Forcing NEMO with the simplified atmospheric boundary layer model CheapAML - Application to a process study of the Equatorial Atlantic inter annual variability.

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Background : variability in the equatorial Atlantic

- Seasonal equatorial cooling (cold tongue formation) during summer mostly in response to subsurface processes (upwelling and mixing) [e.g. Foltz et al. 2003, Jouanno et al. 2011, Hummel et al. 2013, Planton et al. 2017]

- Interannual variations of equatorial SST are influenced by :
  - the Atlantic Equatorial mode [Zebiak, 1993]
  - the Atlantic Meridional mode [Servain, 1991]
  - non-canonical modes [Richter et al., 2013]

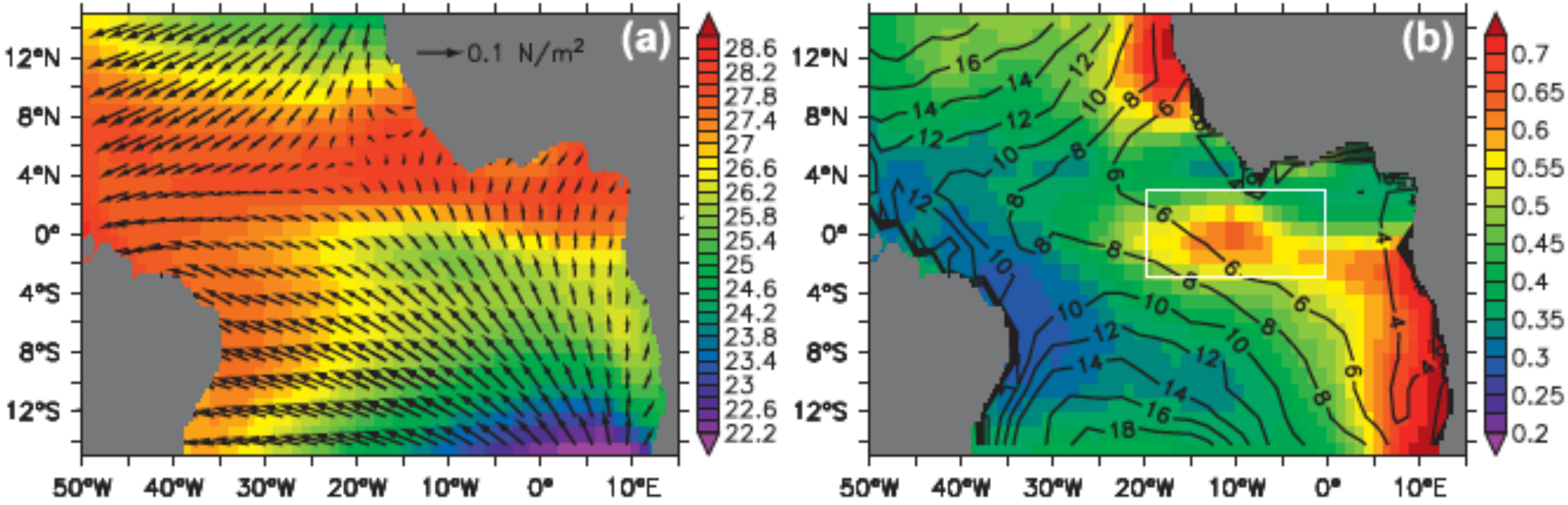


Figure : mean Reynolds SST and s.t.d. of interannual SST [Lubbecke and Mc Phaden 2013]

The Atlantic Equatorial Mode (often referred as Atlantic Niño)

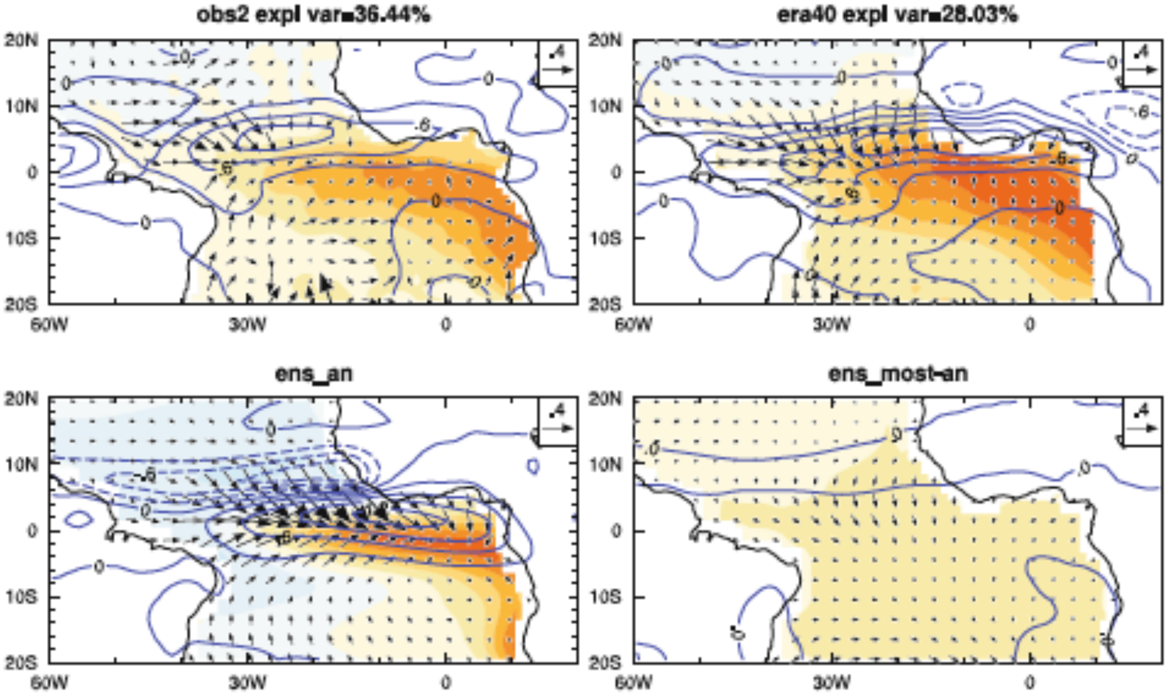


Figure : EOF of SST during JJA for a) HadISST, b) ERA40, c) CMIP3 models with ”realistic” Nino et d) the rest of the CMIP3 models [Richter et al. 2014]

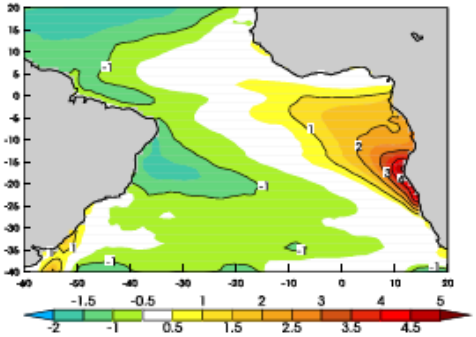
- Periodicity 2-4 years
- Structure almost stationary
- Have a much weaker amplitude than Pacific Niño (s.t.d. of ATL3 index = half of NINO3 index)
- Weaker than the seasonal variability and explains a weaker fraction of the equatorial interannual variability (30% weaker, Zebiak 1993)

Drivers of the ”Atlantic Niños”

- **Ocean dynamics involved**
  - remote forcing of eastern SST anomalies by Atlantic zonal winds in the western part of the basin *[Hirst and Hastenrath 1983, Servain et al. 1982]*
  - delayed oscillator mechanism and Bjerkness feedback at play *[Zebiak 1993, Keenlyside and Latif 2007 , Lübbecke and Mc Phaden 2017]*
  - Kelvin and Rossby waves involved in preconditioning processes *[e.g., Burmeister et al. 2016, Planton et al. 2017]*
- **Thermodynamic forcing may contribute**
  - *Nnamchi et al. [2015]* **In state-of-the-art coupled models, Atlantic Niño variability strongly depends on the thermodynamic component (R^2=0.92)** (perturbations of the equatorial Atlantic trade winds drive changes in surface latent heat flux and thus in surface temperature)

Objectives

- Try to quantify relative contribution of **dynamic vs | thermodynamic forcing** to equatorial Atlantic variability
- If conclusions are different from *Nnamchi et al. 2015* (they are) try to explain why.
  Hypothesis : cold tongue bias may have profound consequences on the processes at play in the Niño resolved by the CMIP5 models.



How to test the relative importance of thermodynamic vs dynamic forcing ?

→ Remove interannual variability of the wind stress & keep interannual variability of the air-sea heat fluxes

Flux required at the ocean surface :

- momentum (τx, τy)
- heat (Qsw, Qnonsolar)
- freshwater (E-P-R)

Flux forcing	**Bulk forcing (e.g. Large and Yeager 2012)** **Fluxes depend on atmospheric variables (u_{10}, v_{10}, t_2, q_2, Q_{sw}, $Q_{lw,}$ precip$_{)}$ and SST.**		
Flux product	Reanalysis	Atmospheric slab layer (*surface atmospheric variables are interactive)*	Fully coupled model
require ”sst restoring" to avoid drift	specifying q_2 and t_2 indirectly restores the sst toward a prescribed state		bias not easy to control and full feedback loop make difficult to disentangle processes

→ Increased complexity

Forcing strategy : the atmospheric slab layer CheapAML

The air temperature (t2) and humidity (q2) are obtained from a **thermodynamically active atmospheric boundary layer** that responds to the model sea surface temperature [***CheapAML***, *Deremble et al. 2013*]

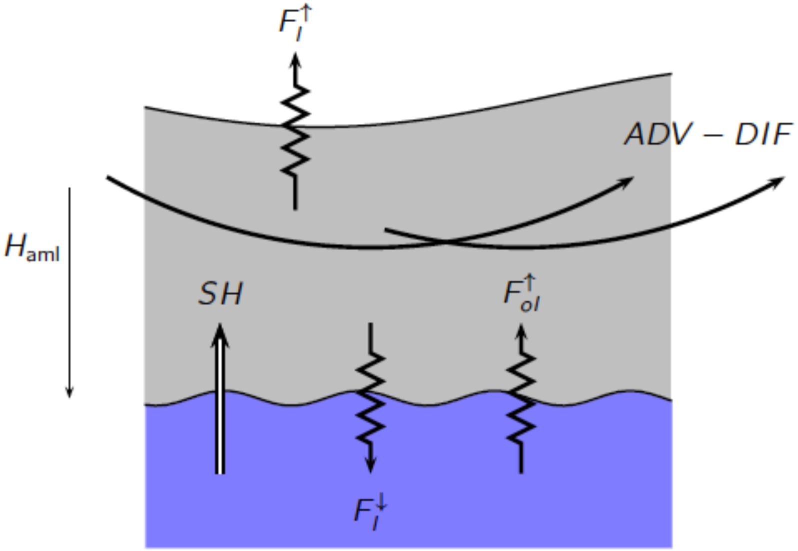
$$\frac{\partial T}{\partial t} = -u.\nabla T + \nabla \cdot (K_T \nabla T) + \frac{SH + F_{ol}^{\uparrow} - F_l^{\downarrow} - F_l^{\uparrow}}{\rho_a c_p H}$$

$$SH = C_{dh} |\boldsymbol{u}| (SST - T)$$

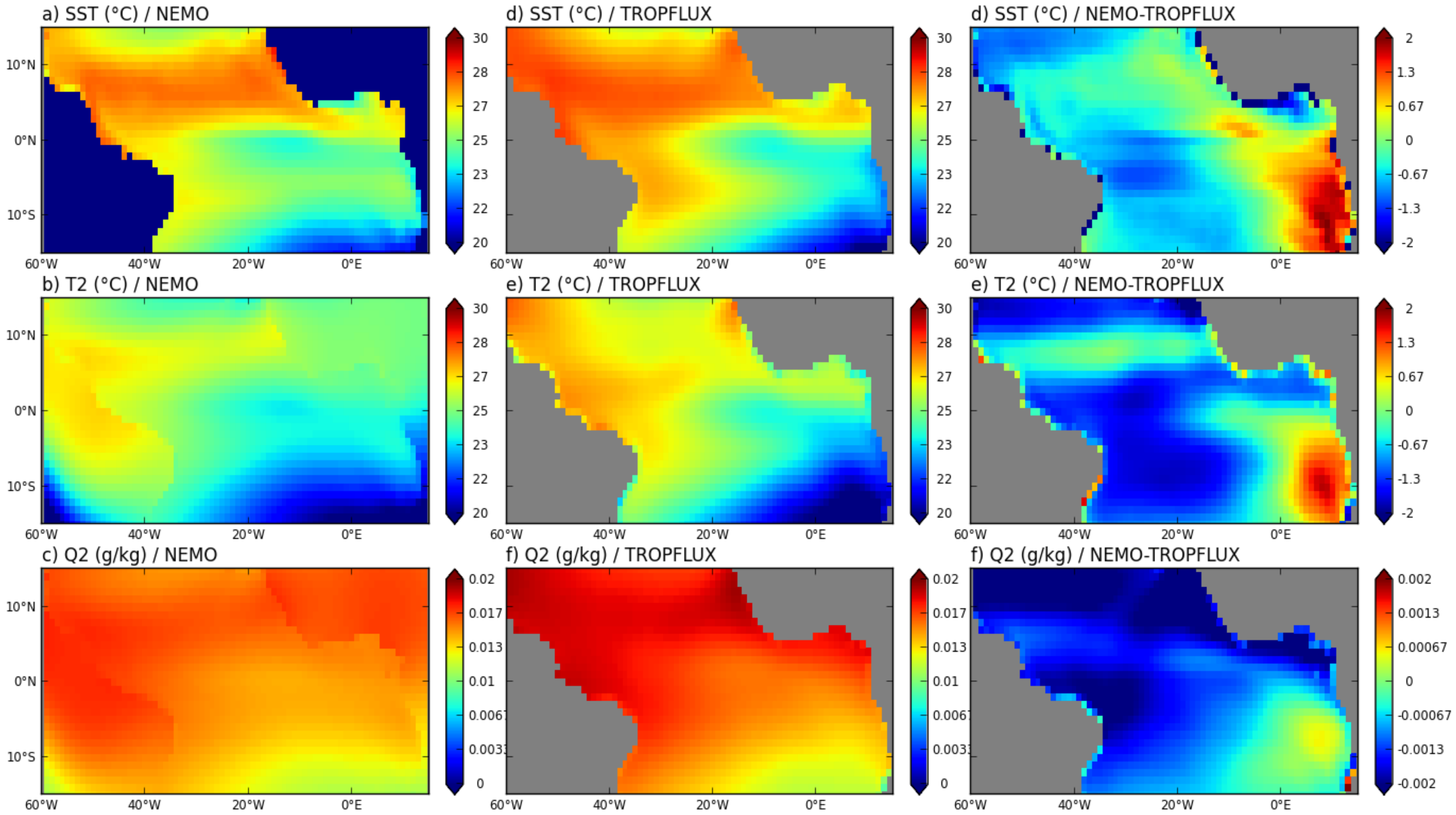
$$F_{ol}^{\uparrow} = \epsilon \sigma SST^4$$

$$F_l^{\downarrow} = \frac{1}{2} \epsilon \sigma T^4$$

$$F_l^{\uparrow} = \frac{1}{2} \epsilon \sigma \left[T(z_l) \right]^4 ; \qquad T(z_l) = T - \Gamma z_l$$

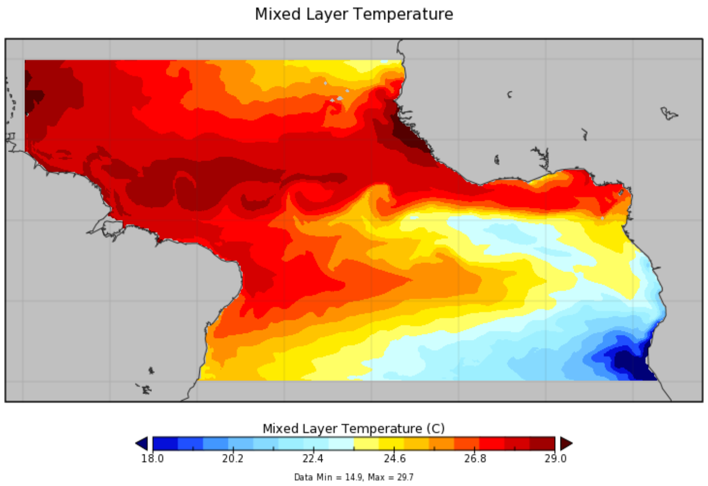


u10, v10, Qsw, Qlw, precipitations, and PBL are from ERA-I and not interactive

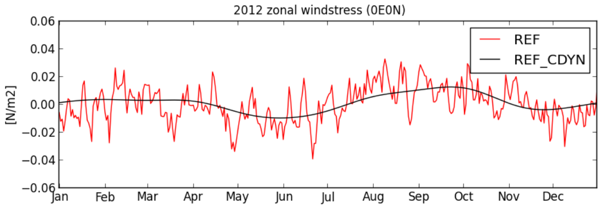

a) SST (°C) / NEMO
d) SST (°C) / TROPFLUX
d) SST (°C) / NEMO-TROPFLUX
b) T2 (°C) / NEMO
e) T2 (°C) / TROPFLUX
e) T2 (°C) / NEMO-TROPFLUX
c) Q2 (g/kg) / NEMO
f) Q2 (g/kg) / TROPFLUX
f) Q2 (g/kg) / NEMO-TROPFLUX
10°N
0°N
10°S
60°W
40°W
20°W
0°E
30
28
27
25
23
22
20
2
1.3
0.67
0
-0.67
-1.3
-2
0.02
0.017
0.013
0.01
0.0067
0.0033
0
0.002
0.0013
0.00067
0
-0.00067
-0.0013
-0.002

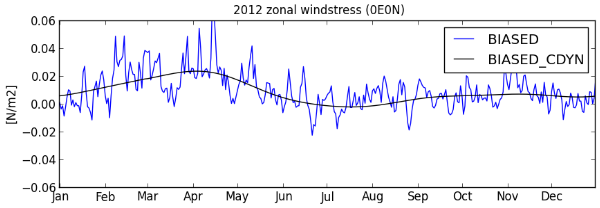
Regional numerical setup

Code: NEMO 3.6
Boundaries : Mercator Daily GLORYS2V3
Vertical mixing : GLS (default options)
Momentum : UBS (third order scheme)
Free surface : time-spliting (60 sub time steps)
Tracers : TVD + laplacian isoneutral
Initial conditions : T/S from LEVITUS
Period : 1979-2012

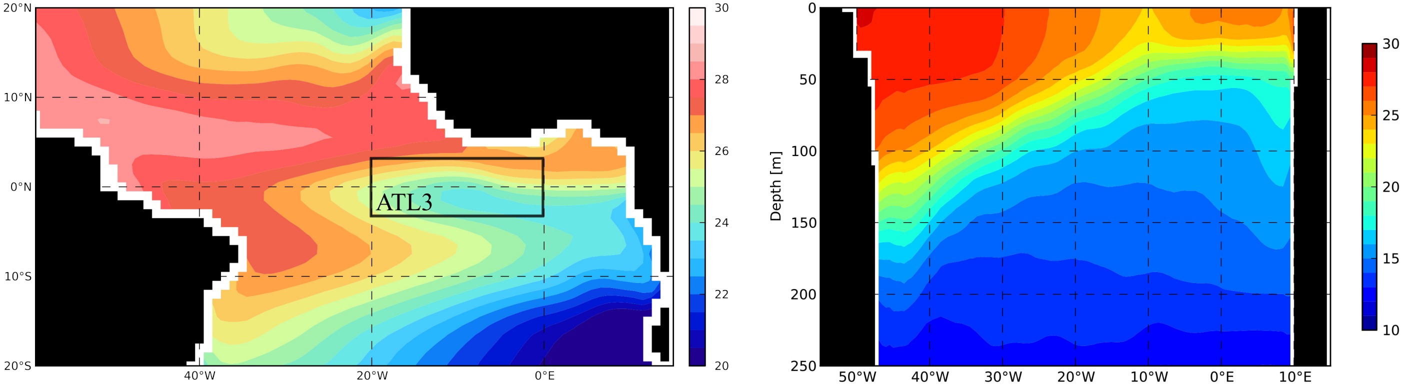


REFERENCE	BIASED
REF : reference simulation with ERA-I interannual forcing (3h u10, v10 and daily sw, lw)	BIASED : forcing biased using CNRM-CM5 coupled model ensemble seasonal cycle and mean state (intraseasonal and interannual variability are kept from DFS)
REF_τ_{clim}: as REF but climatological seasonal cycle of taux/tauy	BIASED_τ_{clim}: as BIASED but climatological seasonal cycle of taux/tauy

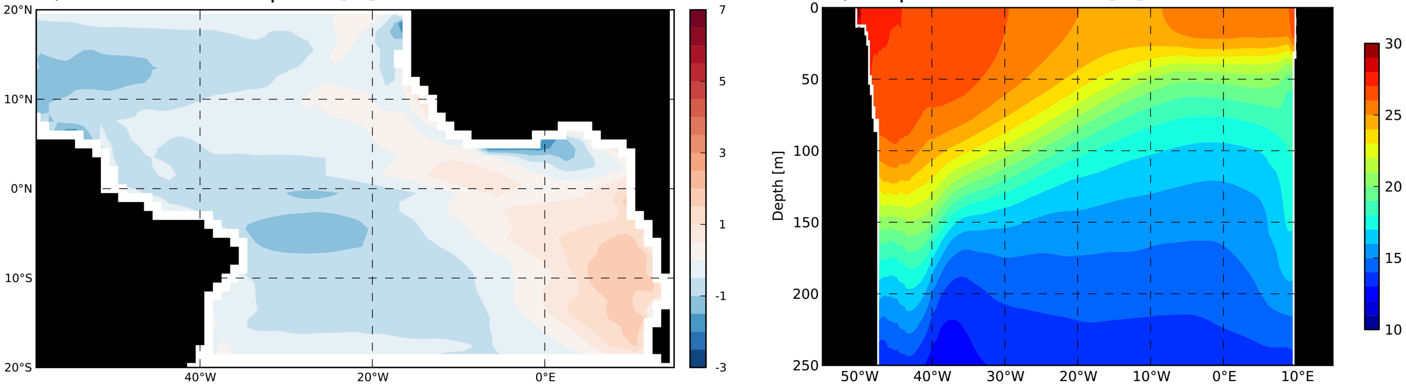




Mean model bias

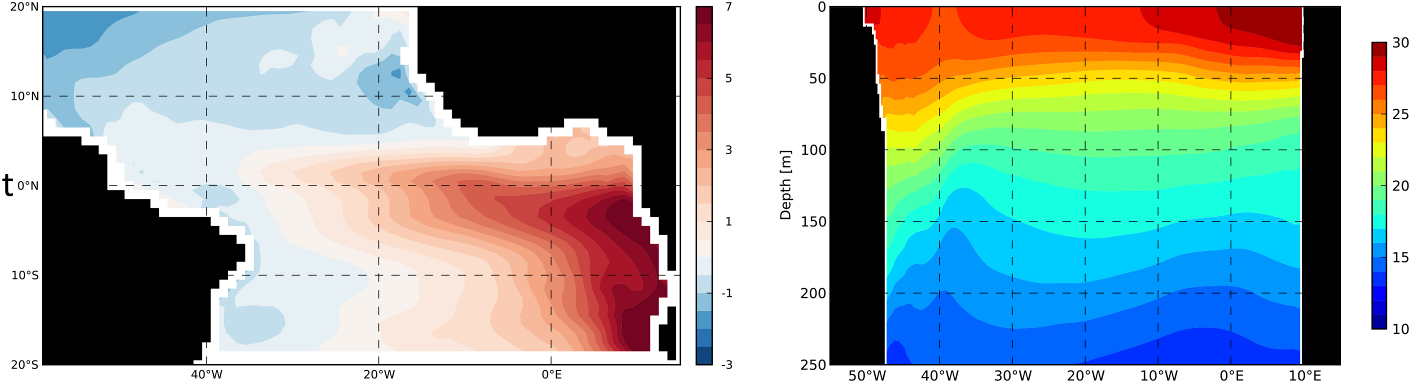

a) SST TropFlux [˚C]

d) Temperature ISAS [˚C]


b) SST anom "REF - TropFlux" [˚C]

e) Temperature model REF [˚C]

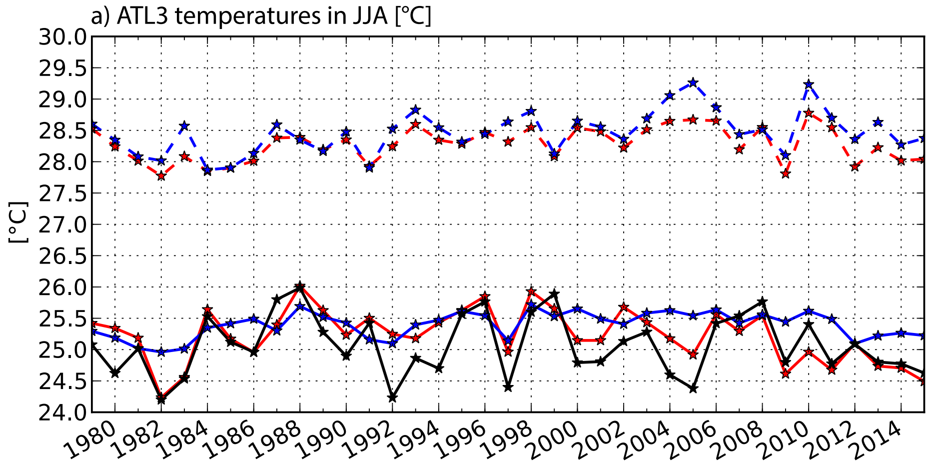
→ Mean SST in the reference simulation with CheapAML compares well with Reynolds observations (bias is relatively weak)

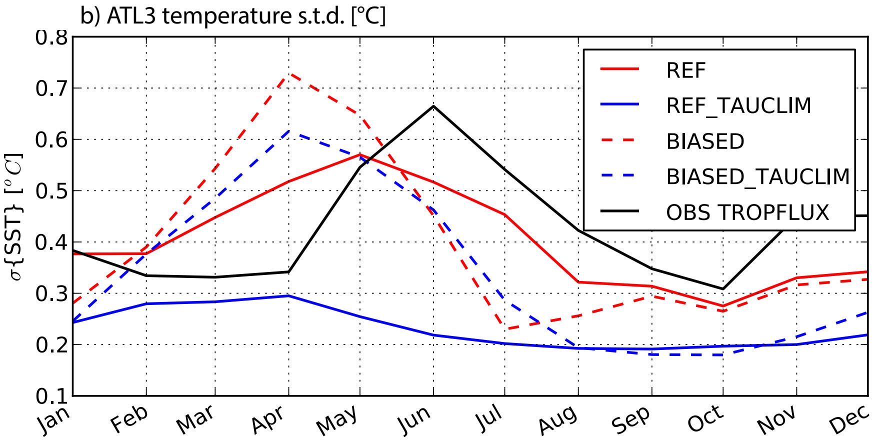

c) SST anom "BIASED - TropFlux" [˚C]

f) Temperature model BIASED [˚C]

→ The biased simulation reproduces a mean bias typical of CNRM-CM5 CMIP5 bias (e.g. Voldoire et al. 2014)

Dynamic vs thermodynamic control of El Nino





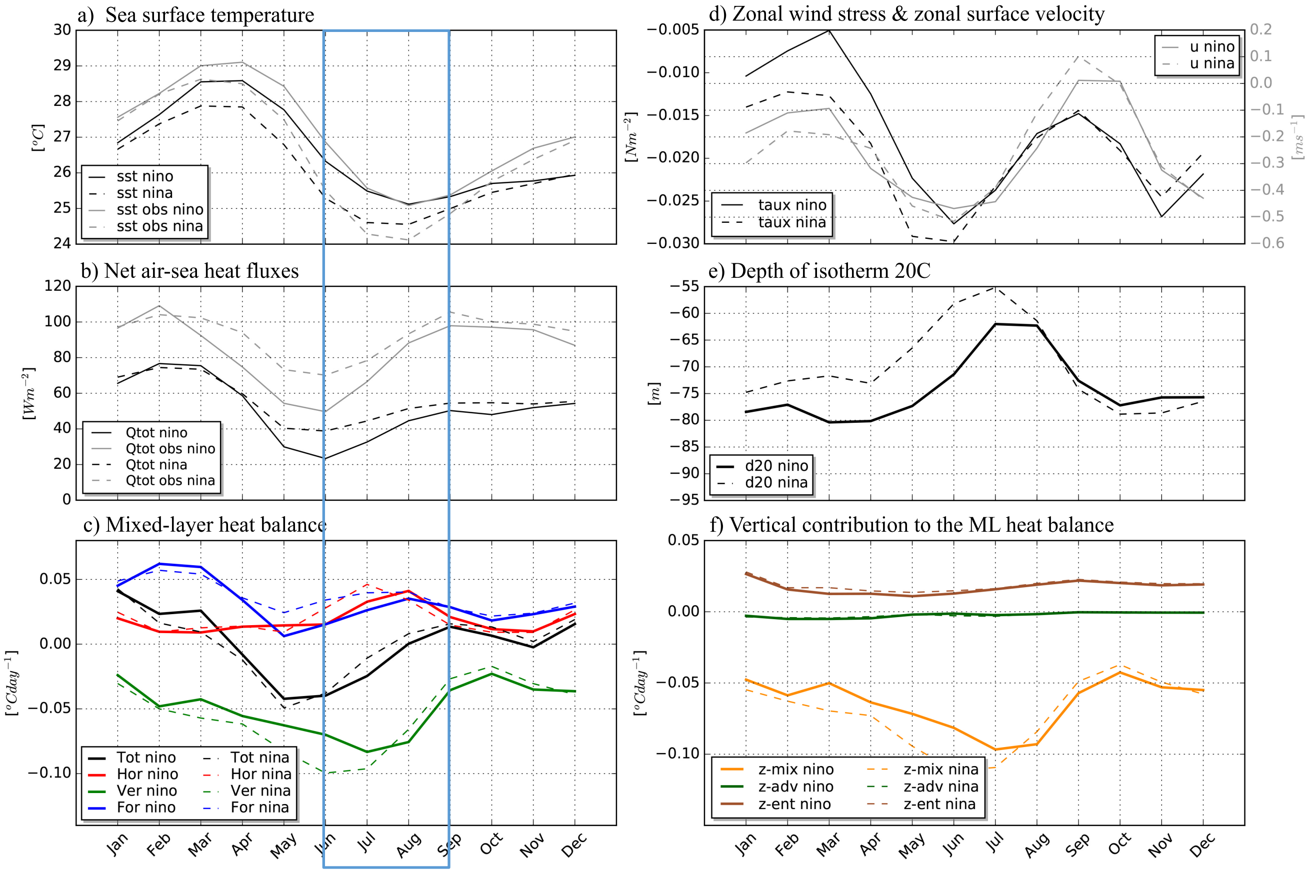
i) REF and BIASED are forced with the same inter-annual variability but show very different Niño variability (mean and seasonal conditions are important)

ii) Large differences between REF and REF_Tauclim → dynamics matter for the Atlantic Niños

iii) Weak differences between BIASED and BIASED_Tauclim → **mean and seasonal bias in the Atlantic Cold Tongue region have consequences on the representation of the Atlantic Niños and processes involved.**

Inter-annual mixed-layer heat balance (REF)

$$\partial_t T = -<u\partial_x T> - <vdyT> + Dl(T) - <w\partial_z T> + \frac{1}{h}\frac{\partial h}{\partial t}(T - Tz_{=-h}) + \frac{1}{h}(Kz\partial_z T)_{z=-h} + \frac{Qns+Qs(1-Fz=-h)}{\rho 0\ Cp\ h}$$



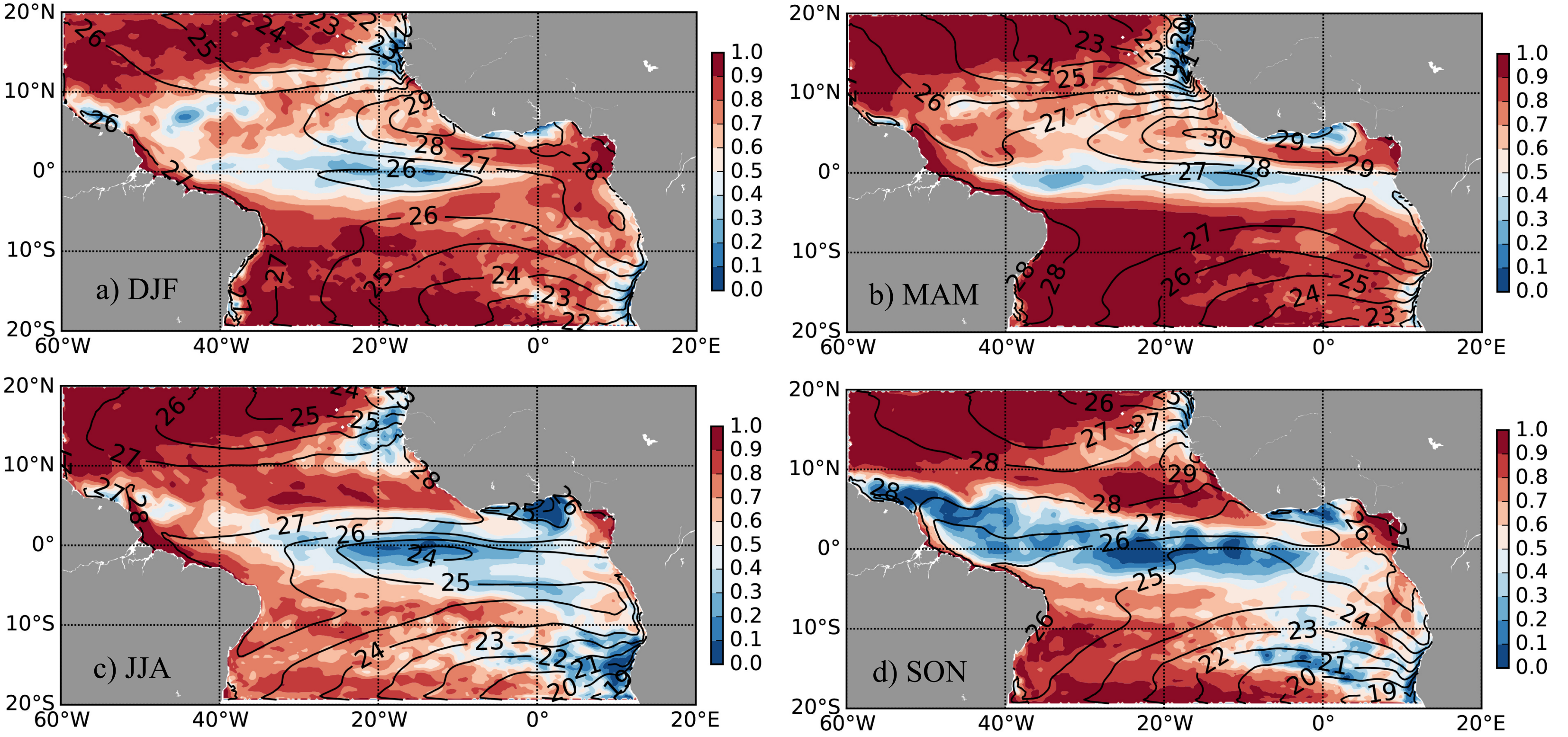
During Niño years :

weaker warming by surface fluxes

subsurface processes (mixing) are less active in cooling the ML

Figure: seasonal cycle of the different contribution to the mixed-layer balance for Niño years (continuous) and Niña years (dashed) in simulation REF

Spatial distribution of the dynamic control (*REF*)

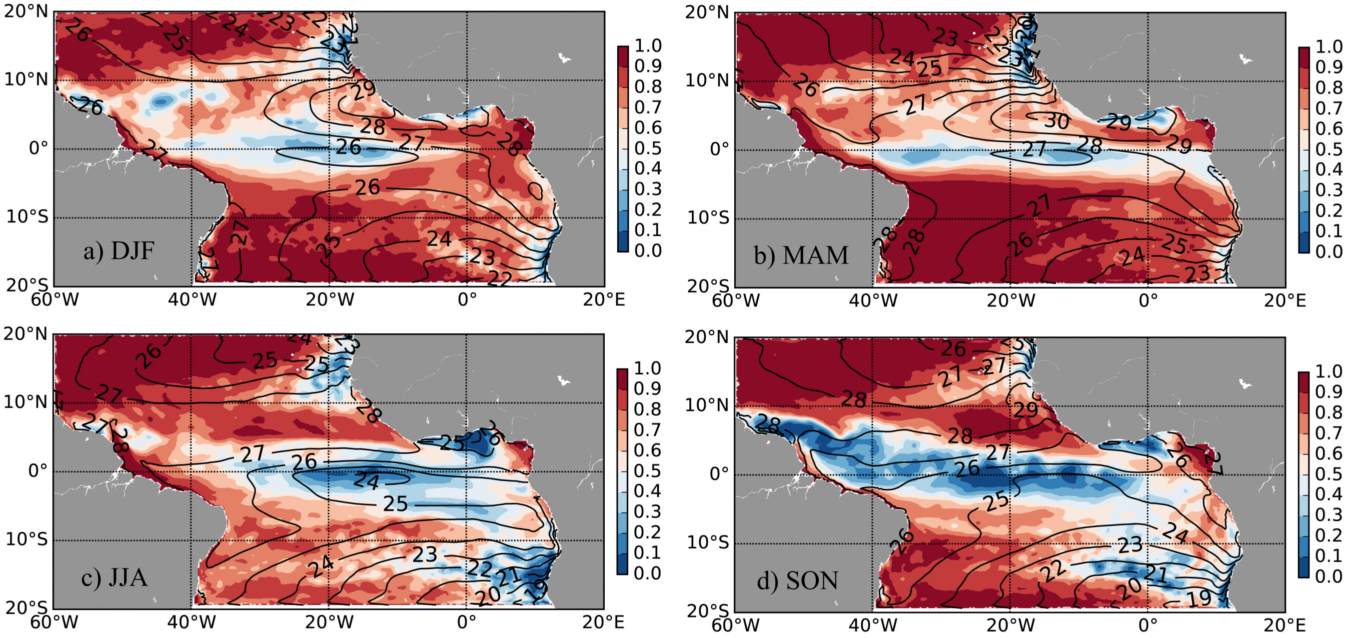


Coefficient of determination (R^2) between REF and REF-T_{clim} seasonal SST time series at each model grid point using data from

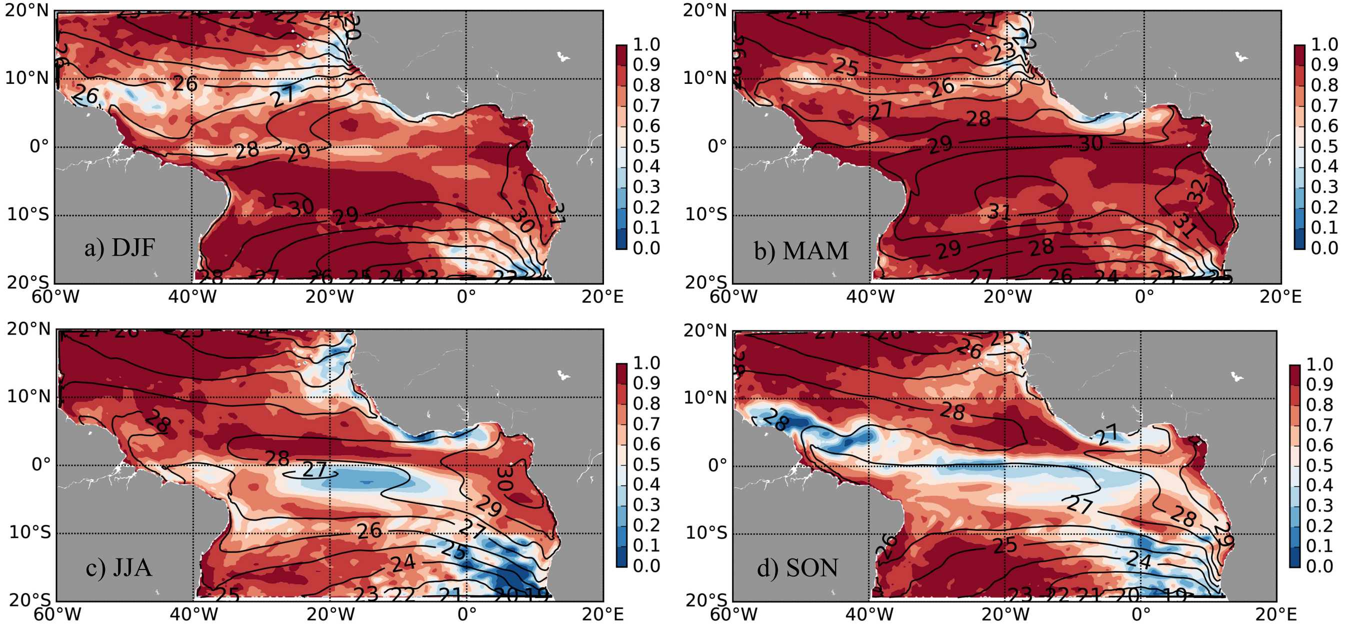
Values close to 1 → interannual SSTs in the two simulations are highly correlated = thermodynamic control

Values close to 0 → interannual SSTs in the two simulations are uncorrelated, suggesting a dynamic control

REF



BIASED → less sensitive to ocean dynamics



Conclusions

Interannual variations of the dynamical forcing largely contributes to the ”Atlantic Niños“

Mean and seasonal upper ocean temperature biases, commonly found in fully coupled models, may favor an unrealistic thermodynamic control of the Equatorial Atlantic interannual variability

CheapAML is a powerful tool to investigate interannual processes with ocean forced model

Jouanno, J., O. Hernandez, and E. Sanchez-Gomez (2017). Equatorial Atlantic interannual variability and its relation to dynamic and thermodynamic processes, Earth Syst. Dynam., 8, 1061-1069, https://doi.org/10.5194/esd-8-1061-2017, 2017.

Main mode of SST inter-annual variability in JJA

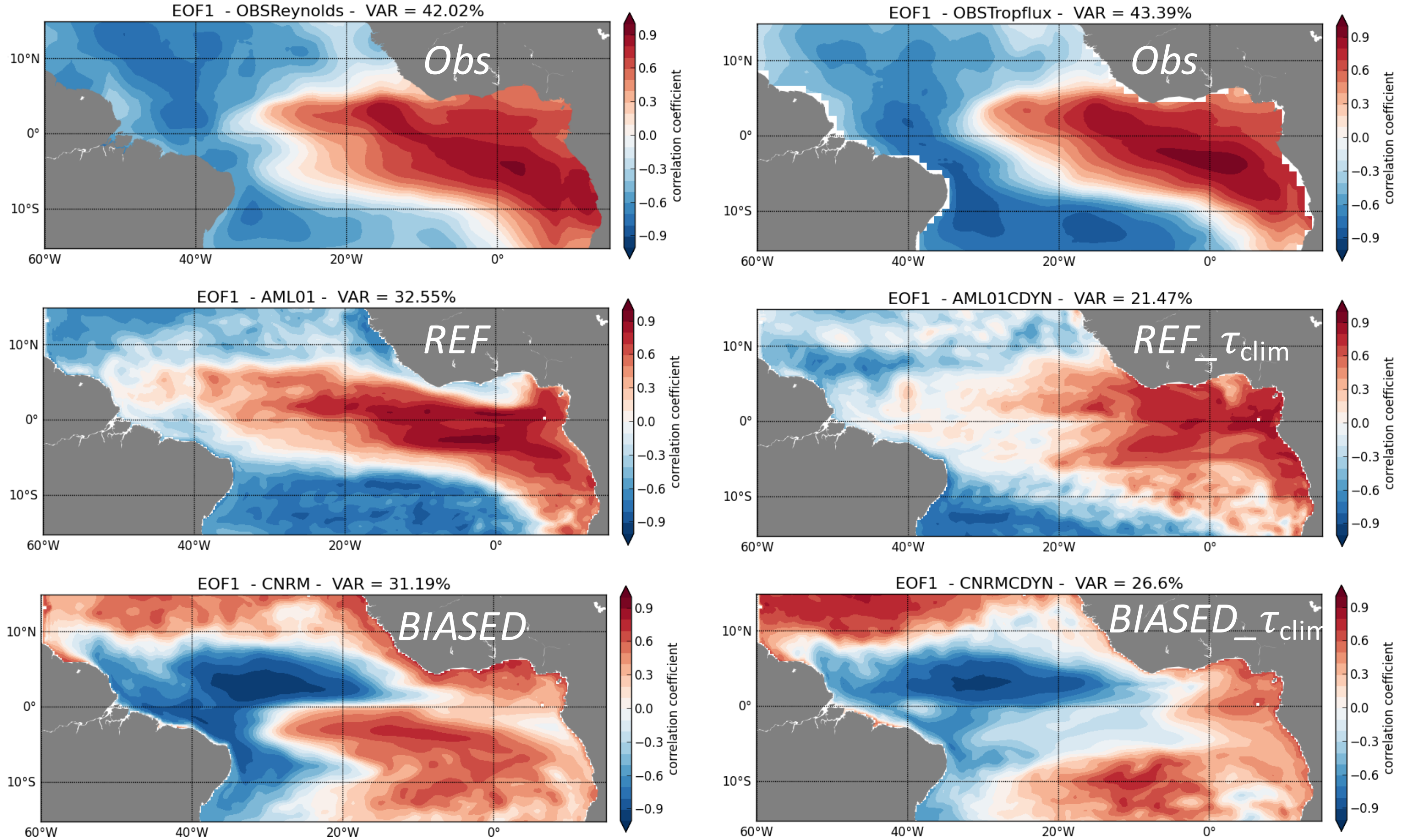
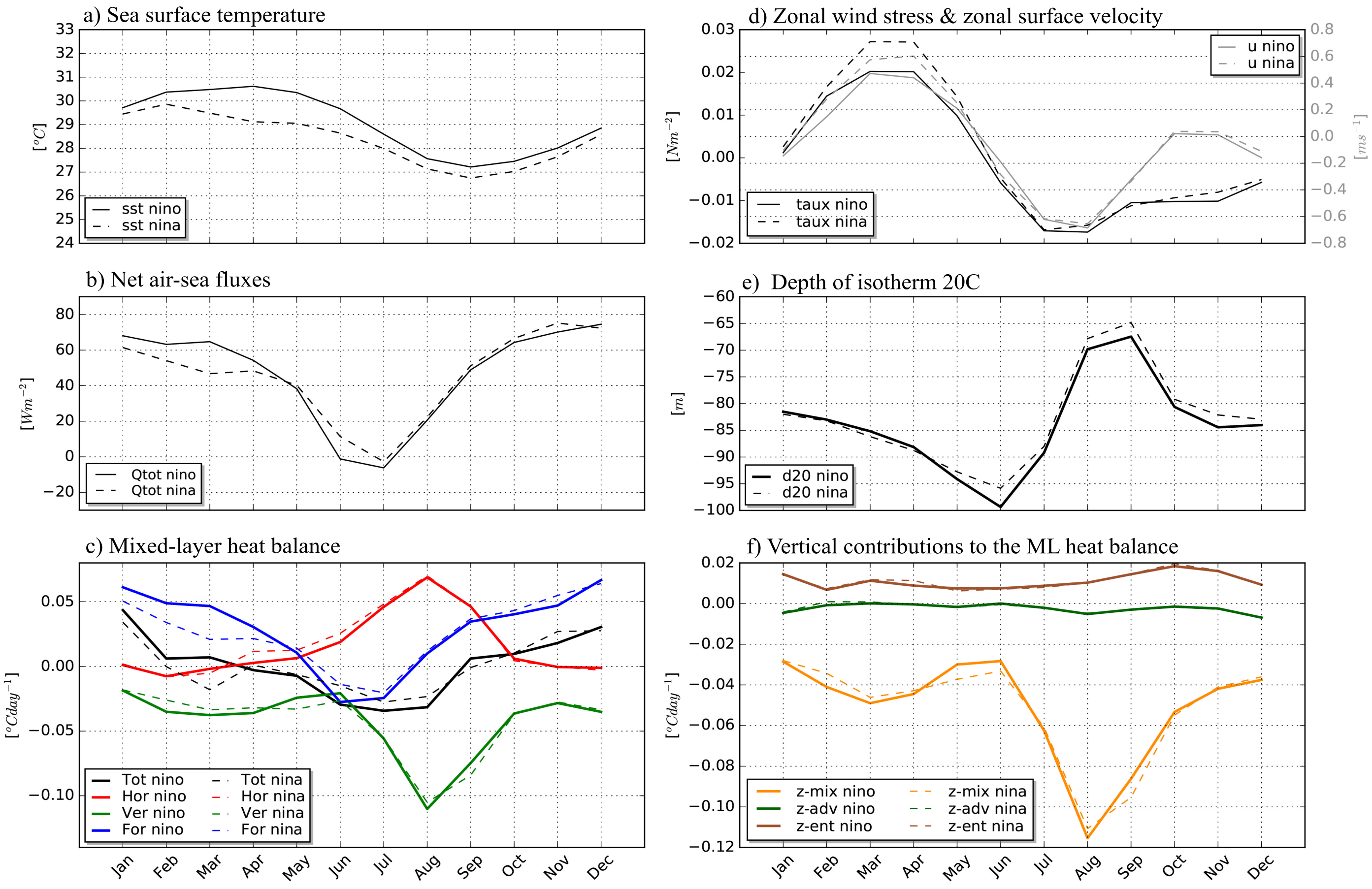


Figure: First EOF mode for JJA sea surface temperature (1980-2012)

Inter-annual mixed-layer heat balance (*BIASED*)



a) Sea surface temperature

d) Zonal wind stress & zonal surface velocity

b) Net air-sea fluxes

e) Depth of isotherm 20C

c) Mixed-layer heat balance

f) Vertical contributions to the ML heat balance