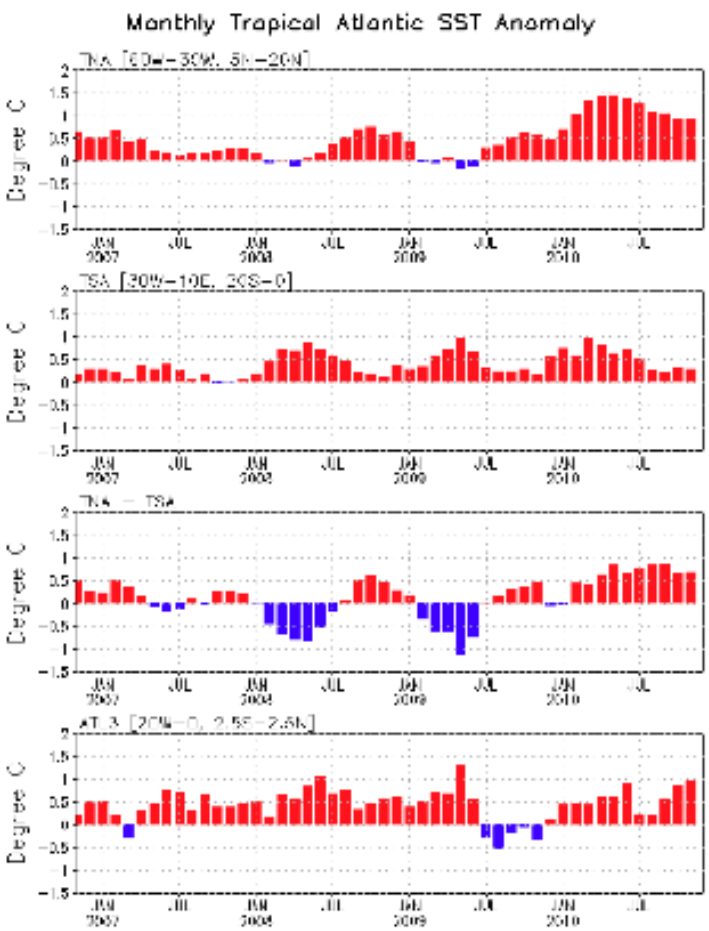
Source: IASCLIP VAMOS

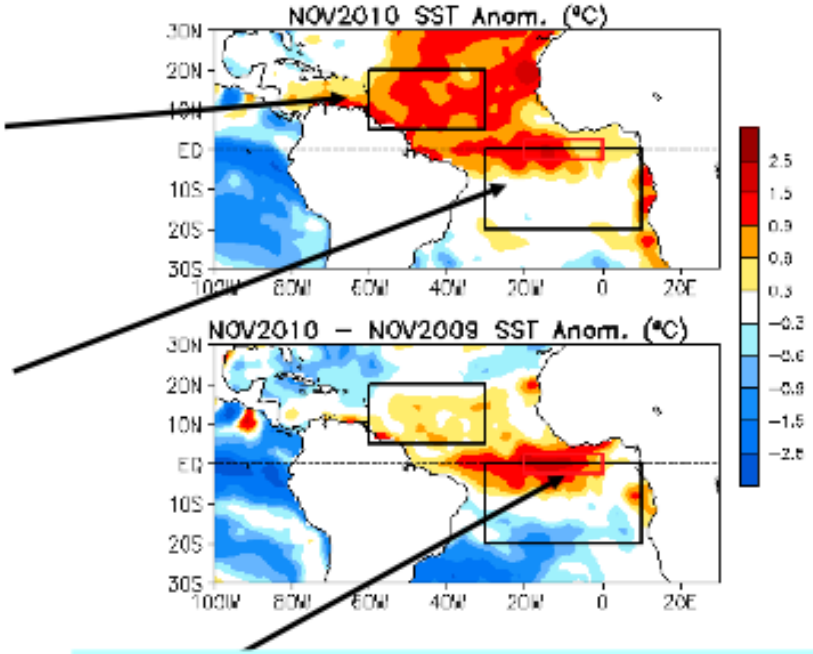
Atlantic Indices:

- Atlantic Inter-hemispheric (or meridional) Mode
- Atlantic Niño and Benguela Niño
- Atlantic Warm Pool (Caribbean Sea + Gulf of Mexico)
- North Atlantic Oscillation (NAO)

CPC's Ocean Monitoring Monthly Discussion

Evolution of Tropical Atlantic SST Indices





- Positive SSTA in TNA and TSA persisted in Nov 2010.
- Meridional Gradient Mode (TNA-TSA) has been above-normal since Feb 2010.
- ATL3 SST has been positive since Dec 2009 and strengthened since Sep 2010.

Recent reports on the Atlantic

- CLIVAR Atlantic Implementation Panel
- Problematic areas:
  - Lack of modeling activities as part of the Tropical Atlantic Climate Experiment (TACE) focus on the Eastern tropical Atlantic
  - Inadequate metrics to use in ocean synthesis intercomparsion project
  - Oceanic instrumentation of the Intra-Americas Sea

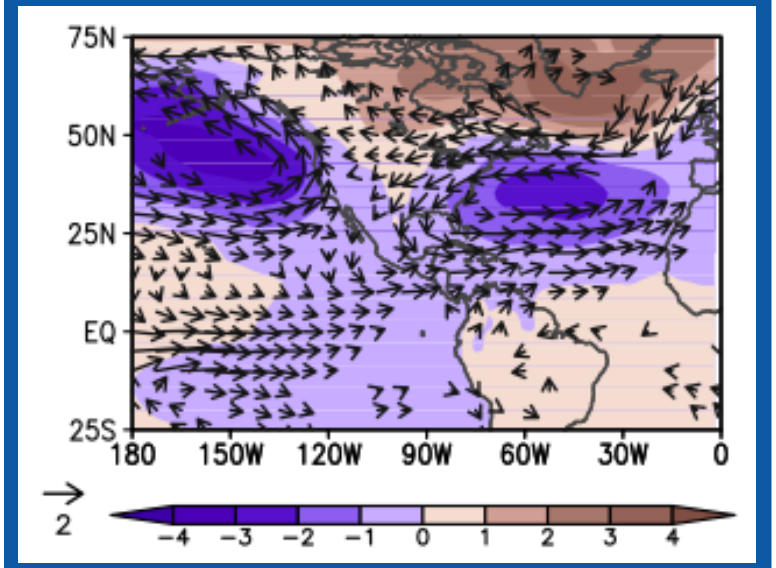
Emerging topics:

- Tropical Atlantic relationship with adjacent monsoon systems (South American, African)
- The Atlantic Warm Pool (Intra-Americas Sea) as a key climatic feature
- Seasonal and inter-annual Atlantic predictability and outlooks
  - Hurricane seasonal outlooks in the Atlantic
- Role of tropical Atlantic in mediation of the AMOC

Intra-Americas low-level jet

Strong moisture transport from IAS towards Central & North America

Low-level (850-hPa) winds, SLP



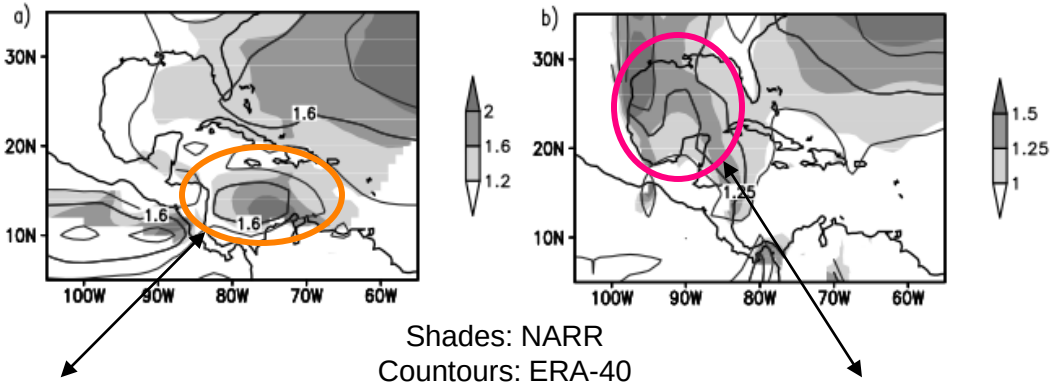
Munoz et al. 2010

IAS low-level (925-hPa) winds

Standard deviation

Zonal wind

Meridional wind



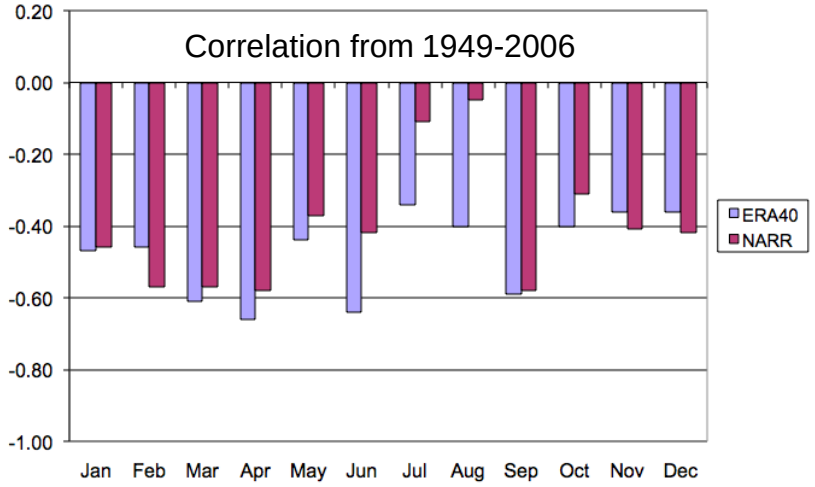
Shades: NARR

Countours: ERA-40

CBN_U

GMX_V

Correlation GMX_V and CBN_U



Munoz et al. 2011

Basic conditions related to IAS dipole events

Atlantic:

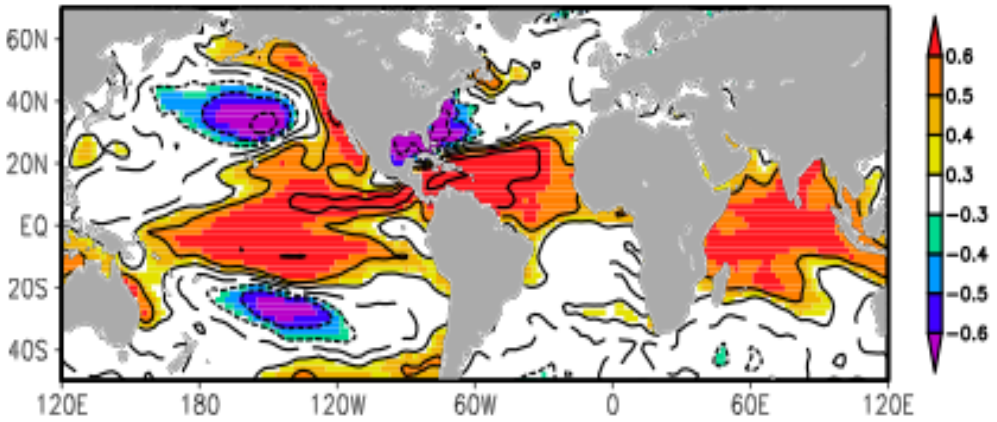
- Cool GMX; Warm CBN;
- Warm TNA

Pacific:

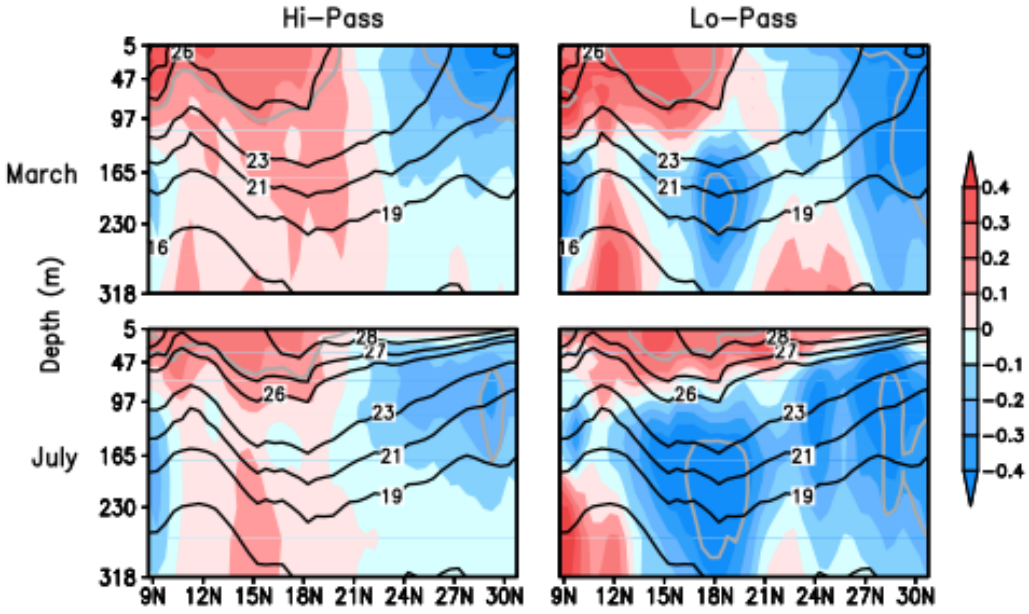
- Warmer tropics
- Cooler b/w latitudes 20-40

Temperature anomalies in upper 300 meters are different between high-pass and low-pass dipole indexes

SSTA Correlation Feb-Apr



Temperature anomalies



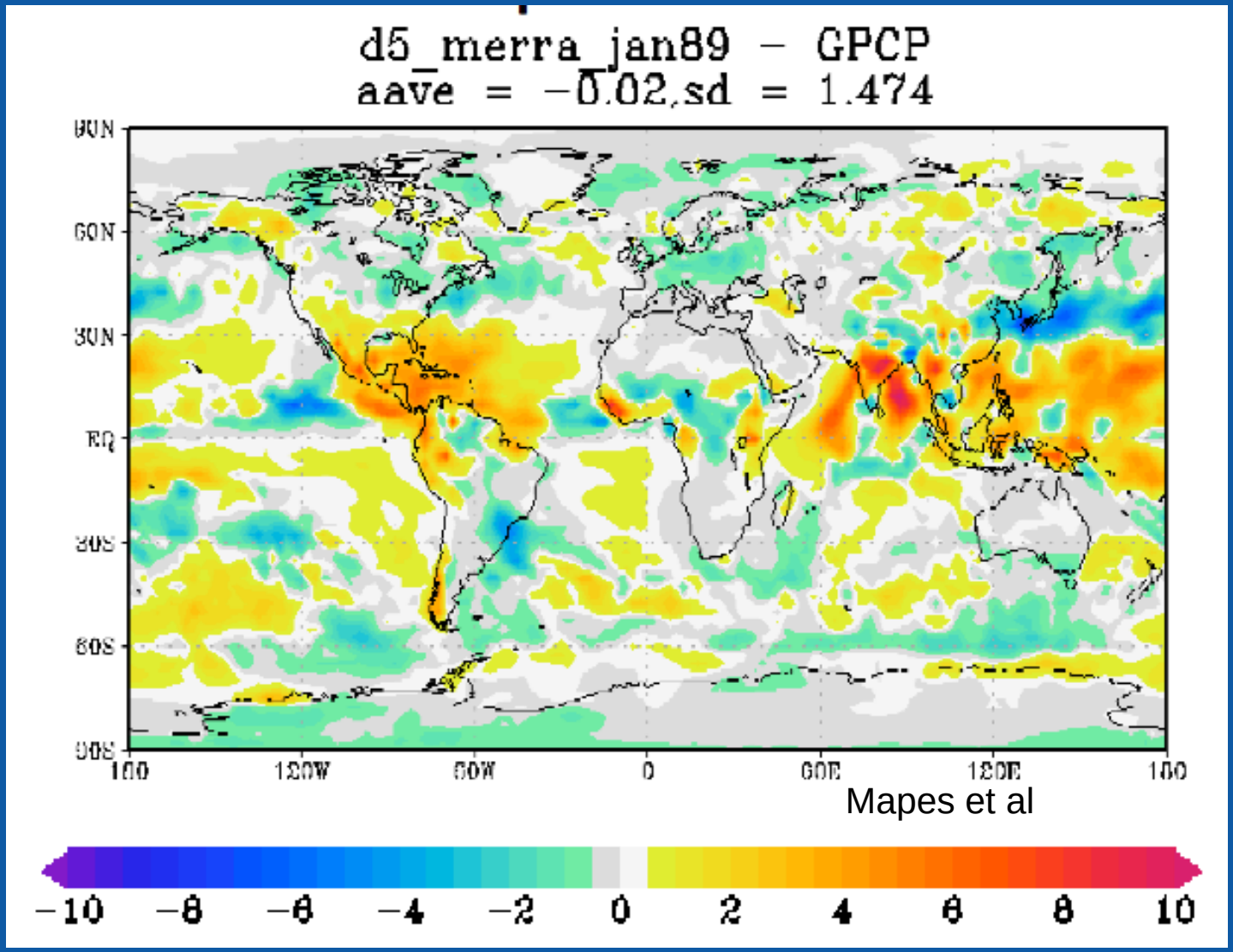
Known challenges

- Amazon freshwater influx and barrier layer formation (Ffield, 2006)
- Big Atlantic Warm Pool with very low precipitation
- Tropical southeastern Atlantic and local ocean-atmosphere interactions

Known biases

- Warm bias in the eastern tropical South Atlantic
- Low (dry) bias in Amazon precipitation (Lee et al. 2007)
  - Weaker easterlies over the equatorial Atlantic
- Low CAPE over Amazon region (C. Zhang, in preparation)
  - Also impacts easterlies in the equatorial Atlantic
- Cold Atlantic Warm Pool
  - Makes precipitation right for the wrong reason

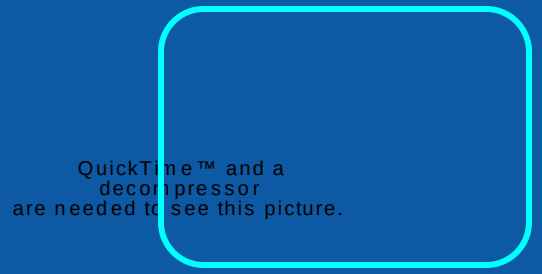
Precipitation bias in atmospheric reanalysis



Mapes et al

SST biases in coupled models

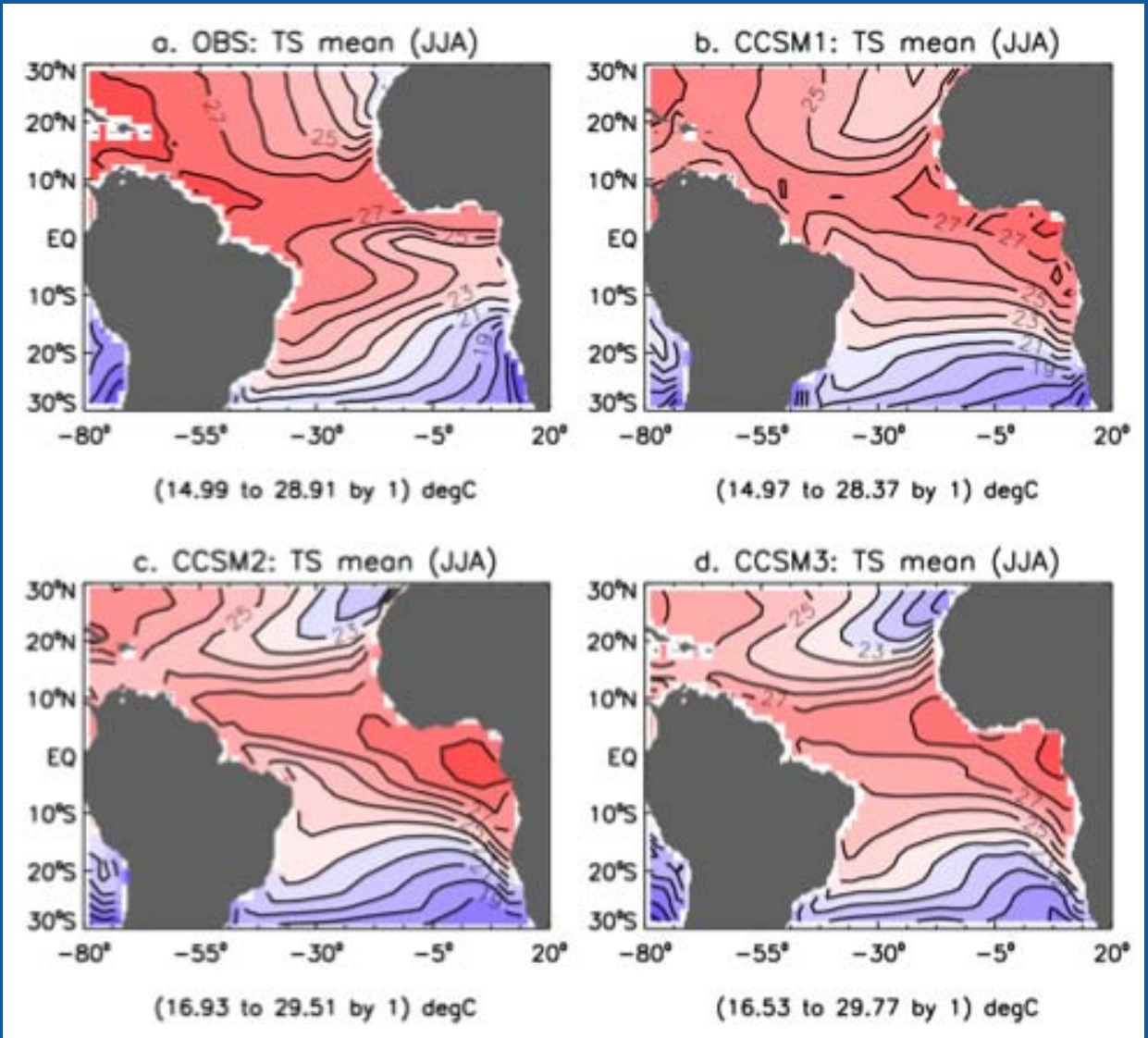
Chang et al 2007, J CLIM



CCSM is not the only coupled model with a significant temperature bias in the Intra-Americas Sea or the eastern tropical Atlantic.

Misra et al 2009, GRL

Tropical Atlantic SST (JJA) in CCSM versions



Saravanan et al

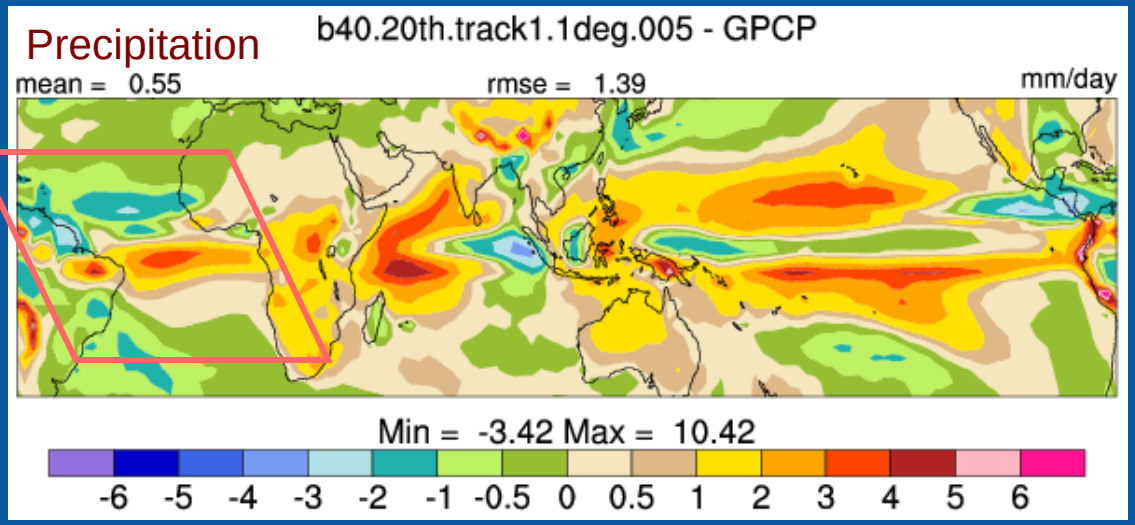
Data Sets:

- CCSM4 Simulations:
- 20th century ensemble members 1-5
  - File names: b40.20th.track1.1deg.005 - (009)
- CTRL run ~100yr (863-959)

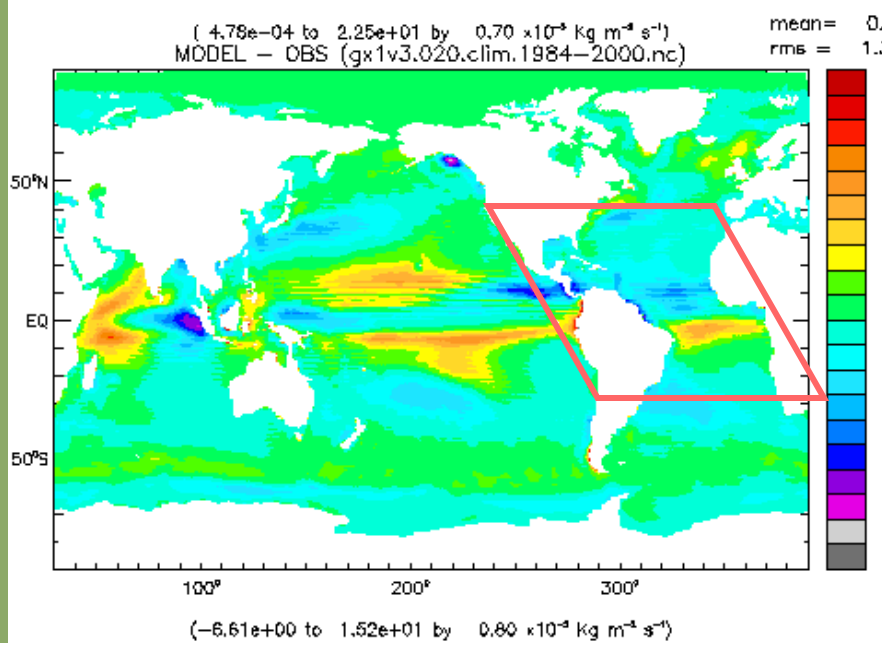
- Observational data sets
- Et cetera

CCSM4 Model-Obs Freshwater Related Fields

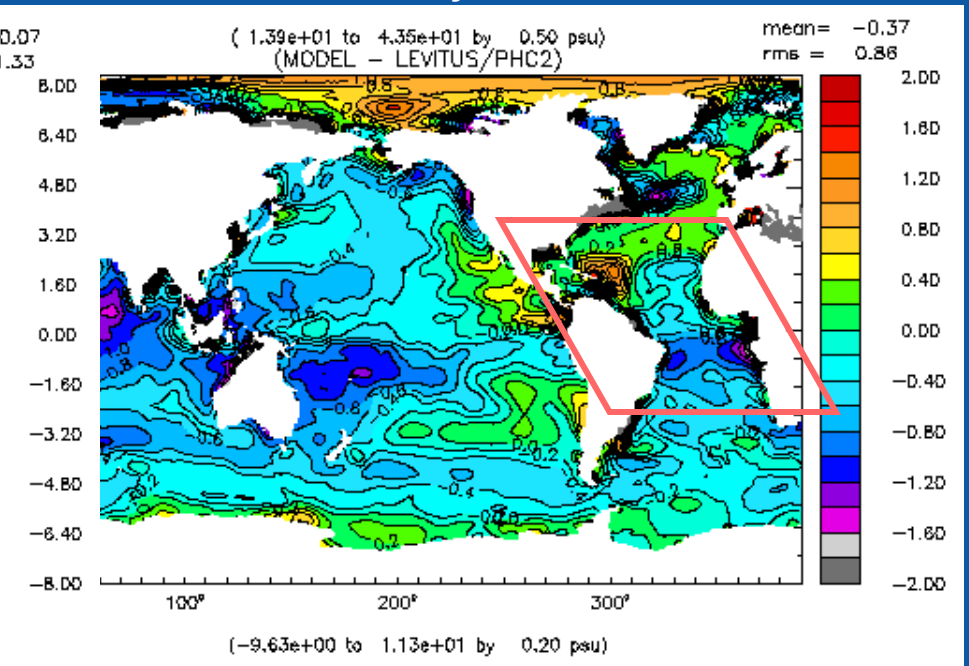
- Model ITCZ stronger in Tropical South Atlantic
- TNA saltier; TSA fresher



PREC_F

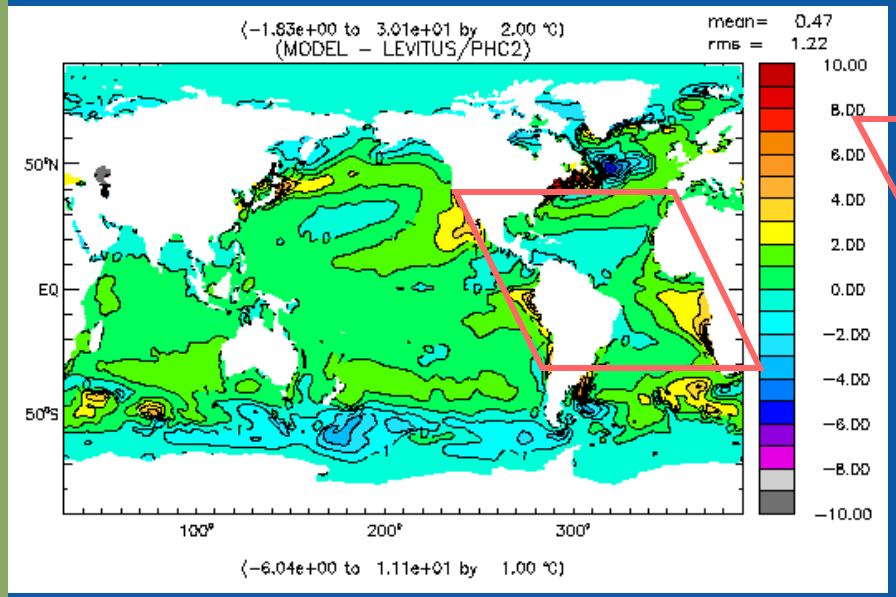


Salinity at 0m

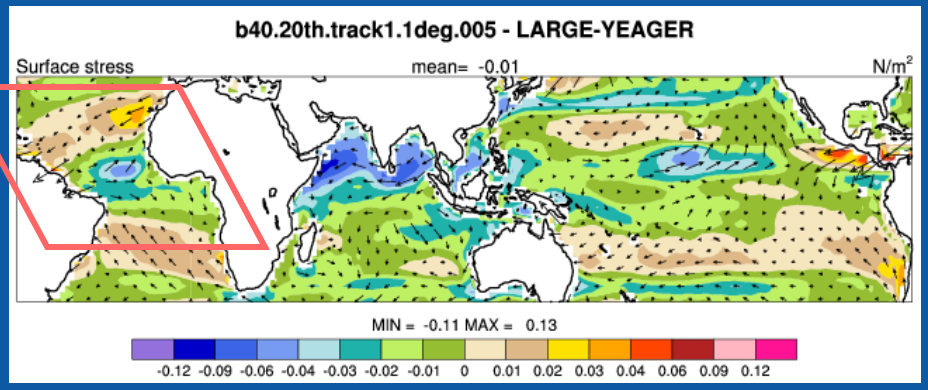


Difference (Model-Obs) in temperature, SSH, wind stress

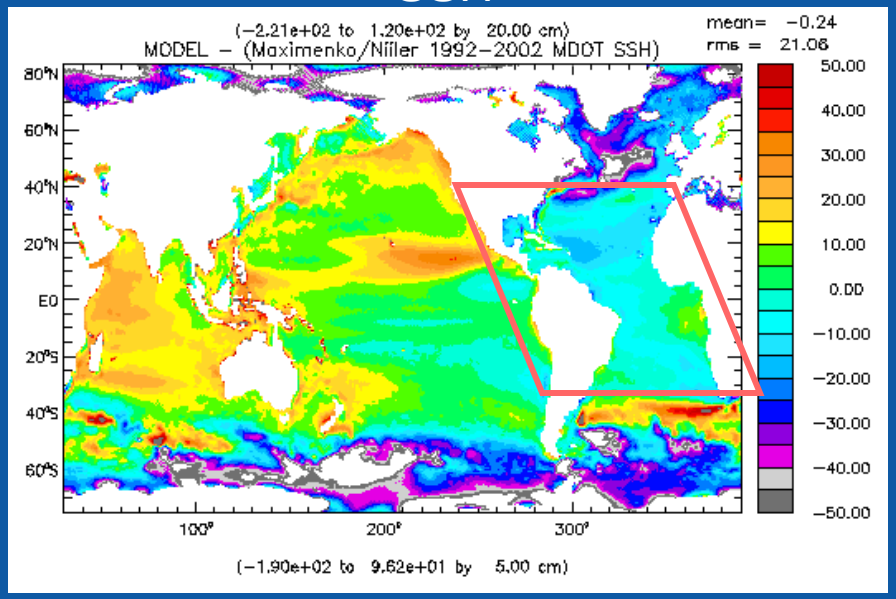
Temperature at 0m



Wind Stress



SSH



- Cold bias in TNA
- Warm bias in TSA
- Stronger TAU in TNA
- SSH in TNA has negative (shallow) bias

Heat budget in the Benguela upwelling region

- Focus: Interannual variability of heat budget in the Benguela region
- Impacts of local versus remote winds
  - recent studies, e.g. Florenchie et al. 2003, emphasize impacts of remote equatorial winds.
  - Is local upwelling equally important?
- Analysis based on ~100yr (863-959) of CCSM4 CTRL run

Heat budget equation

$$C_p\rho \int_{z=0}^{z=H} \frac{\partial T}{\partial t}\, dz = C_p\rho * \int_{z=0}^{z=H} \left(-u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} - w\frac{\partial T}{\partial z} + \frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right) \right) dz + R$$

Heat content rate of change (HCR)

Heat advection

ZON **MER** **VERT**

Vertical diffusion

(Net surface heat flux) – DIFF(z=H)

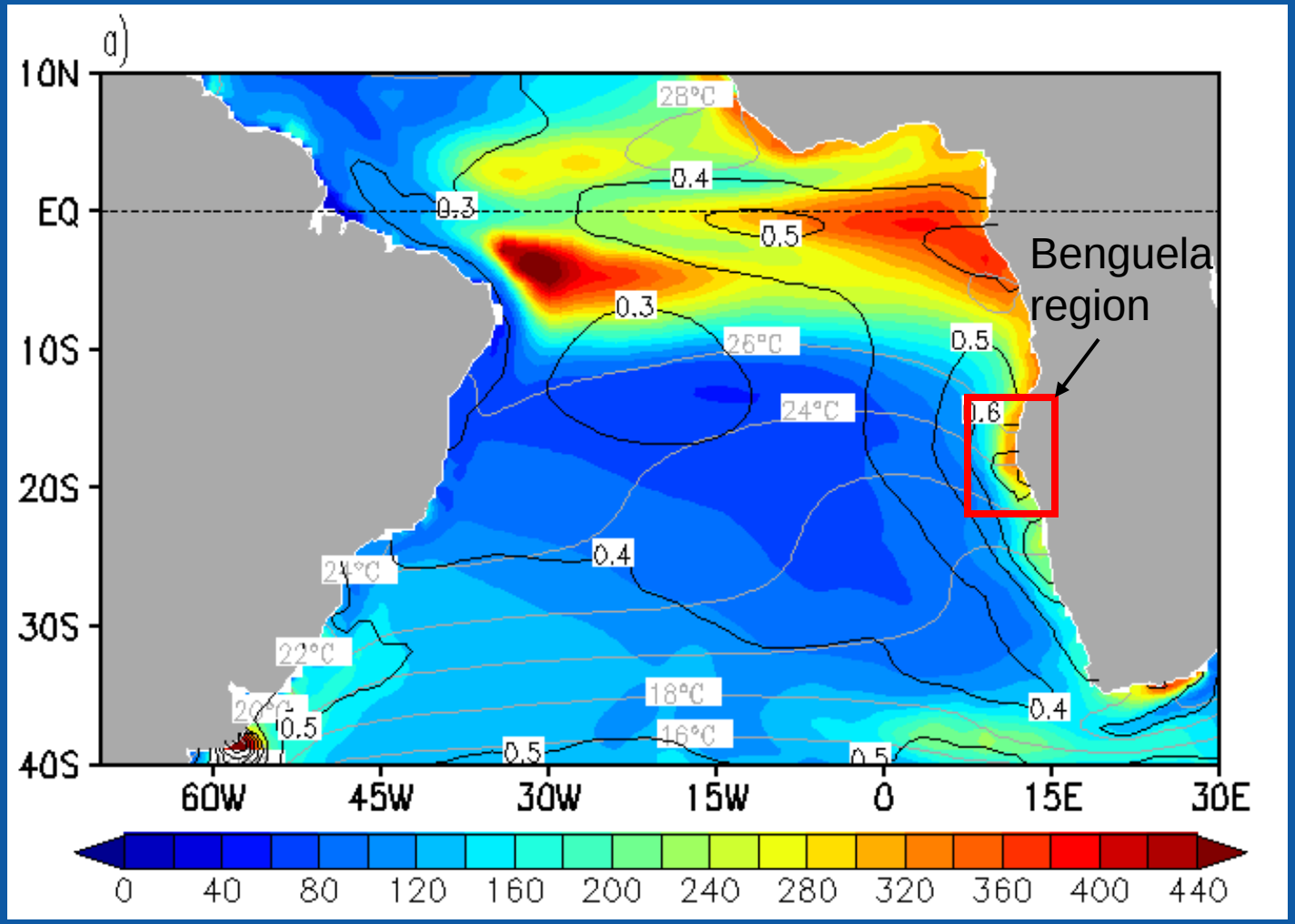
H=80m

Unresolved terms

Our heat budget based analysis focuses on interannual variability that is ‘emphasized’ by considering the time derivative terms. All terms are calculated on the POP grid using model numerics.

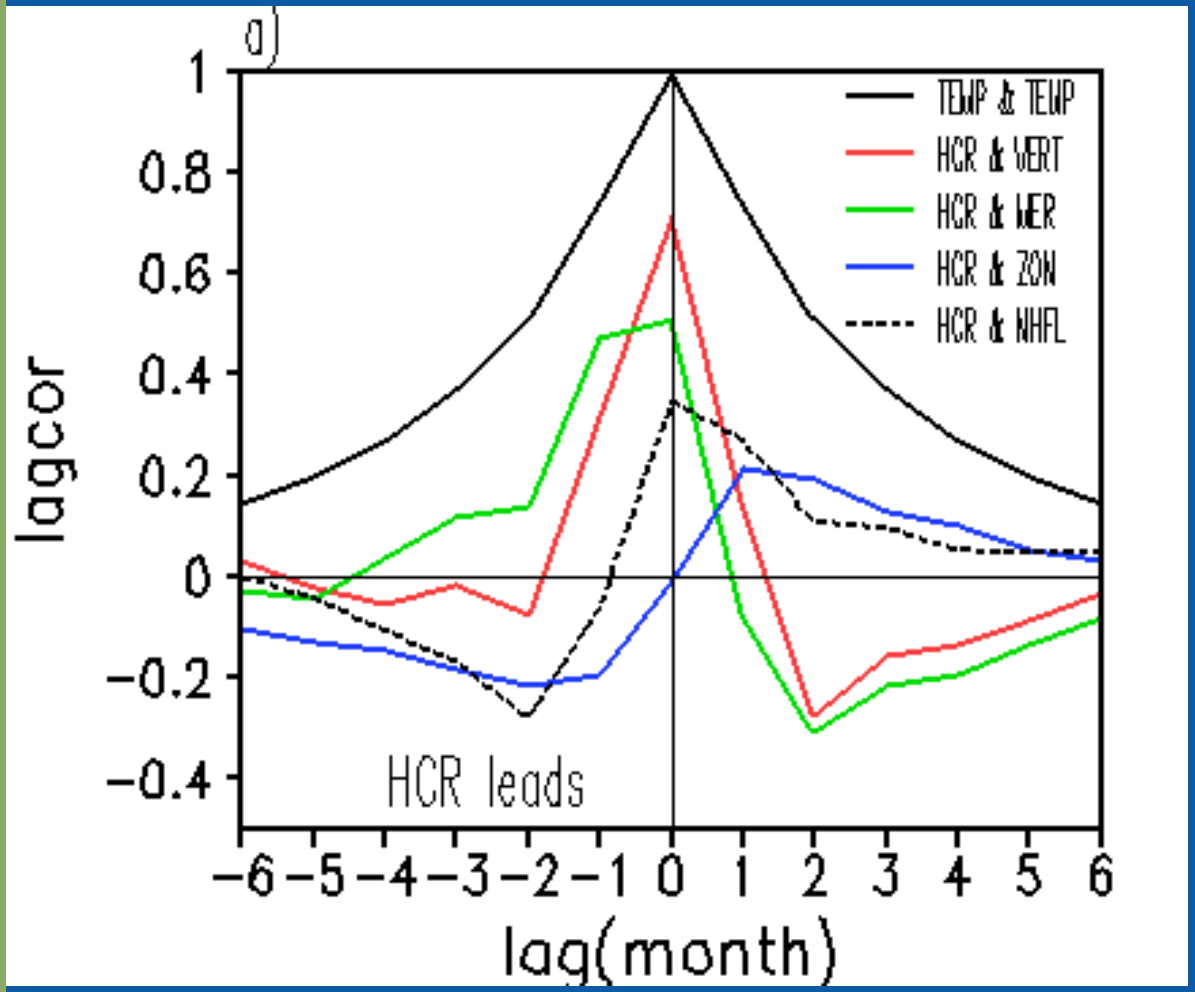
Standard deviation (STD) of anomalous heat content rate of change

(HCR, shading, W/m^2)



Black contours is STD of anomalous SST; gray contours is time mean SST

Lagged correlations of heat budget terms averaged over the Benguela region



- Time scale of ‘events’ is 4 months

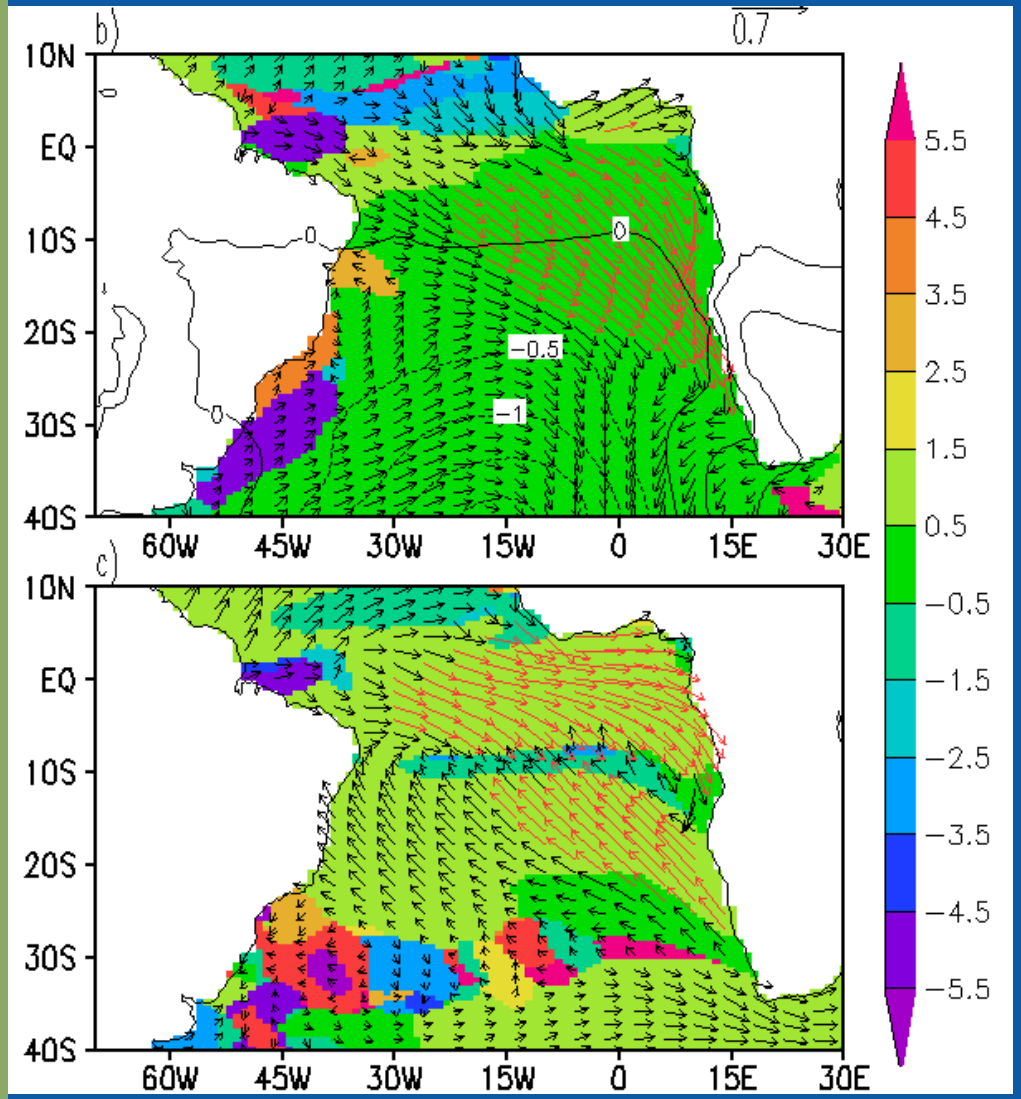
~50% of HCR variance is due to local upwelling

~25% is explained by anomalous meridional advection

~10% is explained by anomalous surface flux

Instantaneous zonal heat advection is weak

Correlation between Benguela heat advection and wind stress



- Lagged correlation of (top) vertical (bottom) meridional heat advection in the Benguela region with wind stress elsewhere.
- Arrows show maximum correlation. Shading shows time lag (month) corresponding to maximum correlation. CORR>0.3 are shown in red.
- Wind stress leads for positive lags.
- Contours show regression on MSLP at zero lag.

Summary of Benguela analysis

- Anomalous vertical heat advection explains ~50% of anomalous heat content rate of change (HCR) variance in the Benguela Region. Vertical advection correlates with instantaneous weakening of the local southeasterly trade winds.
- Anomalous meridional heat advection explains ~25% of HCR variance. It correlates with zonal equatorial winds in the central and eastern Atlantic that lead HCR by 1month.
- Zonal advection is weak due to orientation of thermal front.
- Local surface flux has minor impact on HCR (~10% of variance) and provides minor negative feedback on SST at decaying stage.