The Influence of Ocean Dynamics on the Tropical Atlantic SST Bias in CESM1

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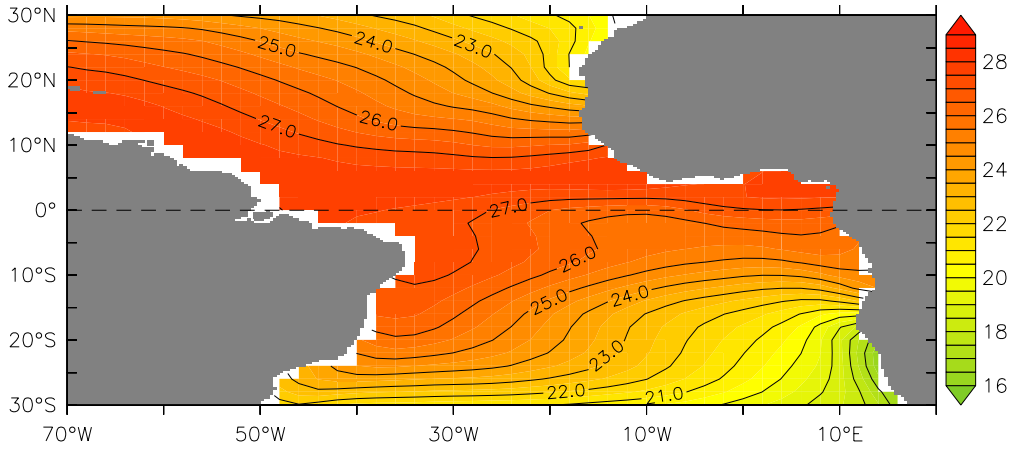
Outline

- Motivation
- Experiment Design
- Method and Analysis
- Summary

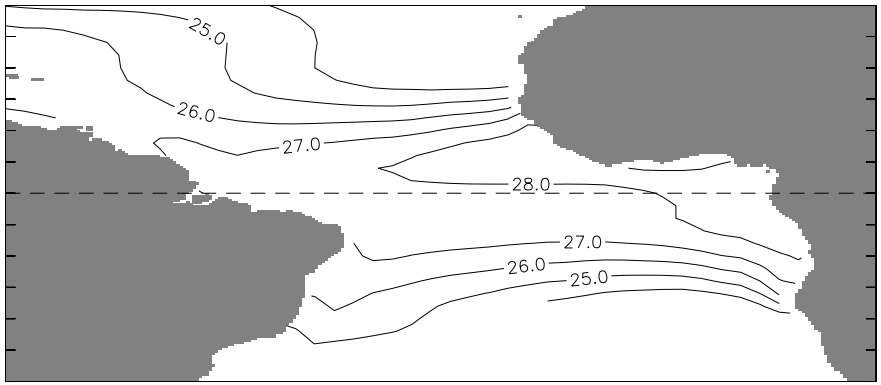
Motivation



Climatological annual mean SST in the tropical Atlantic

(a) ERSSTv3 dataset (1949-2006)

(b) 45 CMIP5 models historical simulation (1949-2005) (contoured) and its bias (shaded)



(c) CCSM4 historical simulation (1949-2005) (contoured) and its bias (shaded)

Some related works

➢ Atmosphere model bias

- Westerly wind bias over western tropical Atlantic in boreal spring----deepen the thermocline in eastern equatorial Atlantic----prevents the cold tongue development (Richter and Xie, 2008, 2012; DeWitt 2005; Chang et al. 2007; Wahl et al., 2011; Grodsky et al., 2011)
- Low-level stratus cloud deck----excessive regional shortwave radiative flux (Yu and Mechoso, 1999; Large and Danabasoglu 2006; Saha et al. 2006; Huang et al. 2007; Hu et al. 2008; Richter and Xie 2008; Wahl et al. 2011; Grodsky et al., 2011)

Some related works

- Ocean model bias
- Upper ocean mixing (Hazeleger and Haarsma, 2005)
- Coastal upwelling (Large and Danabasoglu 2006; Xu et al., 2013)
- Spurious barrier layers associated with excessive regional rainfall (Breugem et al. 2008)
- Oceanic bridge and air-sea coupling feedback (Toniazzo and Woolnough, 2013)
- Instability waves (Seo et al. 2006)
- Other hypotheses
- Model Resolution (Ben Kirtman, 2011; Grodsky et al., 2011)
- Meridional SST dipole (Lee and Wang 2008, Change et al. 2007)
- West African monsoon (Deser et al. 2006)
- Rainfall over the Amazon and Africa (Davey et al. 2002; Chang et al. 2008; Okumura and Xie 2004)
- Air-sea turbulent flux (Ban et al. 2010)

Questions

- Previous works are mainly based on the fully adjusted CGCMs run. It is hard to identify the exact process responsible for the tropical Atlantic SST biases in CGCMs.
- Q1: How does the tropical Atlantic SST bias develop in the CGCMs?
- Previous studies have suggested (1) atmosphere model biases, (2) ocean model biases in the coastal upwelling regions off the west Africa, and (3) coupled model resolution
- Q2: How can we identify and quantify the atmosphere model and ocean model contributions to SST bias?

Experiment Design

Addressing Q1 (Initial development stage)

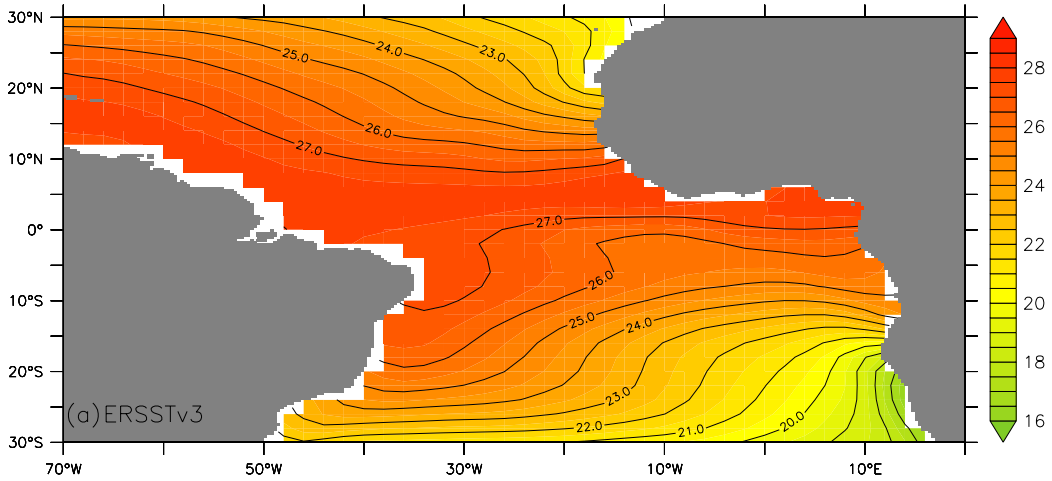
Experiment Design

- Community Earth System Model version 1.1 (CESM1.1)
- Successor to the CCSM (Community Climate System Model)
- CCSM was extended and renamed to CESM in June 2010
- CESM is a superset of CCSM4, include atmosphere, ocean, surface land, sea ice, runoff, Land ice, carbon cycle, ……
- Default configuration is the same science scenarios as CCSM4

Experiment Design

Experiment	Description
EXP_ATM	The atmosphere-land model of CESM1.1, with f19_f19 resolution, is forced by using the observed climatological SST of HadISST, integrated for 30 years
EXP_OCN	The ocean-ice model of CESM1.1, with T62_g16 resolution, is forced by using the observed climatological surface forcing, integrated for 210 years
EXP_CPL	Fully coupled ensemble model experiment, with f19_g16 resolution, is performed using CESM1.1 with the atmosphere-land model initialized using EXP_ATM, and the ocean-ice model using EXP_OCN, 10 ensemble members

EXP_CPL Ensemble member 1: initial from 21a of EXP_ATM and 201a of EXP_OCN
EXP_CPL Ensemble member 2: initial from 22a of EXP_ATM and 202a of EXP_OCN
…….
EXP_CPL Ensemble member 10: initial from 30a of EXP_ATM and 210a of EXP_OCN



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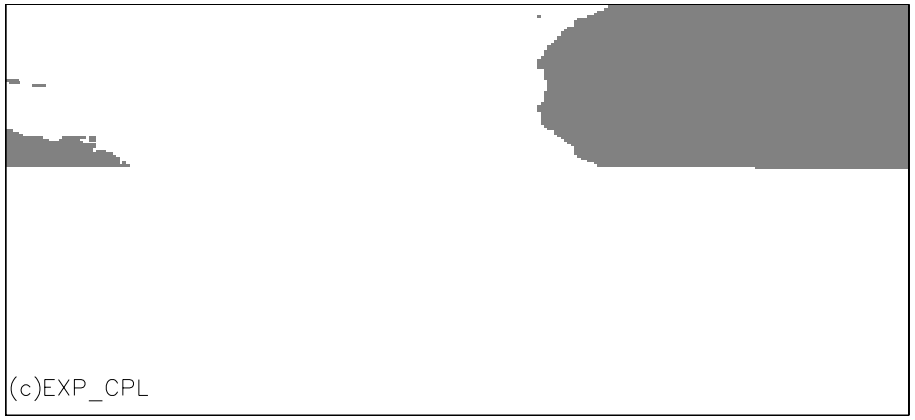
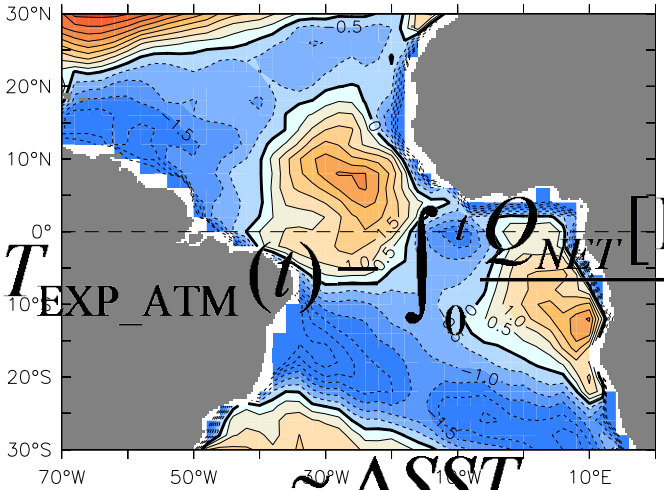


(c) First-year-averaged result (contoured) from EXP_CPL and its bias (shaded)

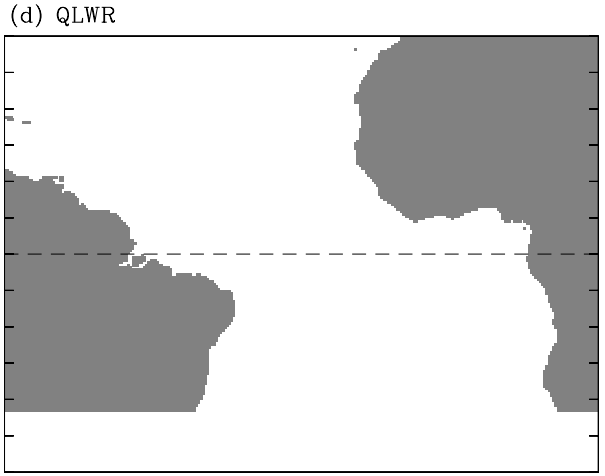
Method and Analysis

Addressing Q2 (Implicit SST bias)

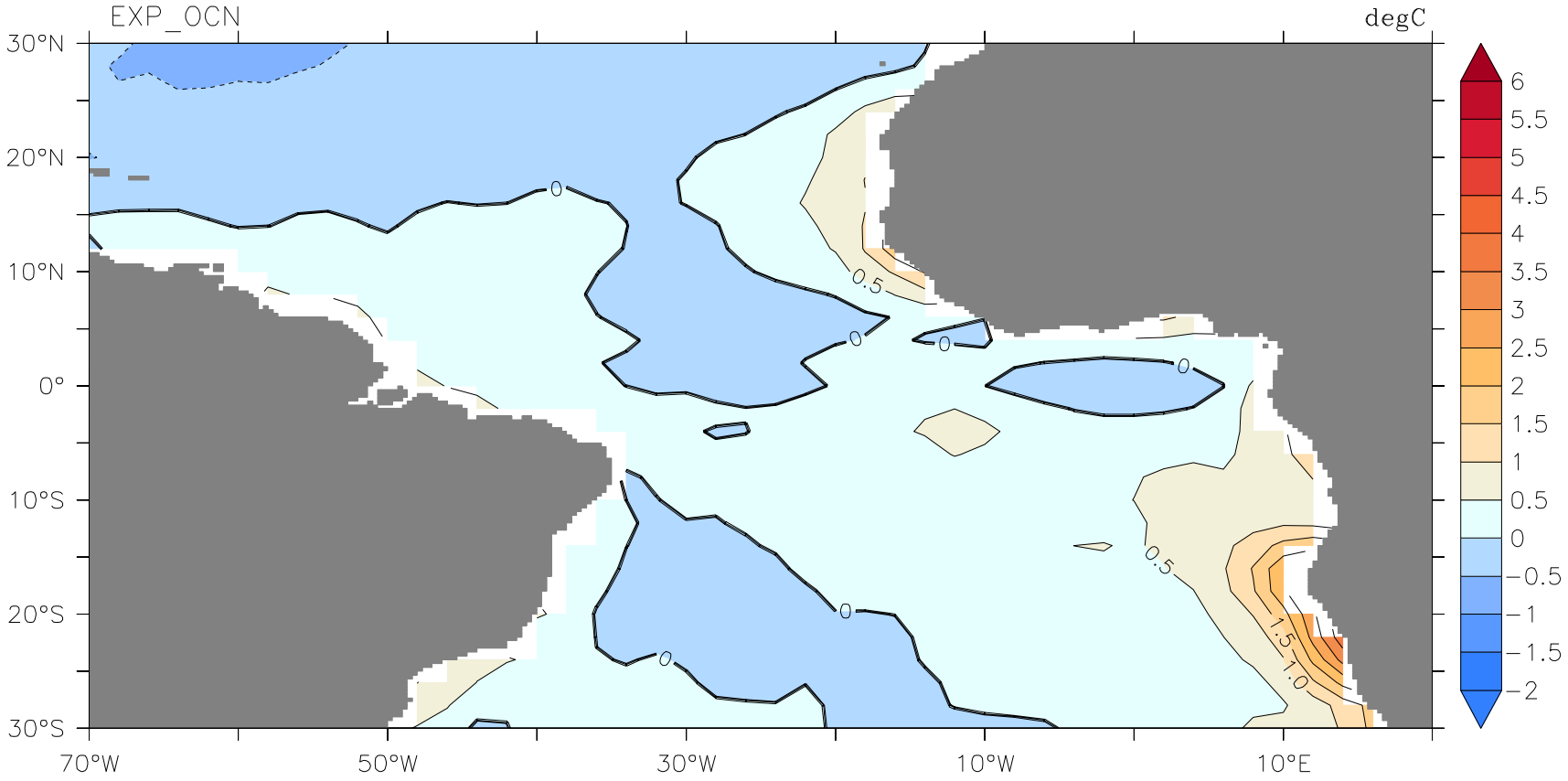
implicit SST bias linked to the heat flux bias in EXP_ATM



$$\Delta T_{\mathrm{EXP\_ATM}}(t) \approx \int_0^t \frac{Q_{NET}[\mathrm{EXP\_ATM}] - Q_{NET}[\mathrm{OBS}]}{\rho_w C_{pw} D}\, dt \approx \Delta SST_{\mathrm{EXP\_ATM}}$$



Annual Mean SST bias in EXP_OCN

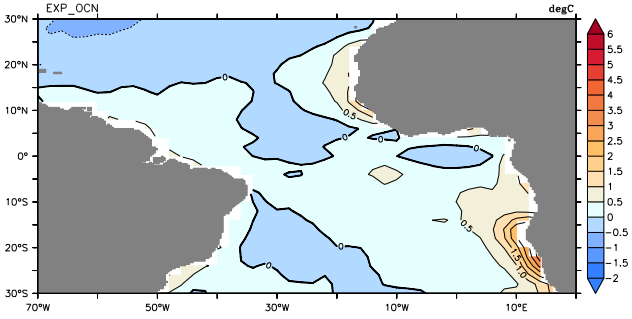


implicit SST bias linked to the ocean dynamics process in EXP_OCN

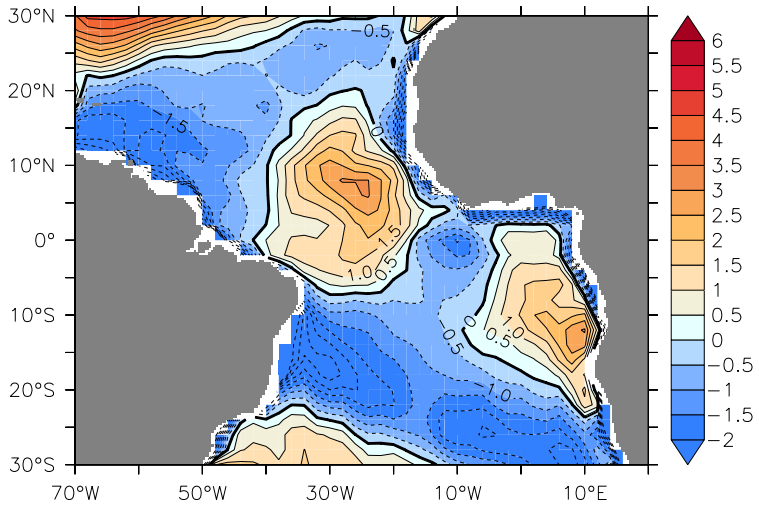
$$\frac{\partial \Delta T_m}{\partial t} = -\Delta\left(u_m \frac{\partial T_m}{\partial x} + v_m \frac{\partial T_m}{\partial y} + w_e (T_m - T_e) \right) + \frac{Q_{NET}[\mathrm{EXP\_OCN}] - Q_{NET}[\mathrm{OBS}]}{\rho_w C_{pw} D}$$

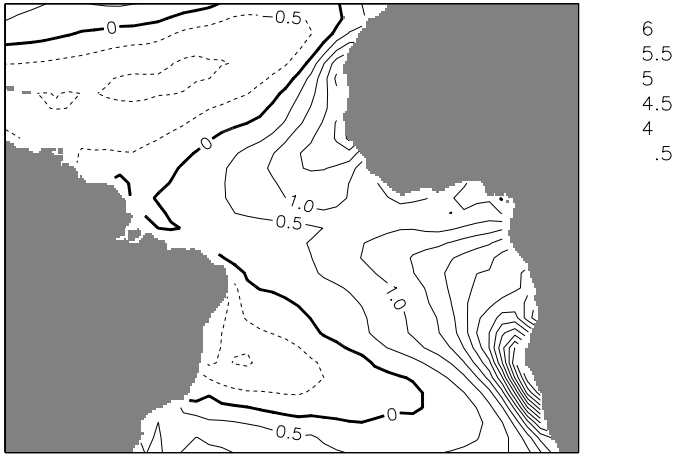
$$\Delta T_{\mathrm{EXP\_OCN}} \equiv -\int_0^t \Delta\left(u_m \frac{\partial T_m}{\partial x} + v_m \frac{\partial T_m}{\partial y} + w_e (T_m - T_e) \right) dt$$

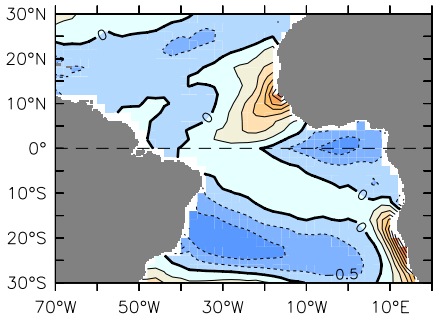
$$= \Delta T_m - \int_0^t \frac{Q_{NET}[\mathrm{EXP\_OCN}] - Q_{NET}[\mathrm{OBS}]}{\rho_w C_{pw} D} dt.$$



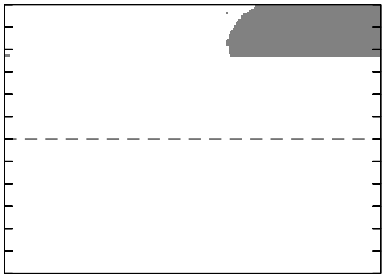
Annual Mean (implicit) SST bias

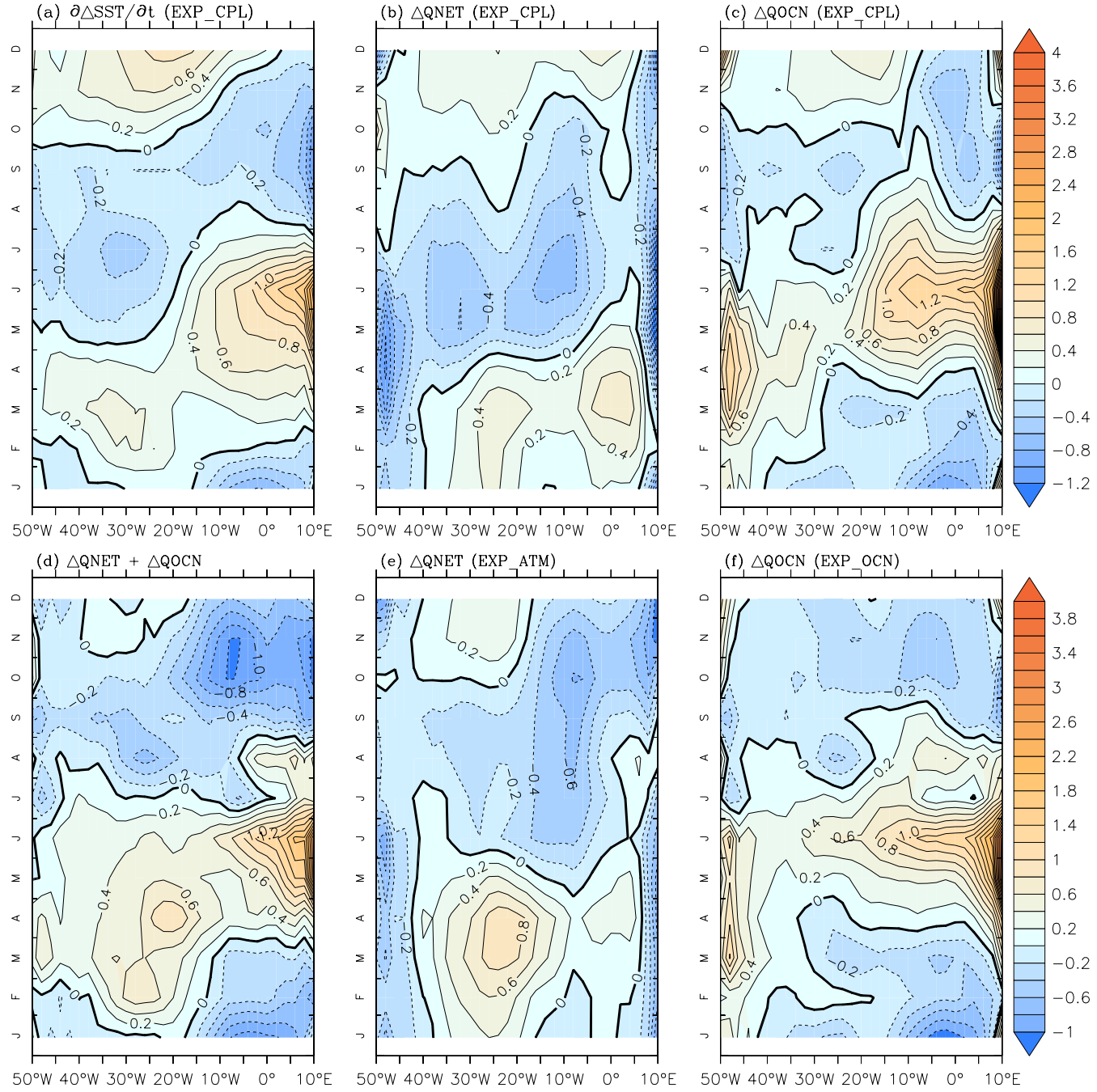




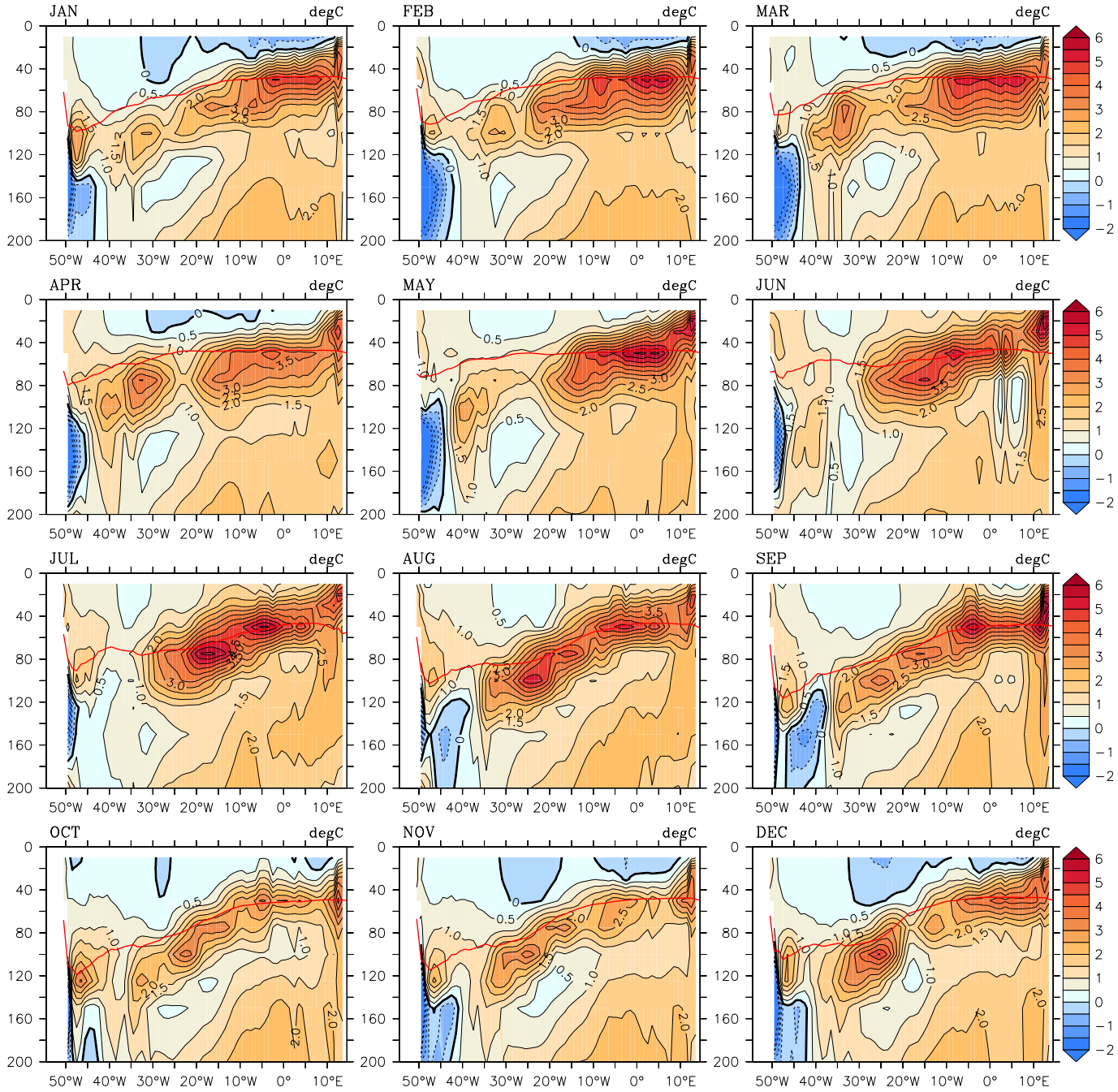


Evolution of SST bias in EXP_CPL during the first and second year





Time-longitude evolutions of SST tendency along the Atlantic equator (deg/month)



Evolution of equatorial (5S-5N) temperature bias in EXP_OCN

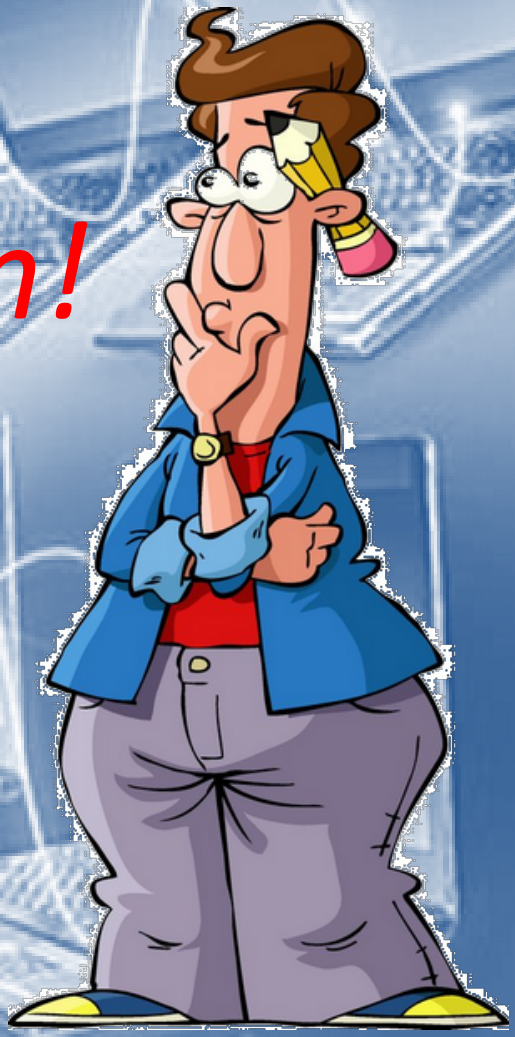
Shade:
Temperature bias
Red line:
Mixed Layer Depth in EXP_OCN

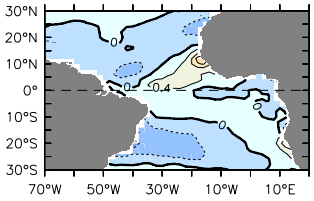
Summary

Summary

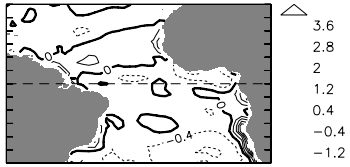
- Propose and use a new methodology (implicit SST bias) to identify and quantify inherent errors in GCMs
- Tropical Atlantic SST bias develops very quickly within a year, and its amplitude and spatial pattern are largely determined by the linear combination of the implicit SST errors in atmosphere and ocean models
- The warm SST biases in the eastern equatorial Atlantic are seeded in boreal spring and early summer MAINLY by the ocean model due to its inherent errors in ocean dynamic processes
- The proposed tool can be further used to pinpoint what aspect or parameterization the atmosphere and ocean models are responsible for the implicit SST biases

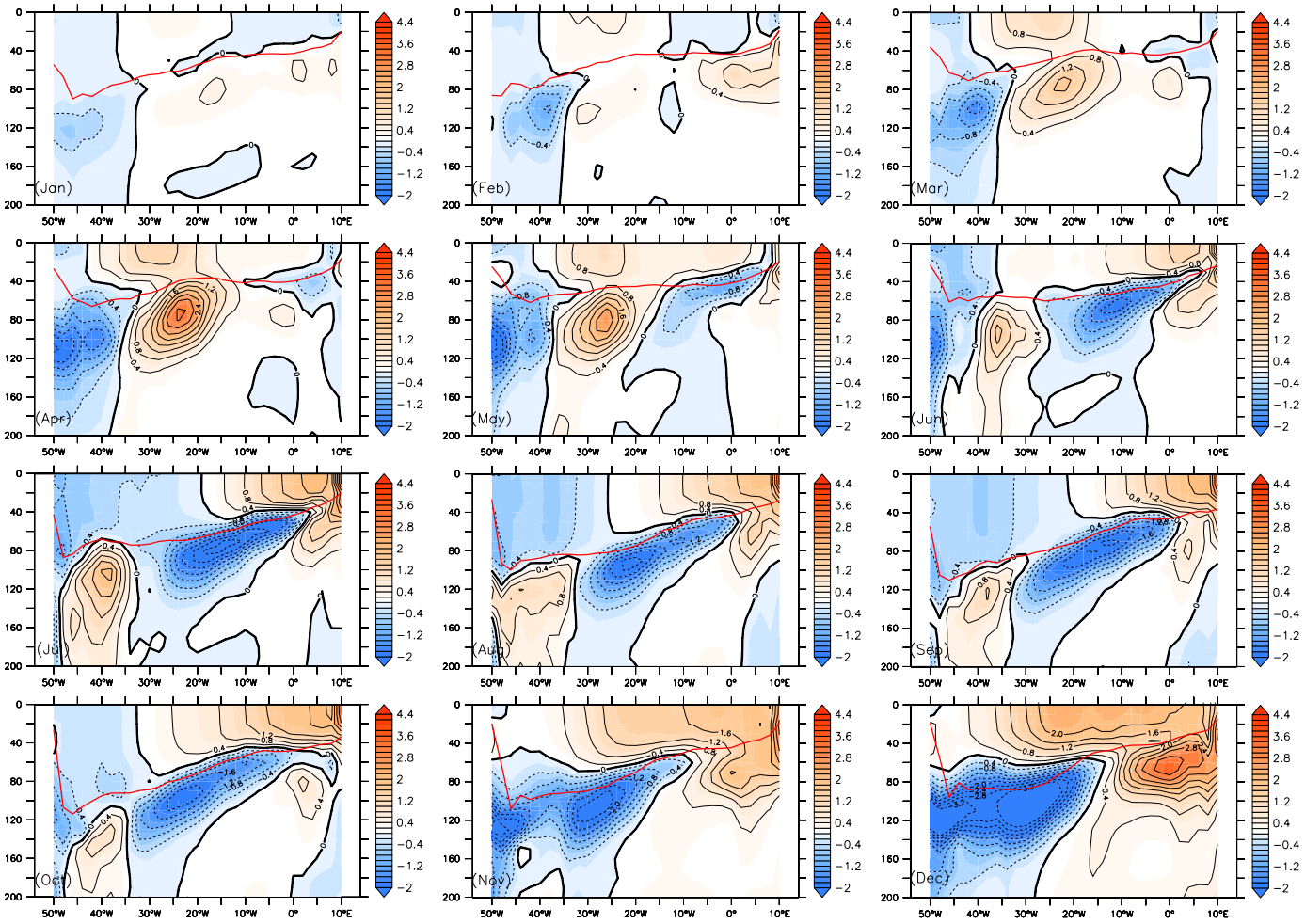
Thank you
for your attention!





SST bias tendency (deg/month)





Evolution of equatorial (5S-5N) temperature difference between EXP_CPL and EXP_OCN

Shade: Temperature difference
Red line: Mixed Layer Depth in EXP_OCN