Influence of ocean salinity stratification on the tropical Atlantic Ocean climate

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Scientific context

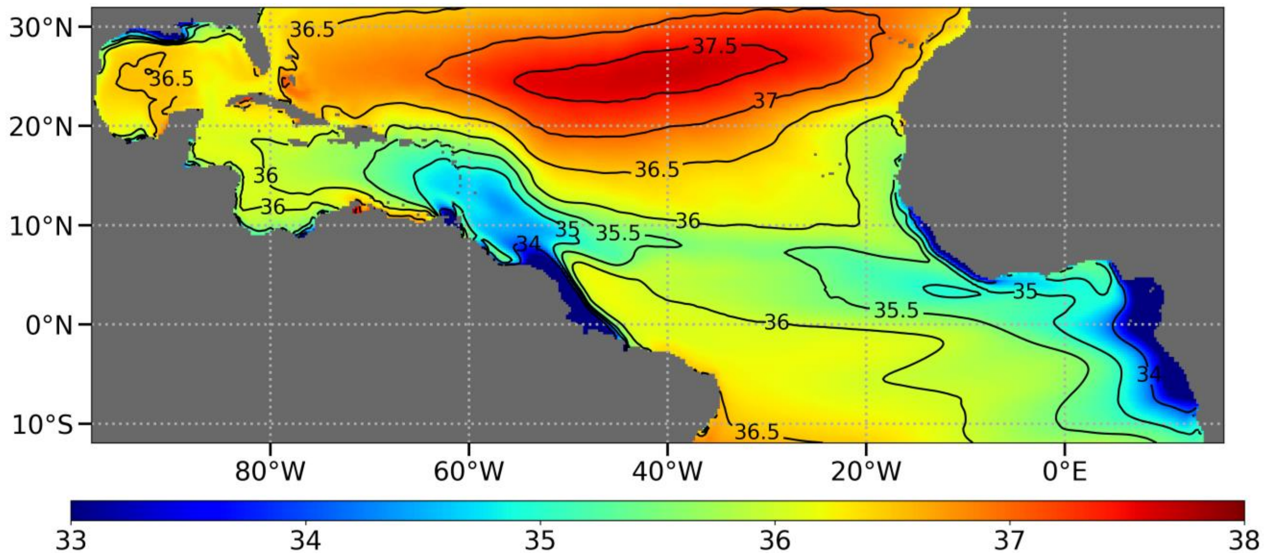
In the tropical Atlantic ocean:

- Important freshwater supply from river runoff (Amazon, Congo, Orinoco, …) and precipitation (ITCZ)

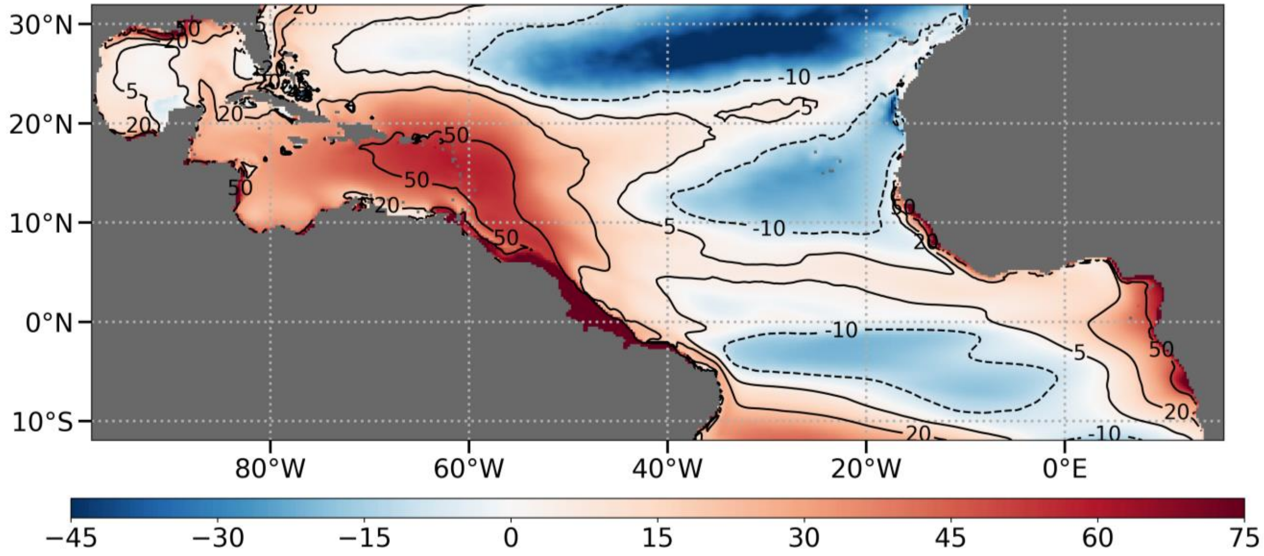
- Strong ocean salinity stratification (OSS), especially in the river plumes

➡ What is the impact of OSS on the SST, and more generally on the tropical Atlantic ocean-atmosphere coupling ?

Sea Surface Salinity [PSU]



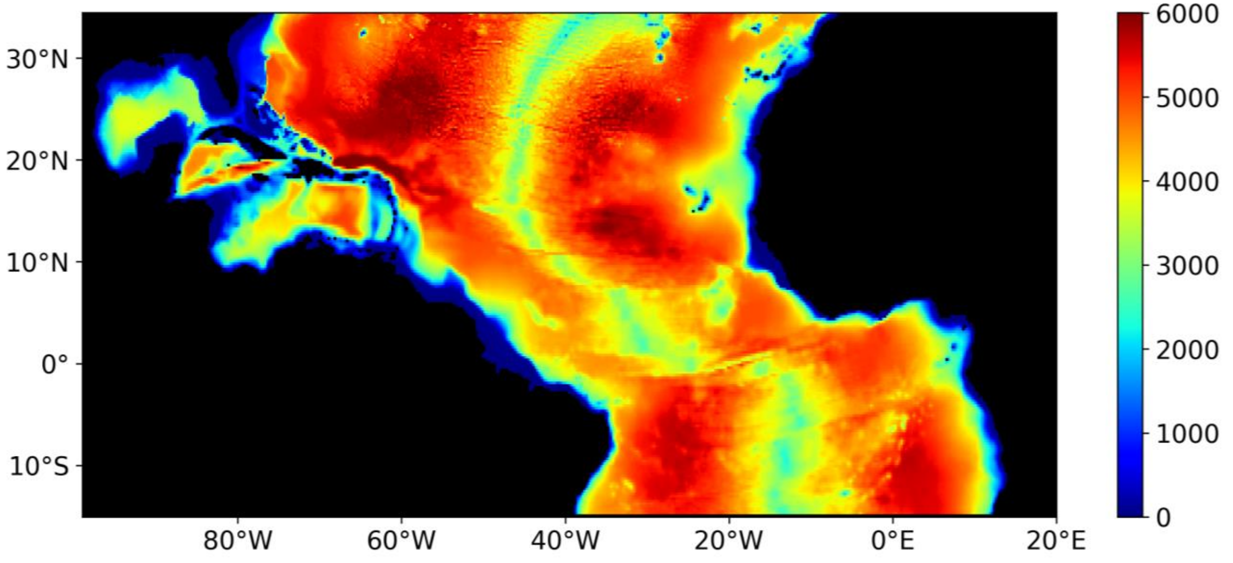
Salinity Stratification (average over 100 m) [%]



Tools and method

Development of a coupled ocean-atmosphere configuration :

- Models
  - Ocean: NEMO 4.0
  - Atmosphere: WRF 3.7.1
  - Coupler: OASIS3-MCT 3.0
- Resolution: 1/4° (~27 km)



Bathymetry of the oceanic model

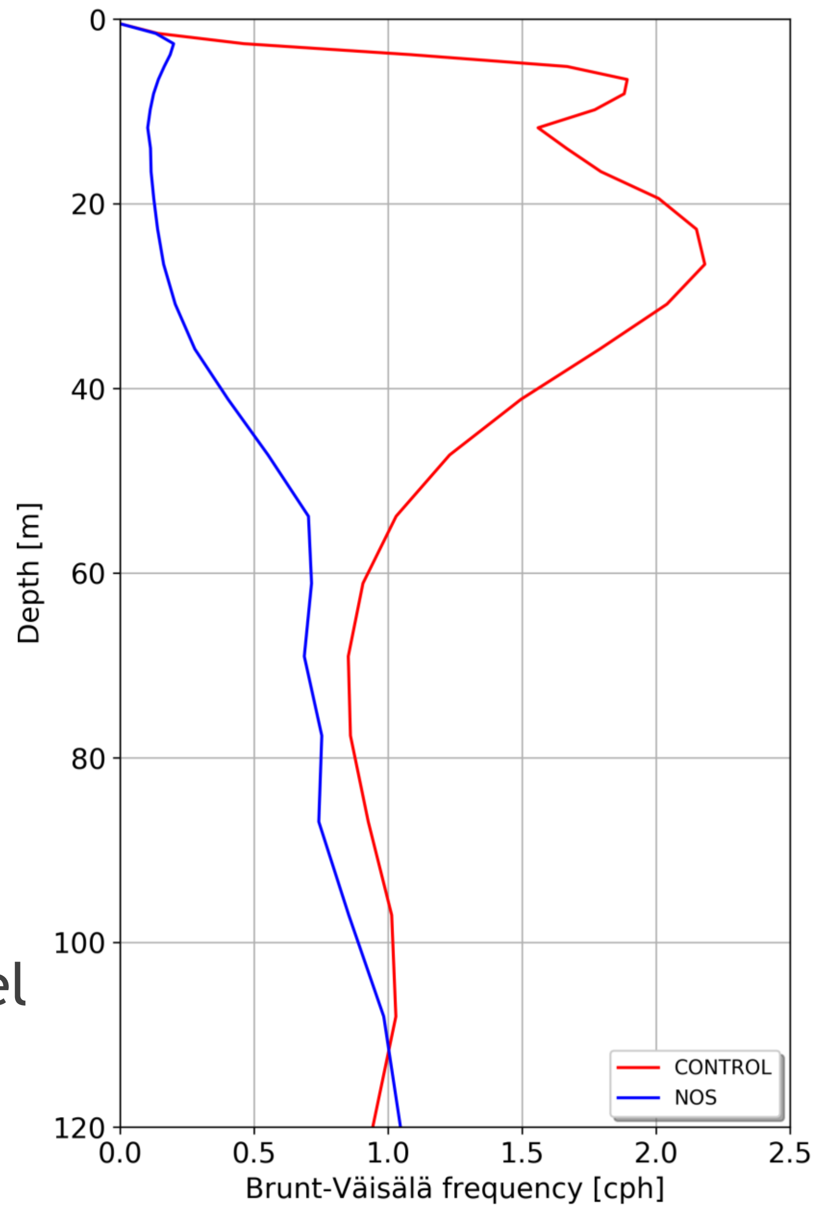
- Grid: 15°S to 35°N – 100°W to 20°E - Mercator projection
- Period: 2001-2015 (after 30 years of forced ocean spin-up + 1 year of coupled spin-up)

Sensitivity test on ocean salinity stratification (OSS)

Aim : to investigate the impact of OSS on the ocean-atmosphere coupling

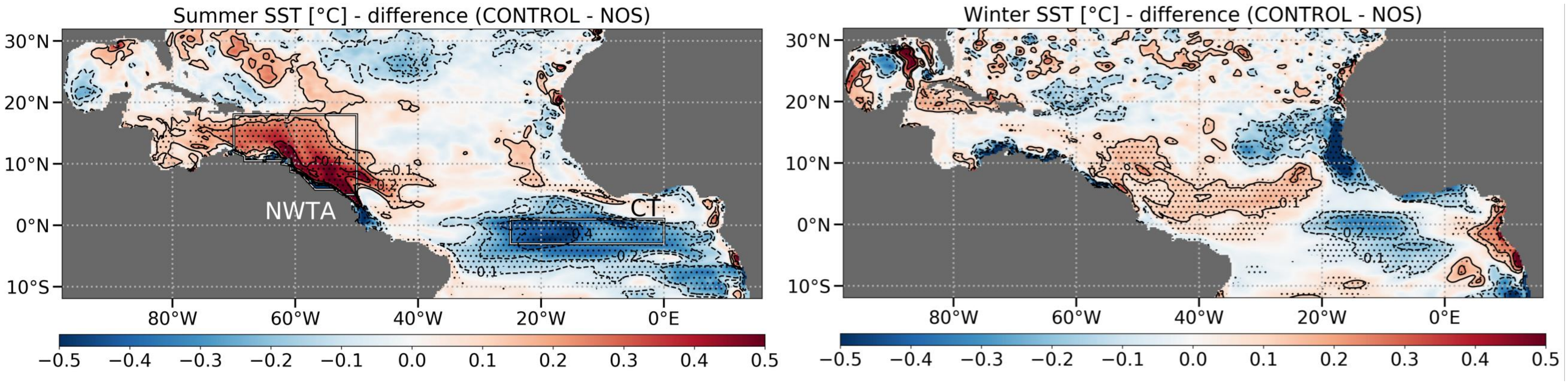
2 simulations :

- CONTROL run
- NOS run :
  - removal of salinity dependency in the calculation of Brunt-Väisälä frequency (N^2) in the ocean model
  - impact on vertical mixing only
  - sea water density calculation not affected



Vertical profile of N^2 in Amazon plume

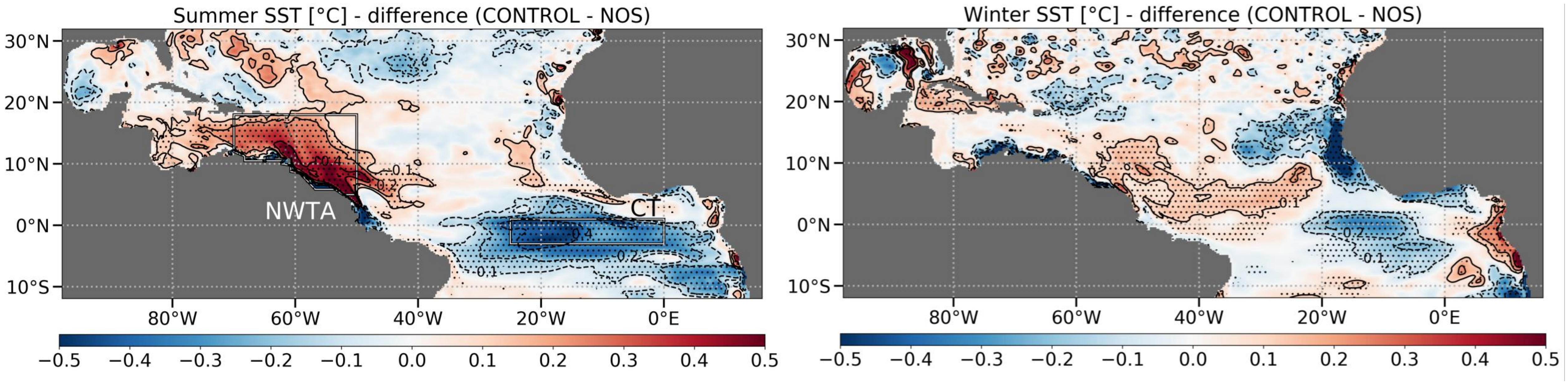
SST sensitivity to salinity stratification



Dots indicate the areas where the difference is significant (Student's t-test with a 99% confidence level)

Difference CONTROL – NOS = impact when salinity stratification is added

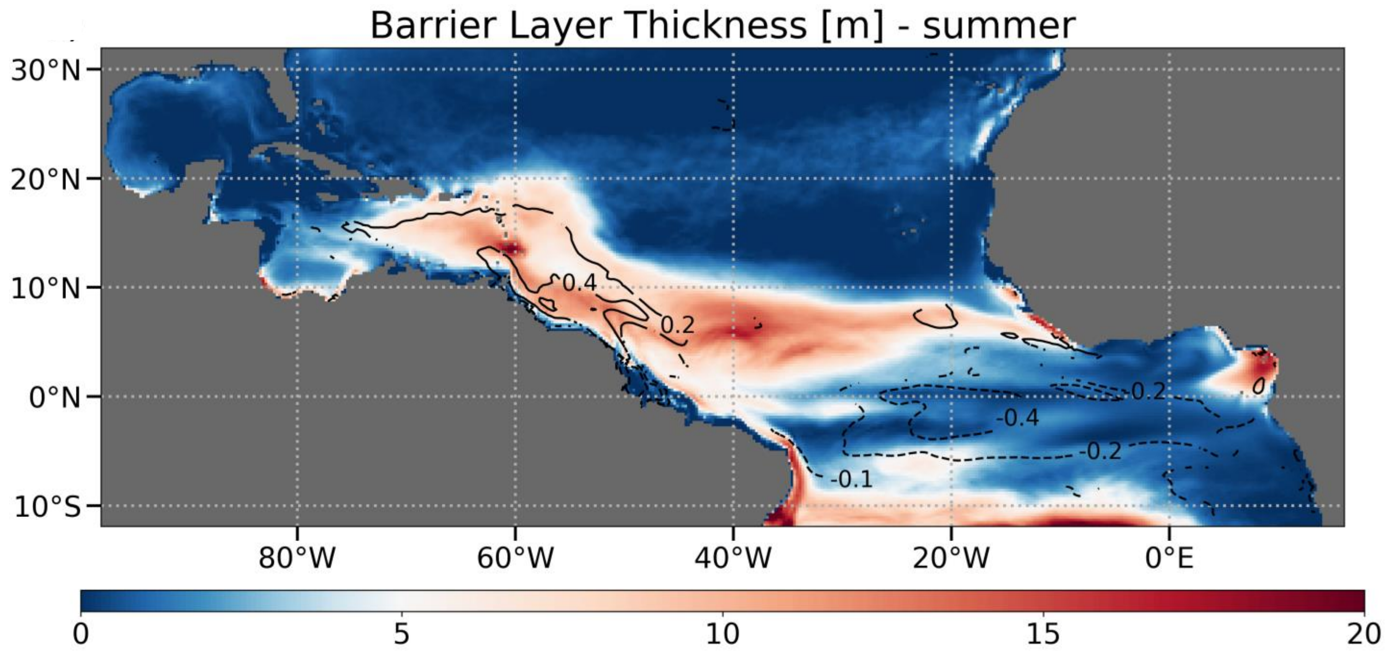
SST sensitivity to salinity stratification



Several patterns arise:

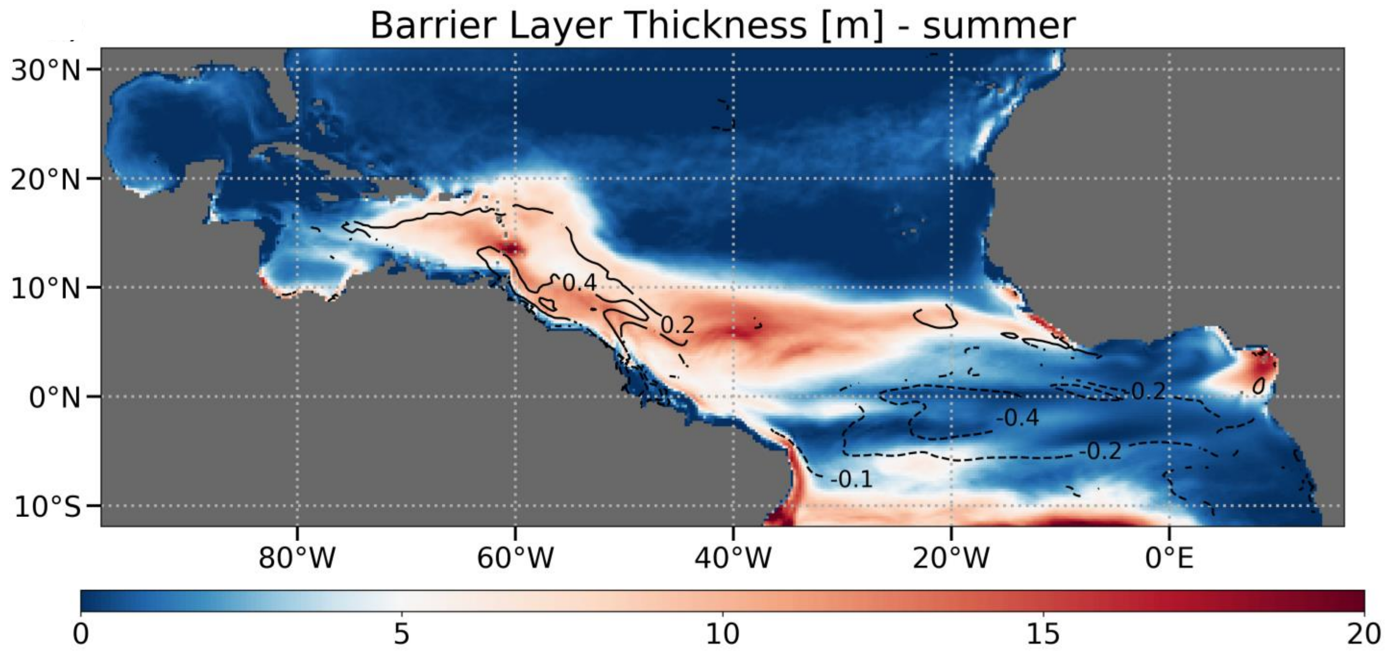
1. Positive SST anomaly in summer in the NWTA
2. Negative SST anomaly in summer in the CT
3. Weak SST change in winter

No apparent connection between SST anomaly and BLT



Contours : isolines of SST difference CONTROL-NOS

No apparent connection between SST anomaly and BLT



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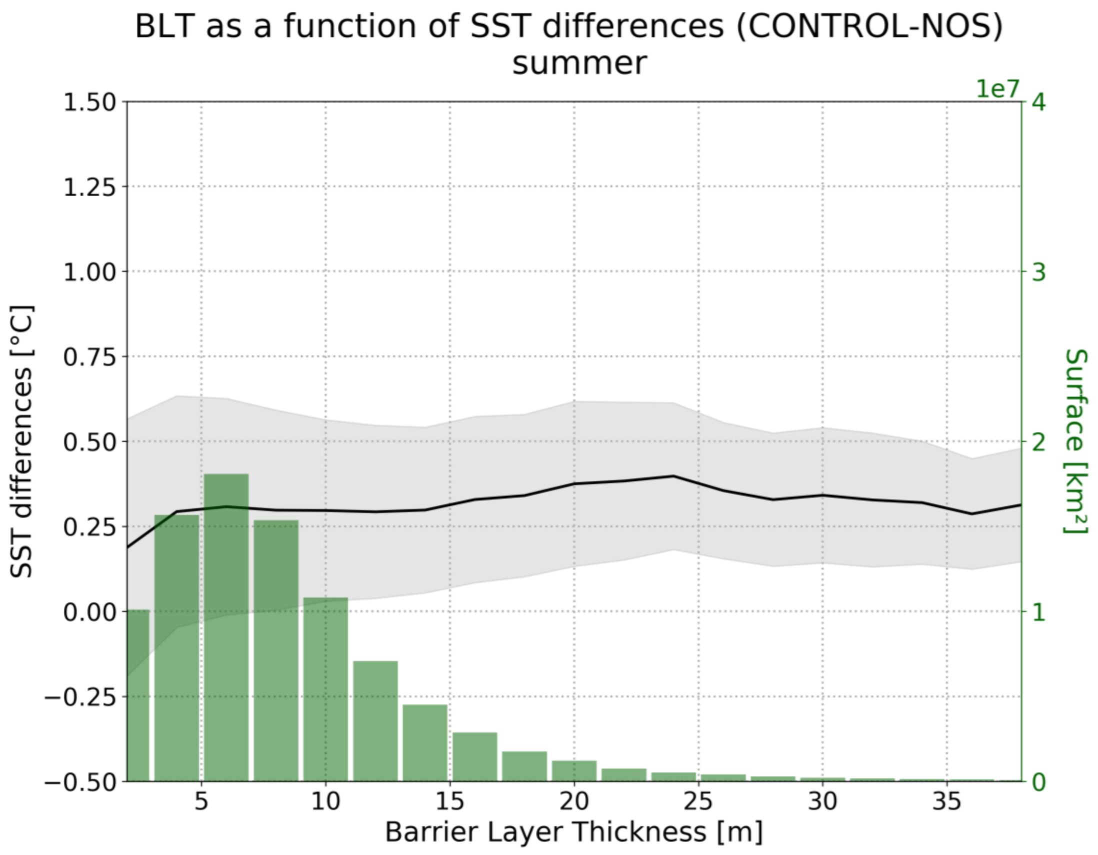
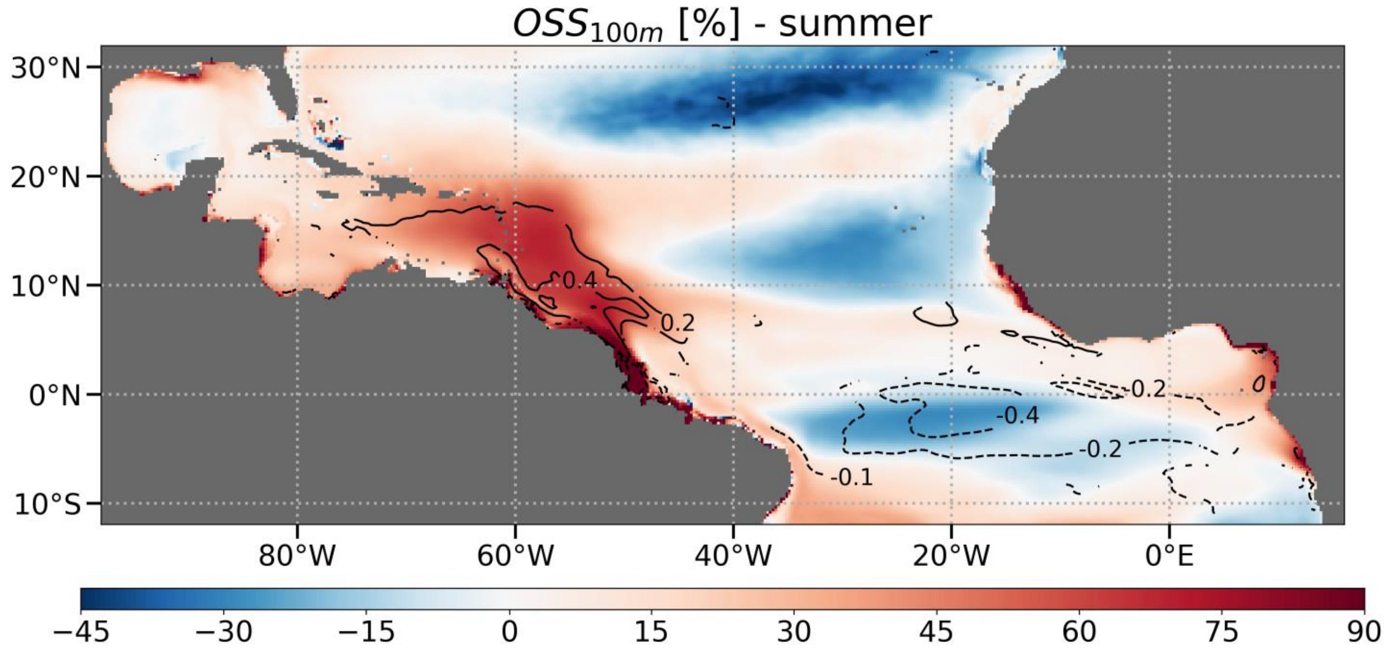


Link between SST and ocean salinity stratification (OSS)

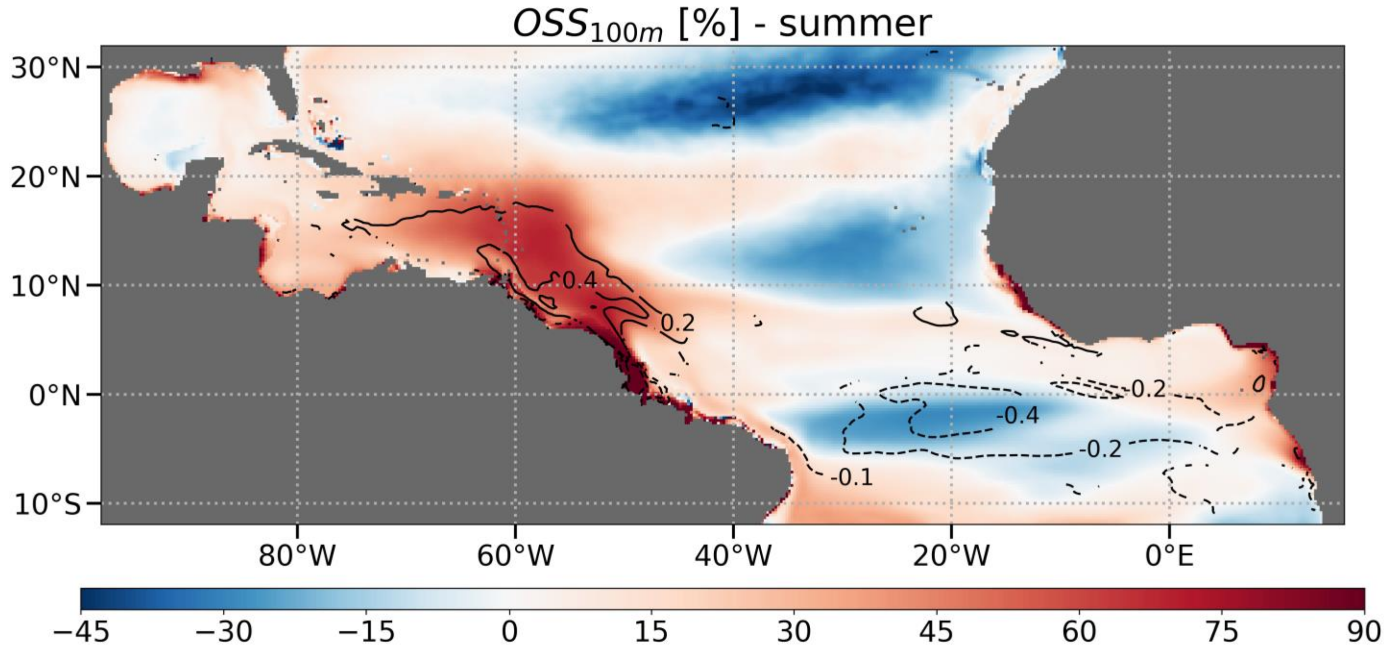


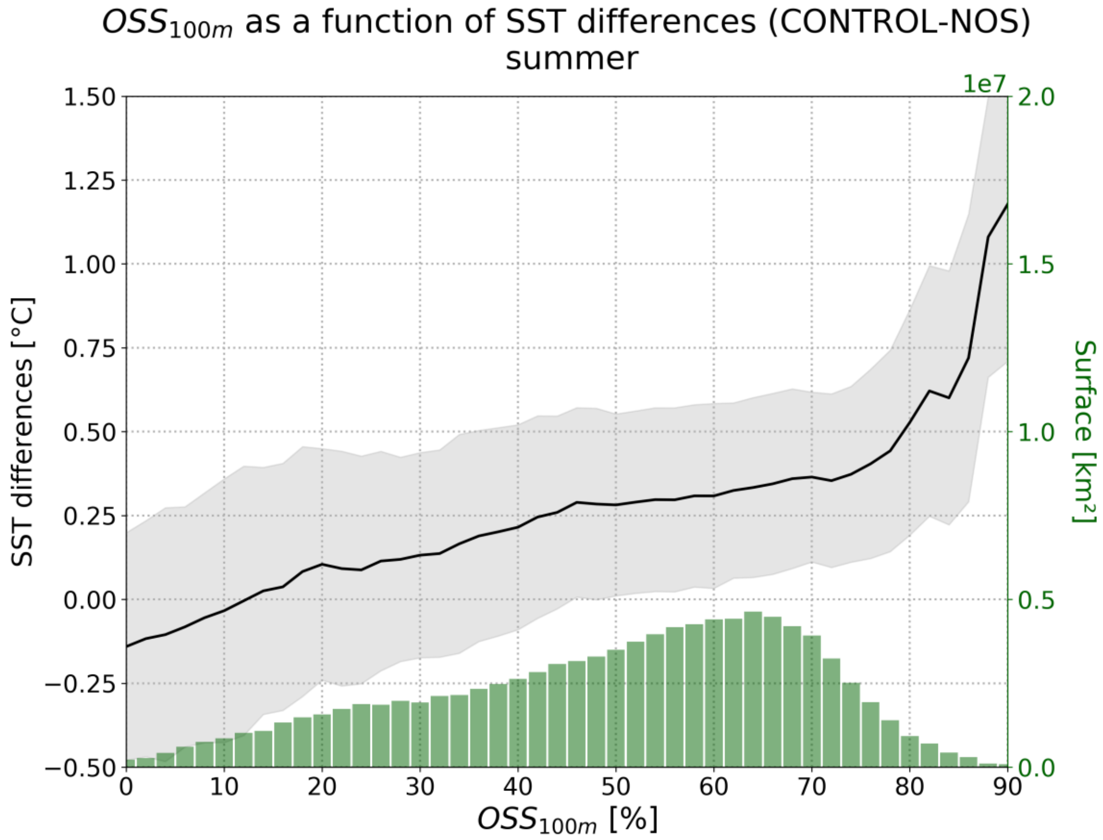
Contours : isolines of SST difference CONTROL-NOS

$$OSS_{100m} = 100 * \frac{\langle N^2 S \rangle_{100m}}{\langle N^2 \rangle_{100m}}$$

(cf. Maes and O'Kane 2014)

Link between SST and ocean salinity stratification (OSS)





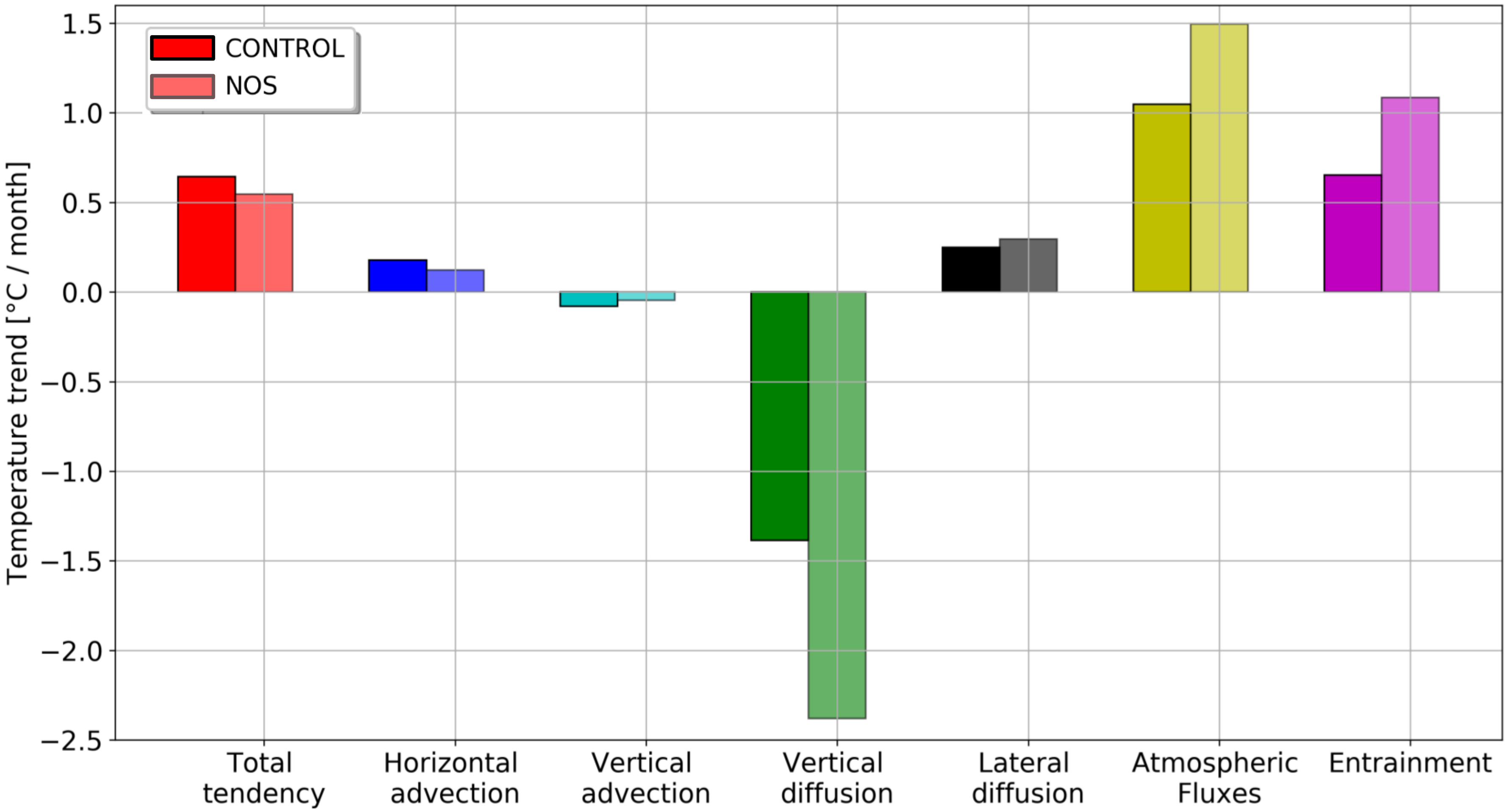
- The higher the OSS_{100m} the larger the SST anomalies

Mixed Layer heat budget

$$\frac{\partial T}{\partial t} = \langle -u\,\partial_x T - v\partial_y T\rangle + \langle -w\,\partial_z T\rangle + \frac{(K_z\partial_z T)_{(z=-h)}}{h} + \langle D_l\rangle + \frac{Q_s(1-F_{-h}) + Q_{ns}}{\rho_0 C_p h} + \frac{\partial_t h}{h}(T_{-h} - \bar{T})$$

with $\langle \blacksquare \rangle = \frac{1}{h}\int_{-h}^{0} \blacksquare \, dz$

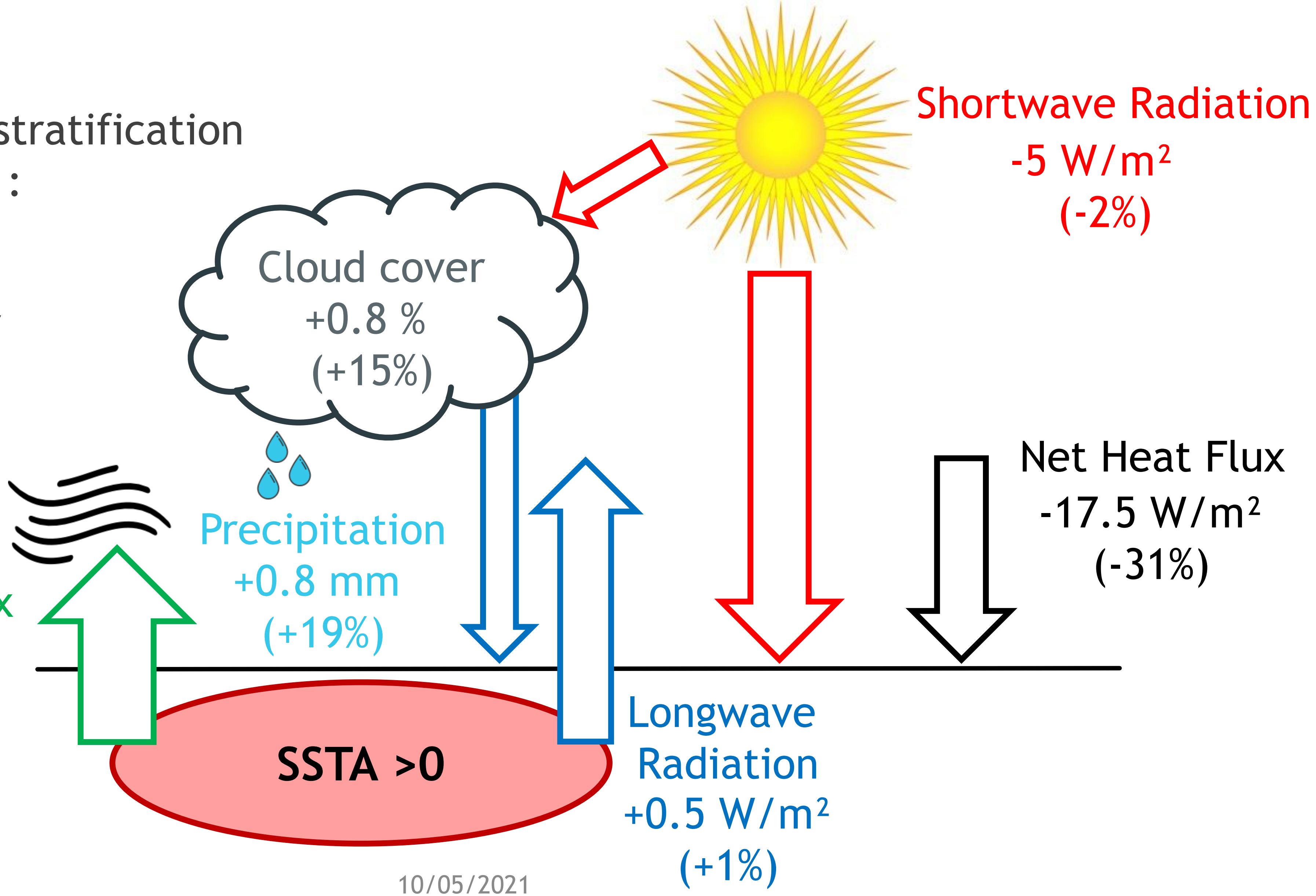
- Increase of temperature by inhibition of vertical mixing
- Damping by atmospheric fluxes and entrainment



Summary scheme of ocean-atmosphere feedback

Impact of salinity stratification on the heat fluxes :

Mean summer values in the NWTA



Summary

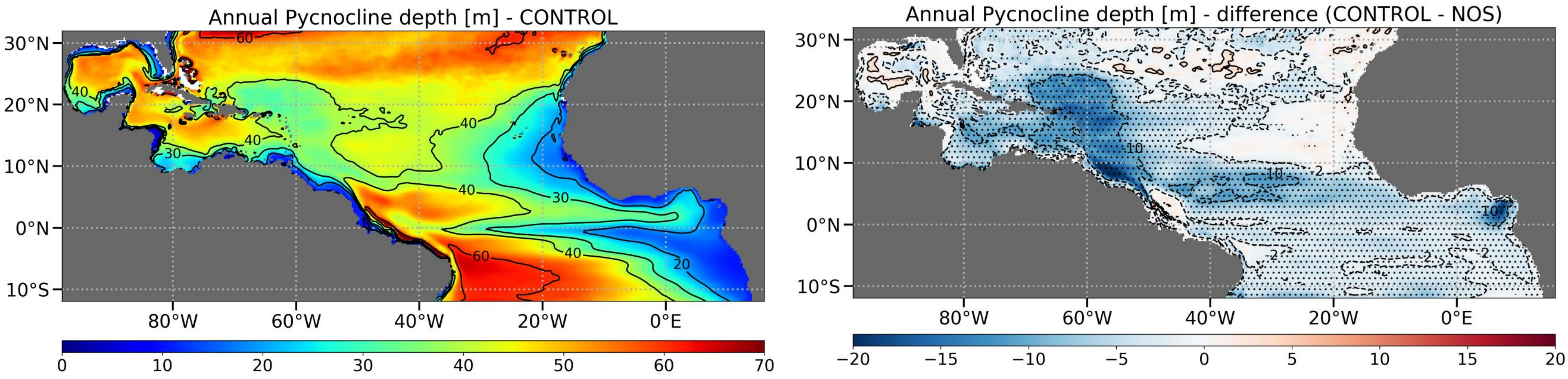
- Amplification of SST seasonal cycle due to salinity stratification :
  - +0.2 to +0.5°C in summer in the NWTA
  - -0.2 to -0.5°C in summer in the CT
  - Little change in winter
- No impact of BLT on SST
- Decrease of cooling due to vertical mixing, damped by a decrease of warming due to atmospheric fluxes and entrainment

Take-home message :

The strong salinity stratification in the northwestern tropical Atlantic induces a significant increase of SST and rainfall in summer, hereby intensifying the ocean-atmosphere water cycle, despite a negative atmospheric feedback

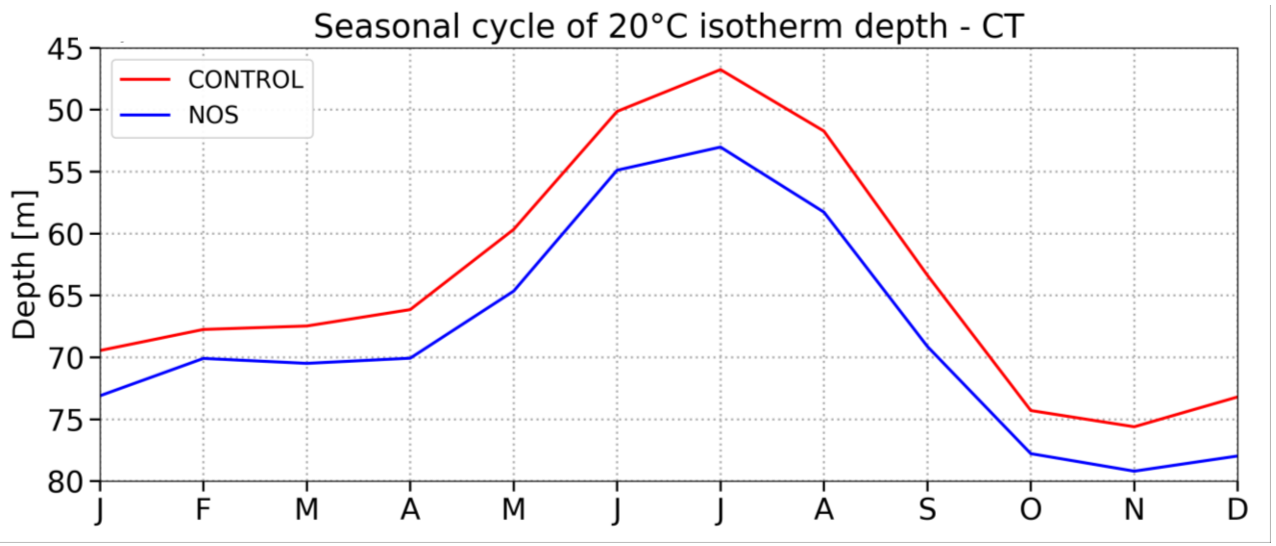
Supplementary material

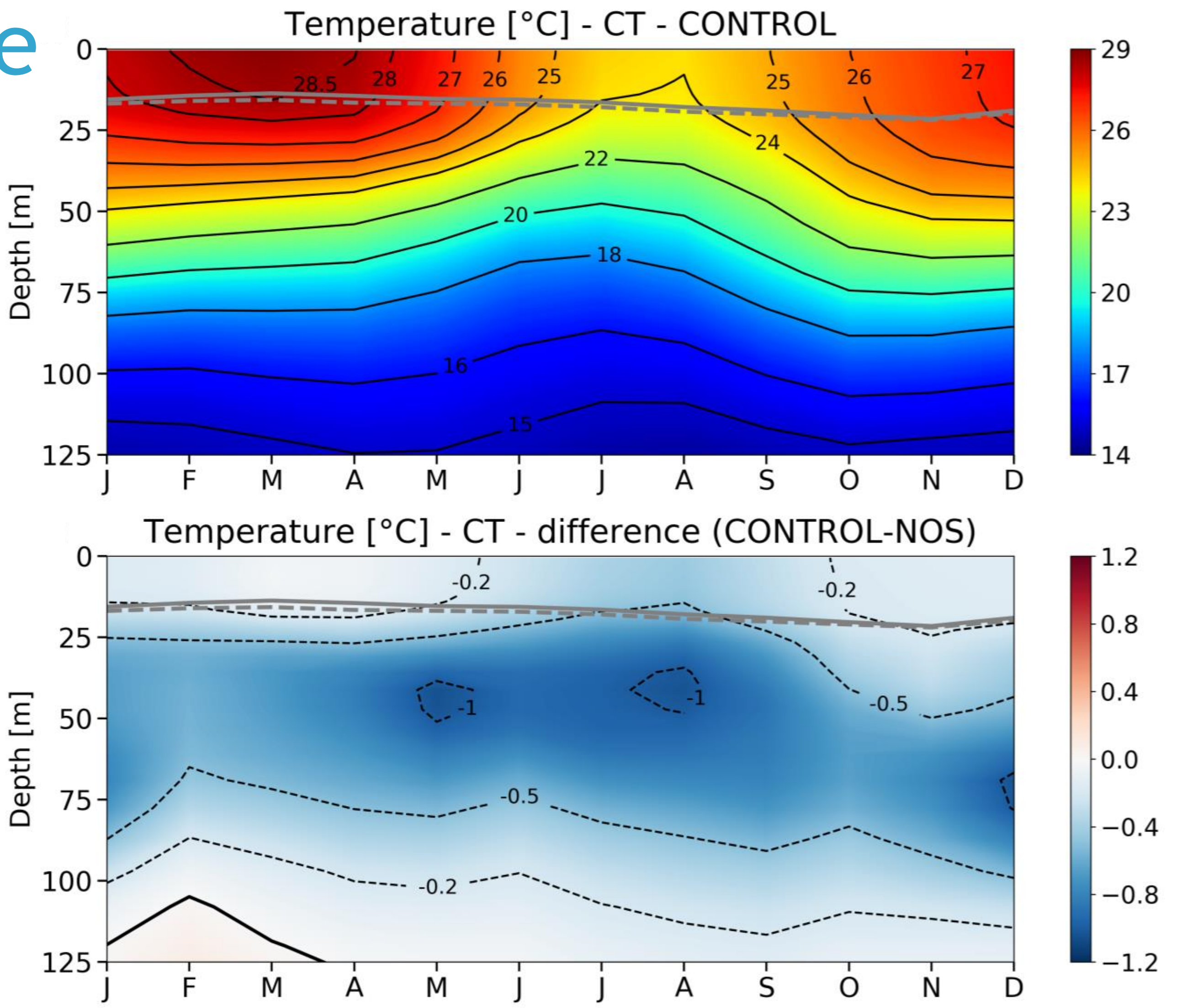
Shoaling of the pycnocline



- Strong shoaling of the pycnocline in the NWTA due to reduced vertical mixing
- Density adjustment over the whole basin

Shoaling of the thermocline



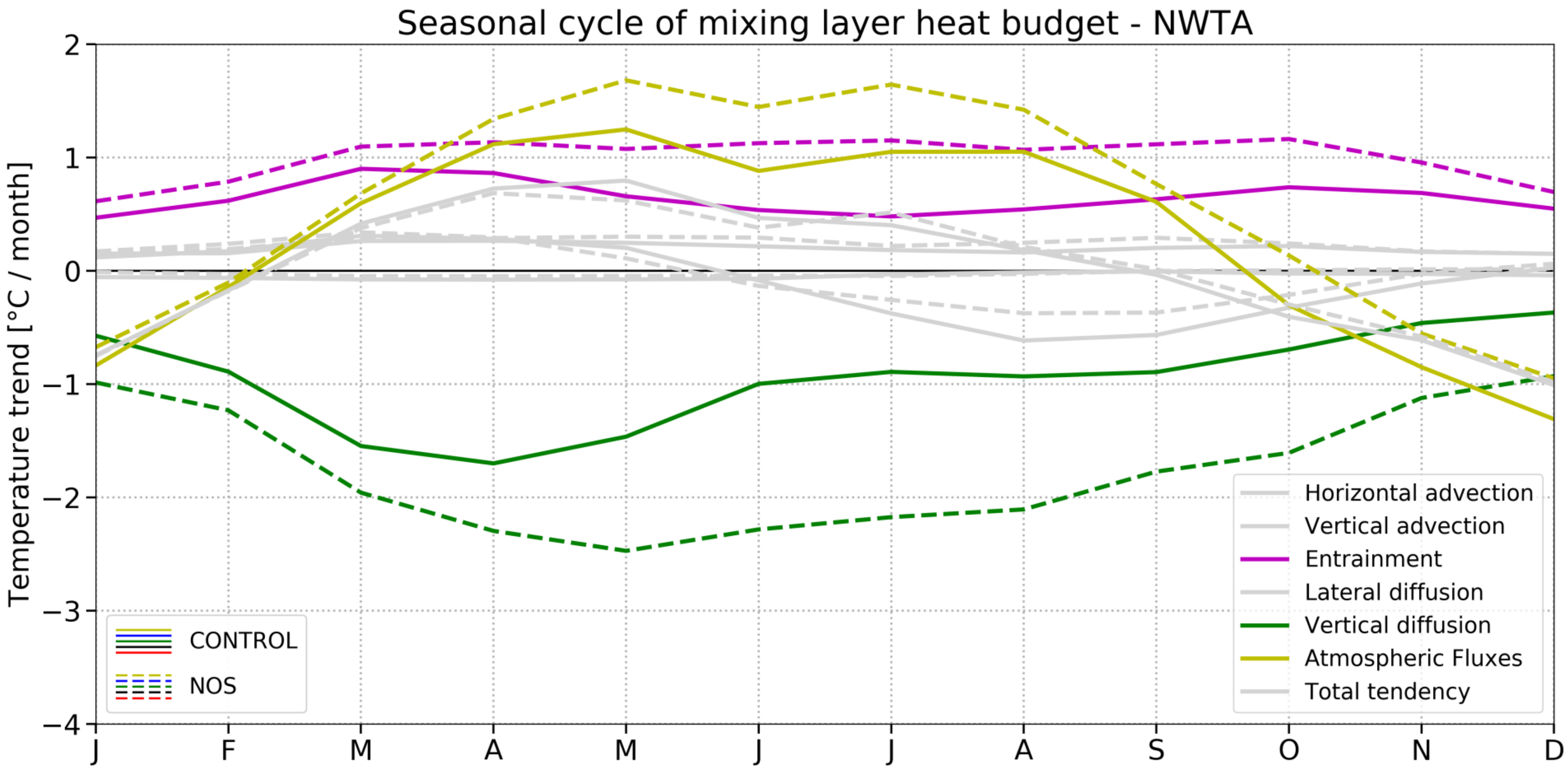


Seasonal cycle – CT mean
(3°S to 1°N ; 25°W to 0°E)

- Year-round shoaling of the thermocline
- Surface signature in summer only (upwelling season)

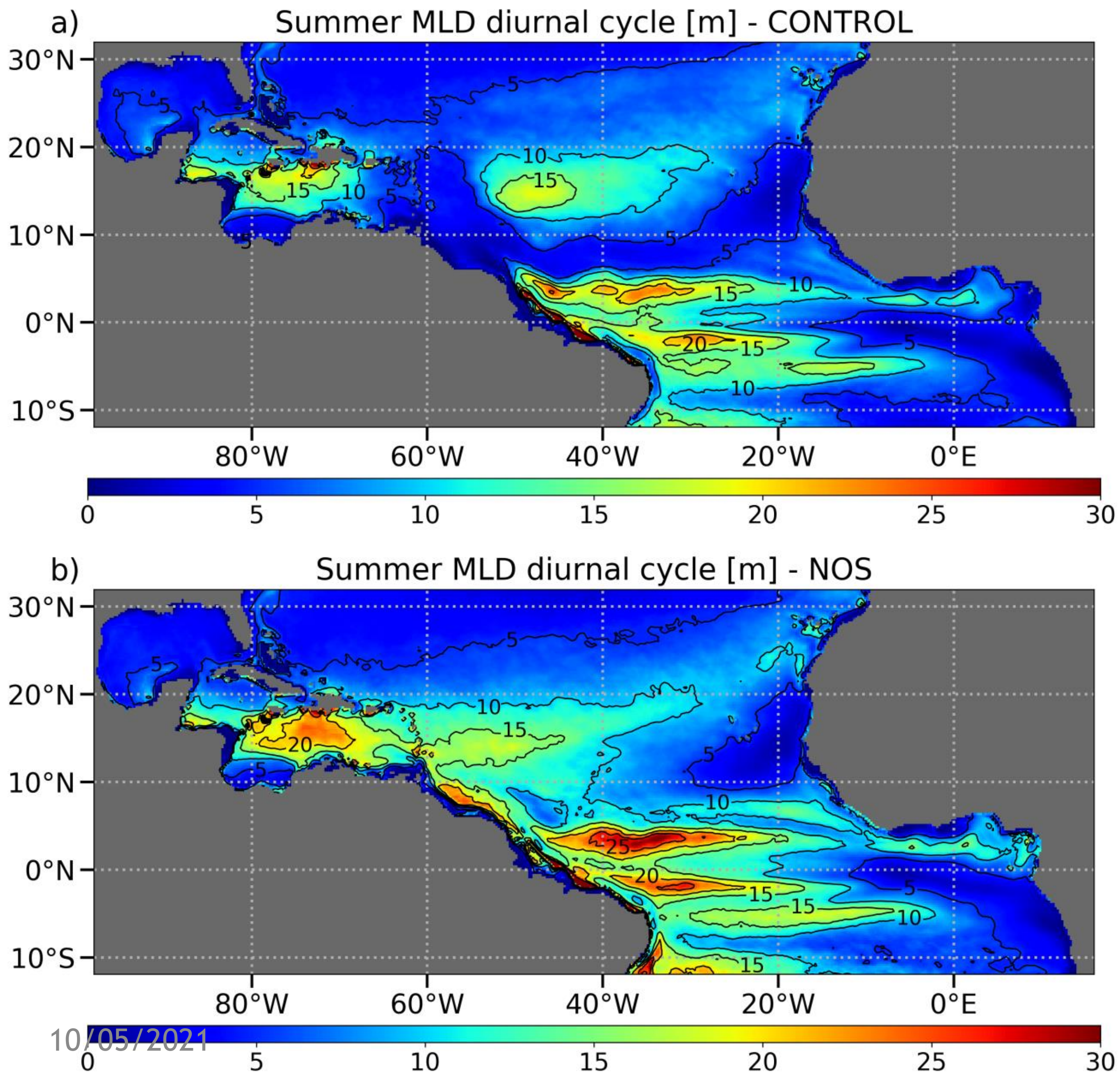
MLD heat budget

- $\text{Entrainment} = \frac{\partial_t h}{h}(T_{-h} - \bar{T})$



MLD diurnal cycle

- Null during ML deepening events: $(T_{-h} - \bar{T}) = 0$
- Entrainment controlled by restratification events, and especially diurnal cycle
- MLD diurnal cycle, and therefore entrainment: low in CONTROL and high in NOS



Tools and method

Development of a coupled ocean-atmosphere configuration :

WRF:

- 40 vertical levels (σ coordinates)
- Top of the atmosphere : 50 hPa
- Forcing : ERA-Interim (6-hourly), albedo: MODIS (monthly)

NEMO:

- 75 vertical levels (z coordinates)
- Forcing : MERCATOR GLORYS2V4 (daily), runoff: ISBA-CTRIP (daily)

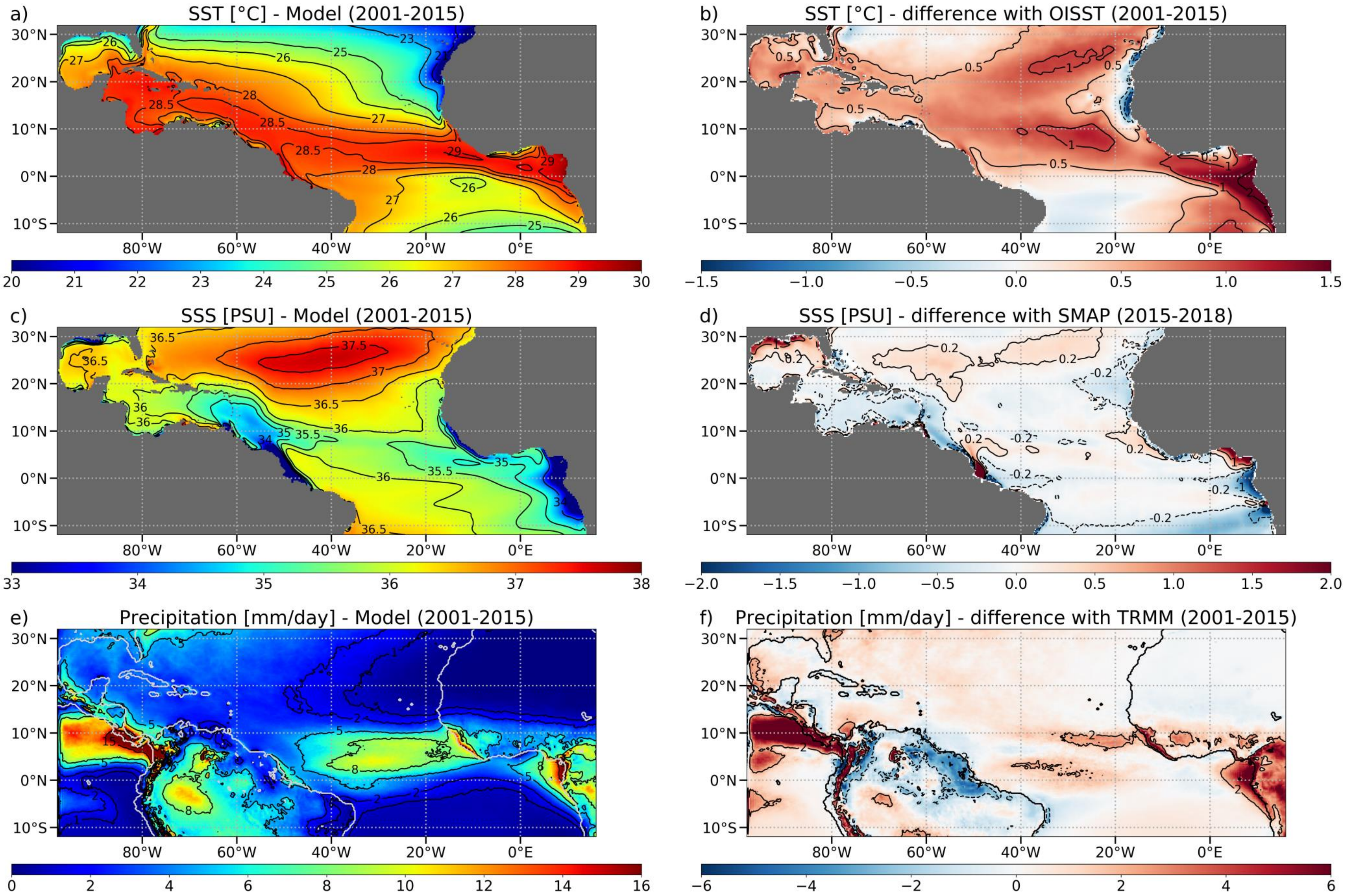
OASIS:

- fields exchanged every hour
- WRF to NEMO : surface winds, heat and water fluxes
- NEMO to WRF : surface currents, SST

HPC:

- Irene (CEA) – 48 CPUs/node
- 288 CPUs : WRF ⟶ 270 + NEMO ⟶ 12 + XIOS ⟶ 6
- 1 month simulated in 1 hour

Validation



Sea Surface Temperature [°C]

Sea Surface Salinity [PSU]

Precipitation [mm/day]

Manon Gévaudan

Validation

Mixed Layer Depth [m]

Net Heat Flux [W/m²]

20°C isotherm depth [m]