Influence of ocean salinity stratification on the tropical Atlantic Ocean surface

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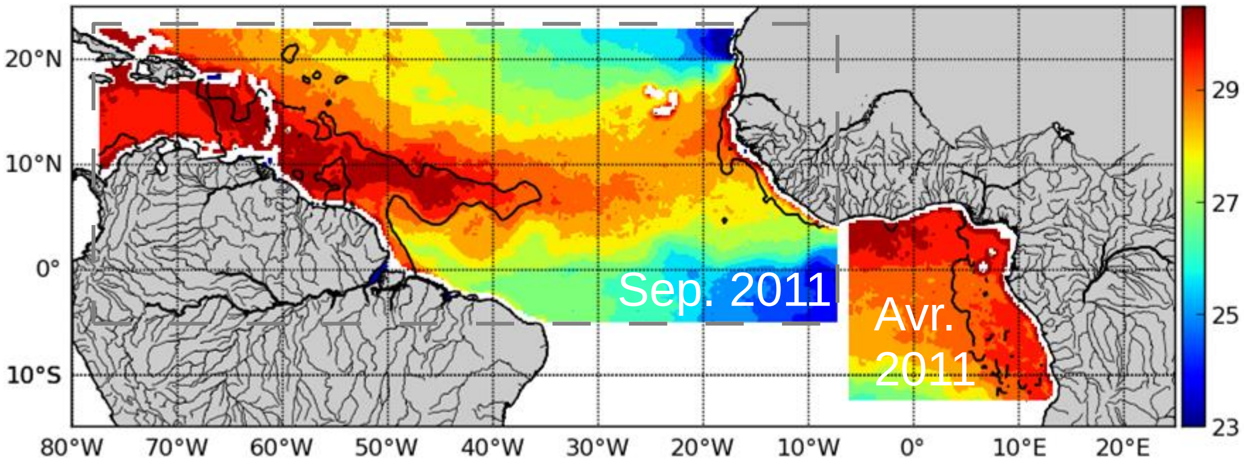
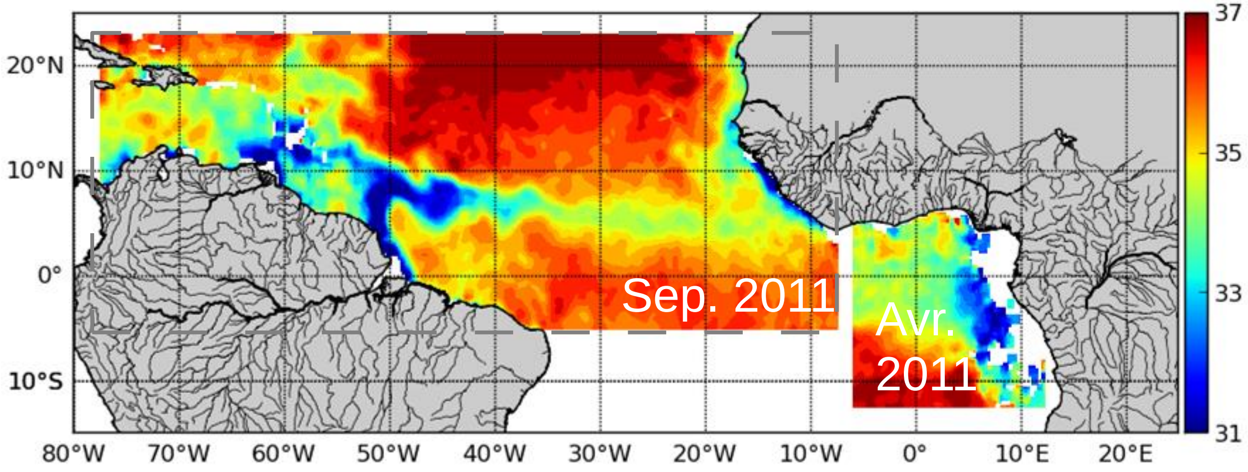
Scientific context

In the tropical Atlantic ocean:

Sea Surface Temperature (SST)



Sea Surface Salinity (SSS)



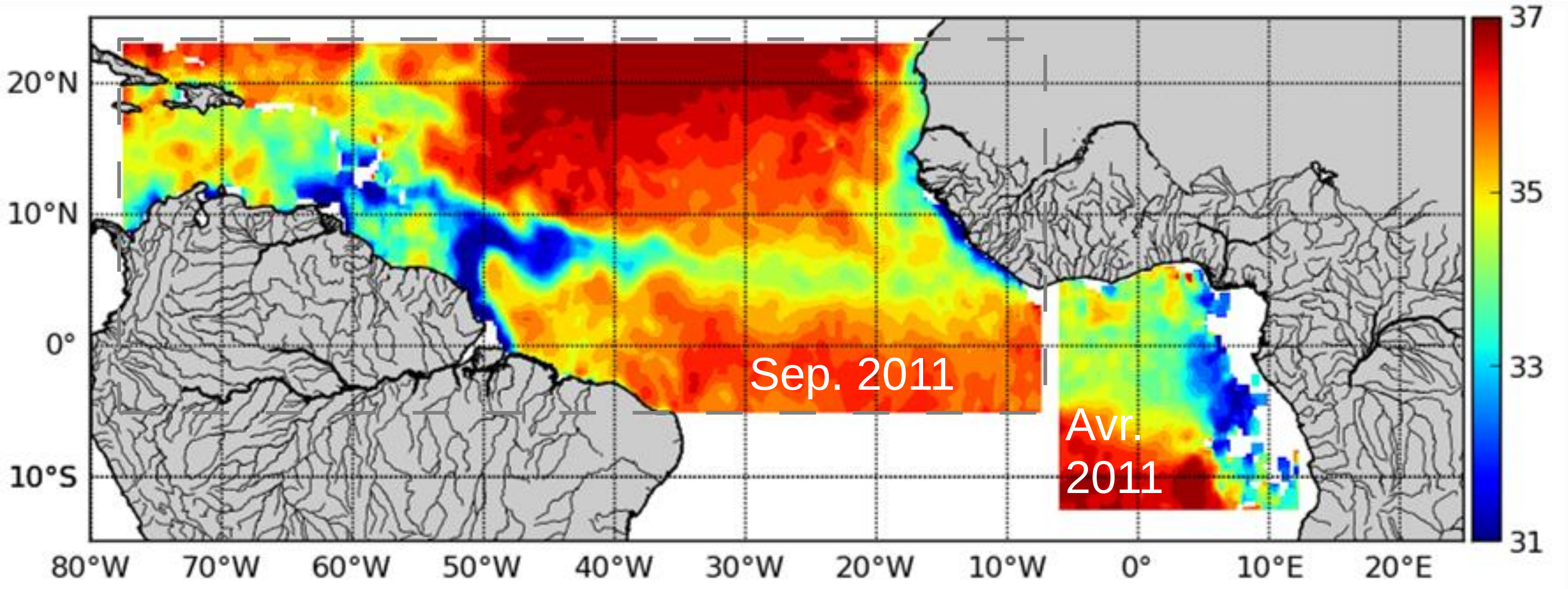
Presence of warm waters inducing :

- Development of deep-convection
- High precipitation under the Inter-Tropical Convergence Zone (ITCZ)

- Important freshwater supply from river runoff and precipitation (ITCZ)
- Strong salinity stratification

Scientific context

Sea Surface Salinity (SSS)



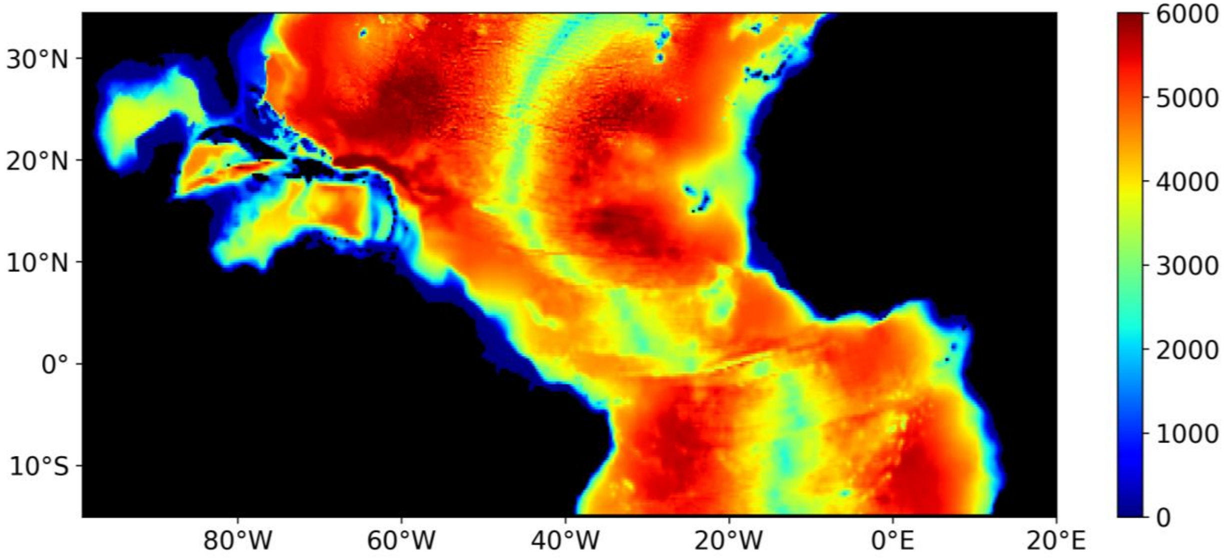
Several studies suggest that salinity impacts the Atlantic climate:

- Thinning and warming of the mixed layer (Miller 1976 ; Pailler 1999 ; Foltz 2009)
- Modulation of the seasonal cycle of SST (Foltz 2009)
- Remote impacts on AMOC and North Atlantic climate (Huang 2010, Jahfer 2017)
- Cyclone intensification (Balaguru 2012a, 2020 ; Grodsky 2012 ; Reul 2015 ; …)
- Regional sea level (Giffard 2019)

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

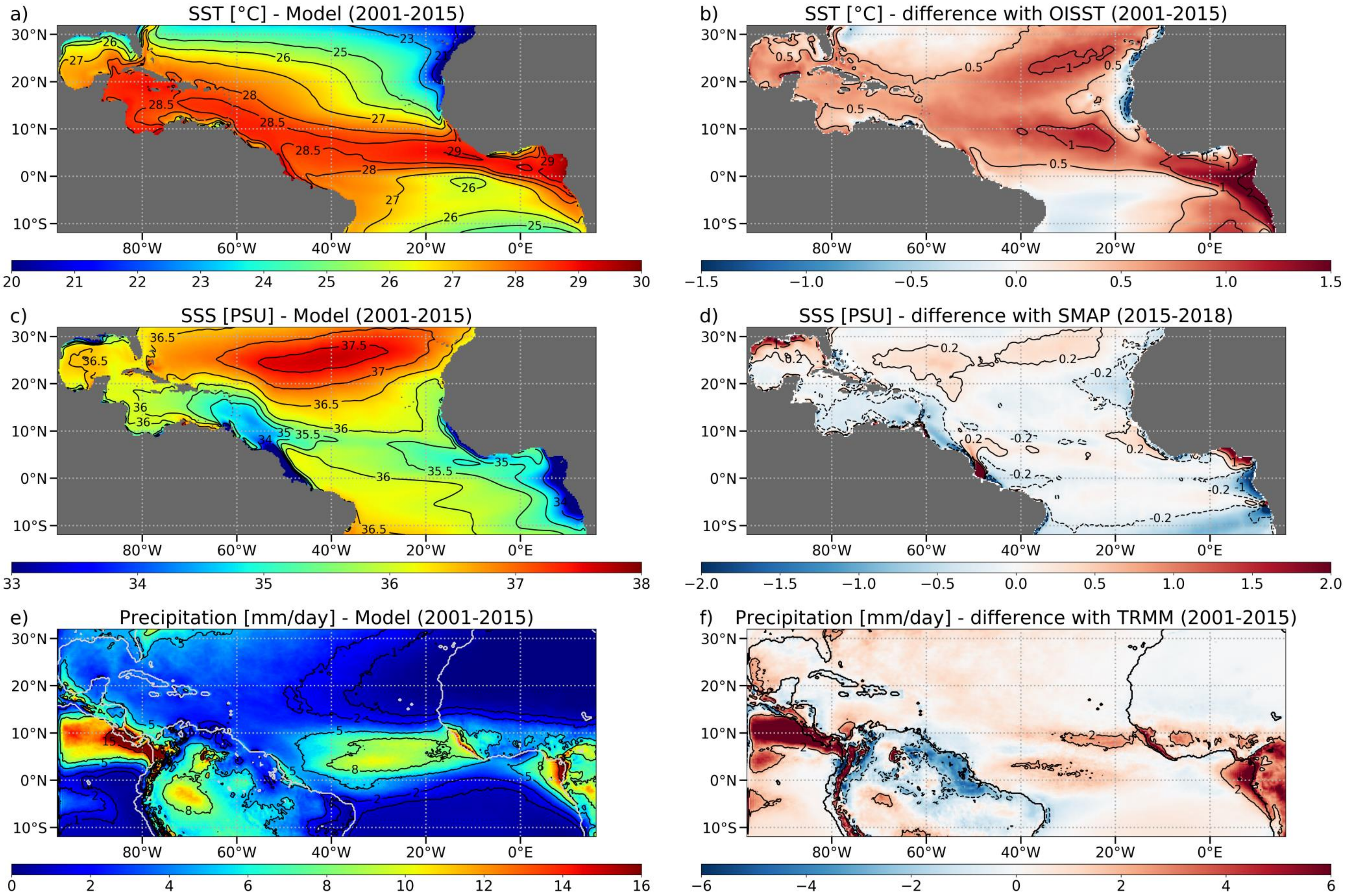
- Grid: 15°S to 35°N – 100°W to 20°E - Mercator projection
- Period: 2001-2015 (+ 1 year of coupled spin-up + 30 years of forced ocean spin-up)

Validation

Sea Surface Temperature [°C]

Sea Surface Salinity [PSU]

Precipitation [mm/day]

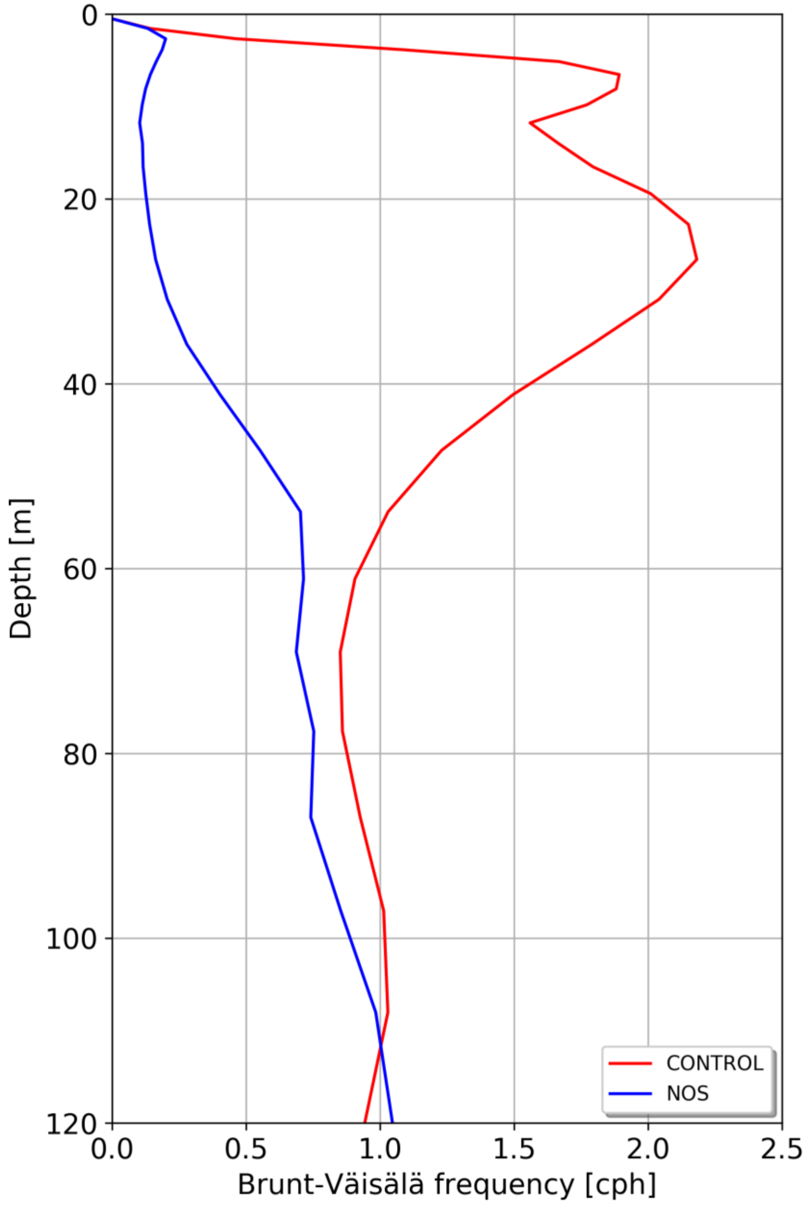


Sensitivity test on salinity stratification

Aim : investigate impact of salinity stratification on the Sea Surface Temperature

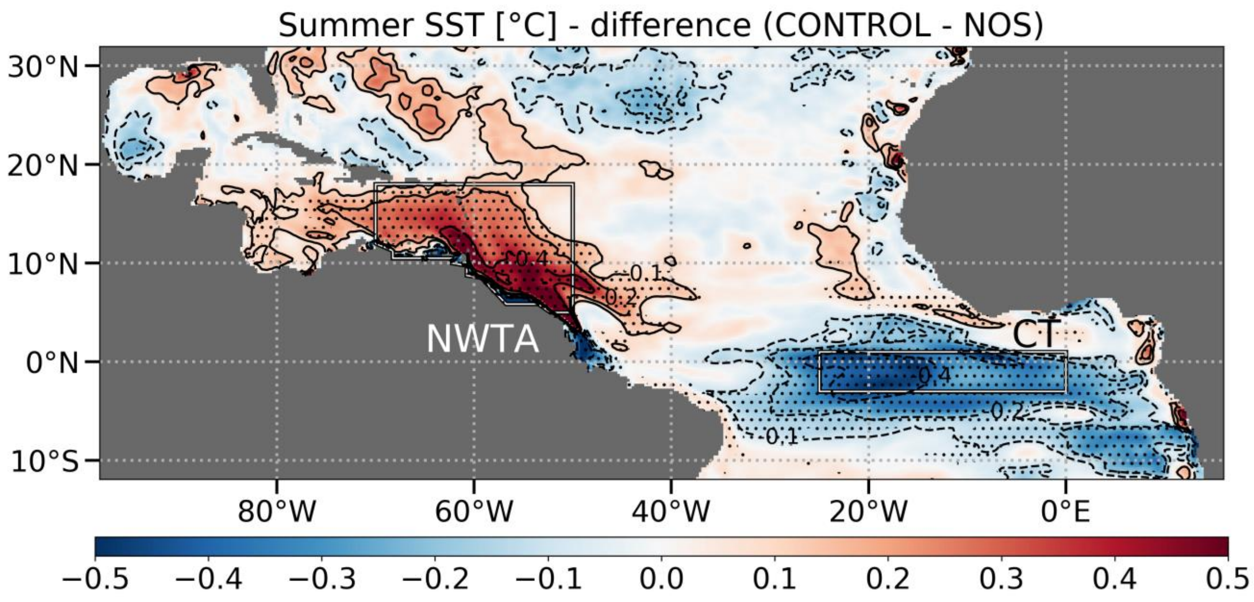
2 simulations :

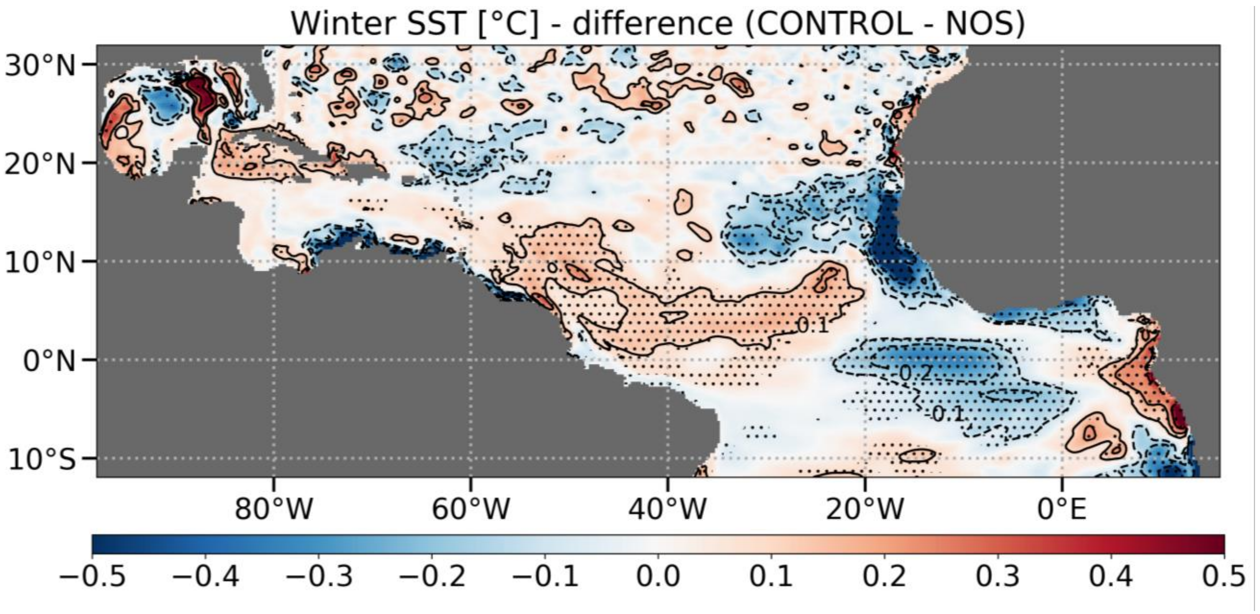
- CONTROL run
- NOS run :
  - removal of salinity dependency in the calculation of Brunt-Väisälä frequency (N^2)
  - impact on vertical mixing only
  - density calculation not affected



Vertical profile of N^2 in Amazon plume

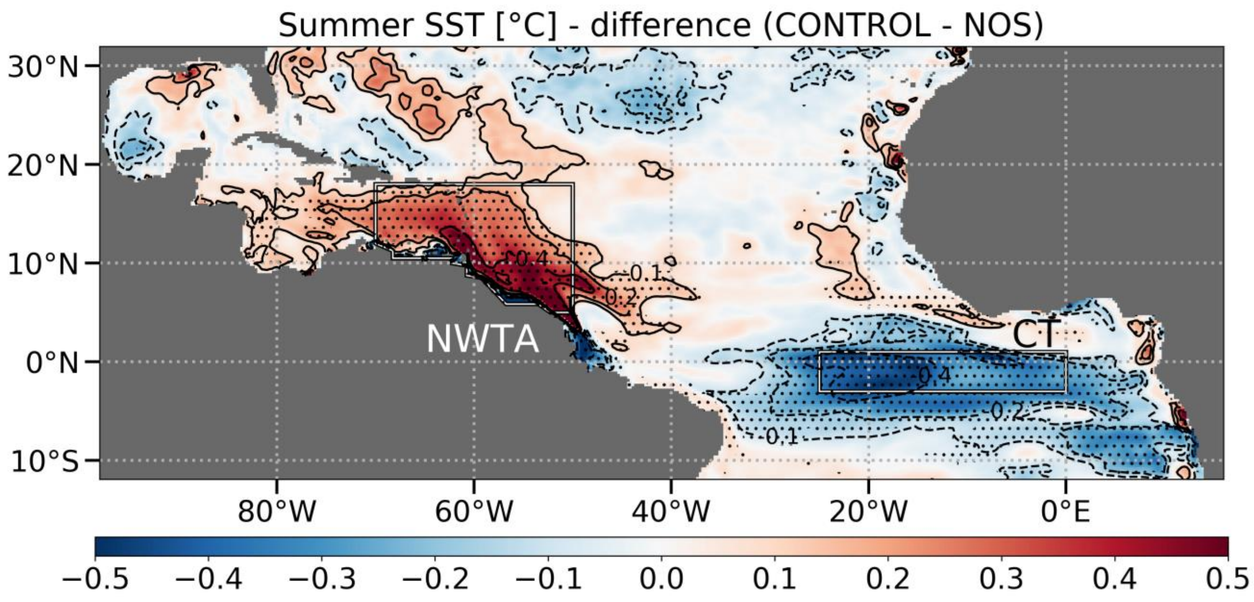
SST sensitivity to salinity stratification

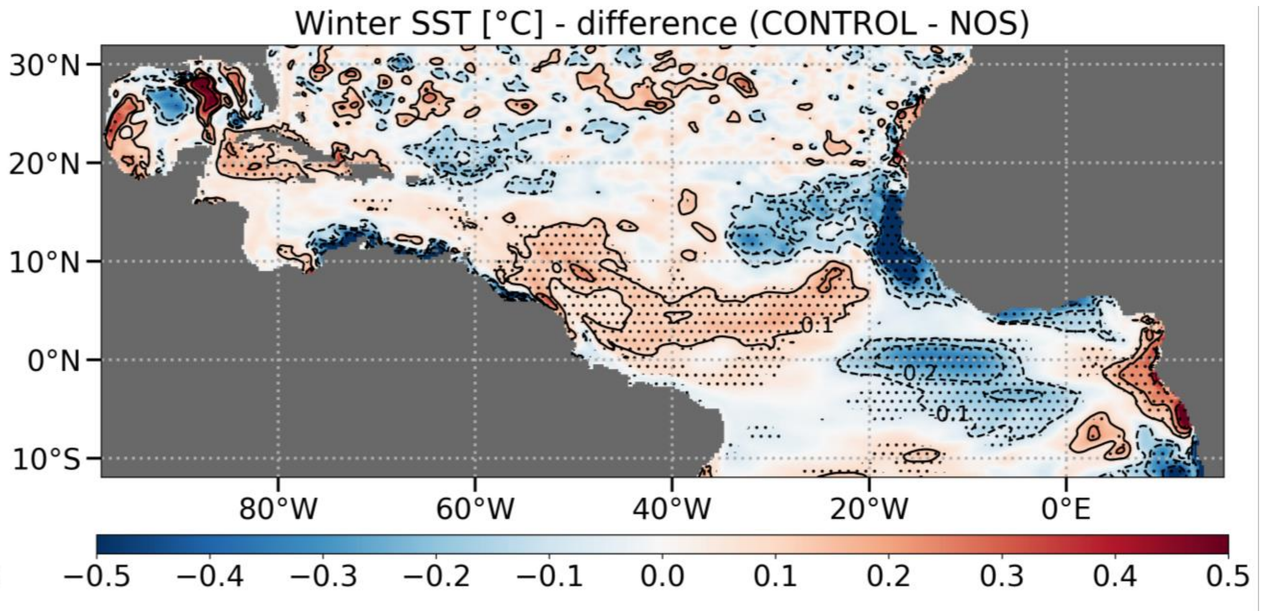




Dots indicate the areas where the difference is significant (Student's t-test with a 99% confidence level)

SST sensitivity to salinity stratification





Several questions arise:

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

Link between SST and salinity stratification

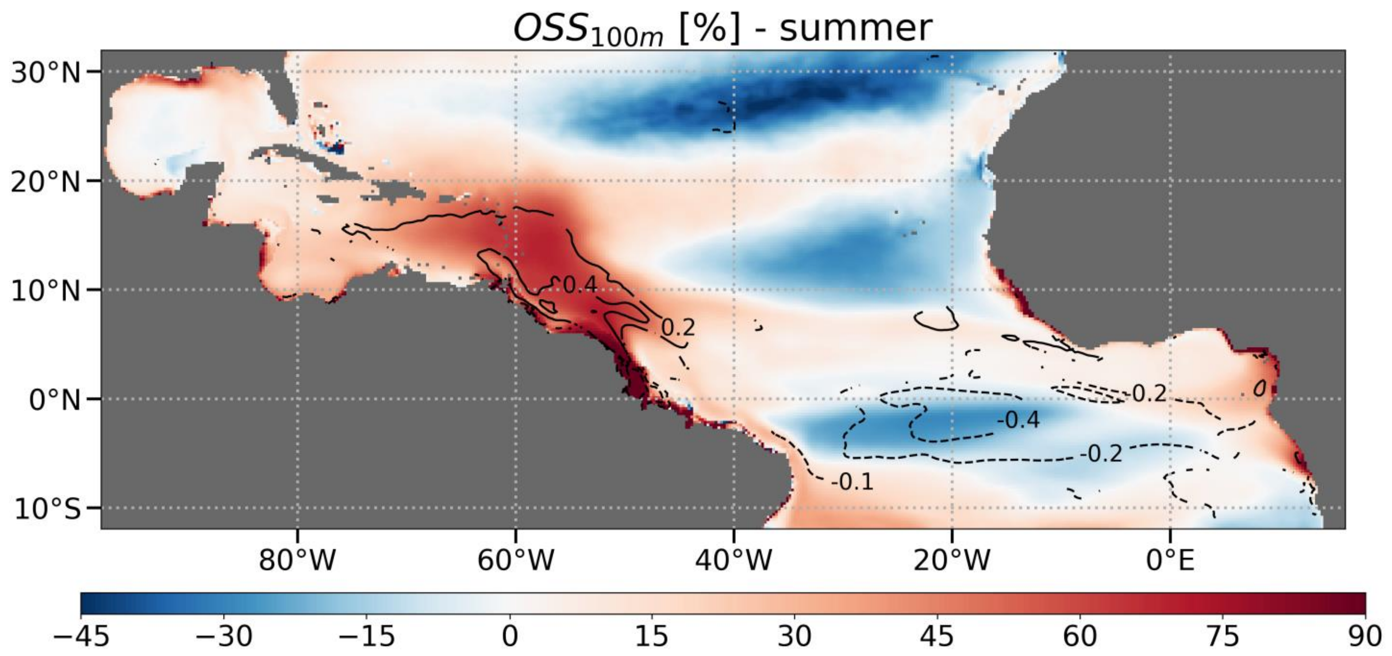
$$OSS_{100m} = 100 * \frac{\langle N^2 S \rangle_{100m}}{\langle N^2 \rangle_{100m}}$$ (cf. Maes and O'Kane 2014) with $$\langle \blacksquare \rangle = \frac{1}{h} \int_{-h}^{0} \blacksquare \, dz$$

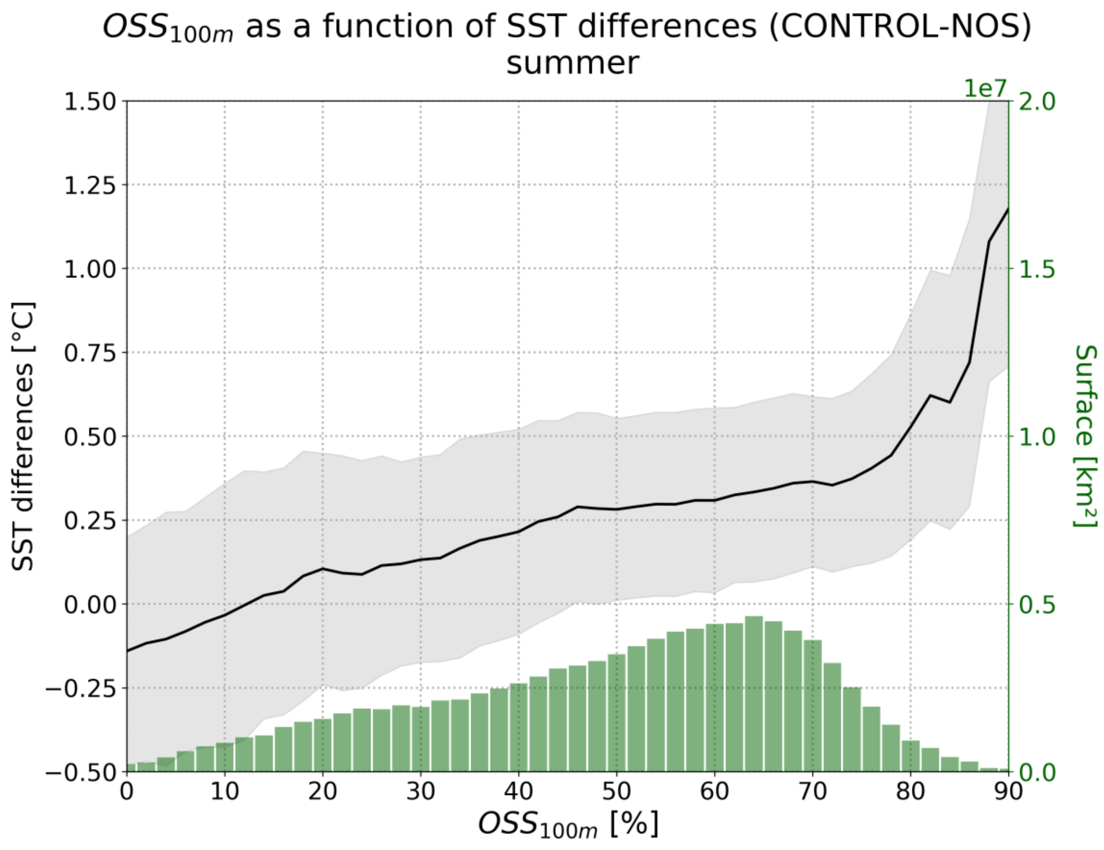
N^2 : Brunt-Väisälä frequency (total stratification)

N^2S : contribution of salinity stratification to total stratification

OSS_{100m} : contribution of salinity stratification N^2S (averaged over the upper 100 meters) to total stratification N^2 (also averaged over the upper 100 meters), expressed as a pourcentage of N^2

Link between SST and salinity stratification





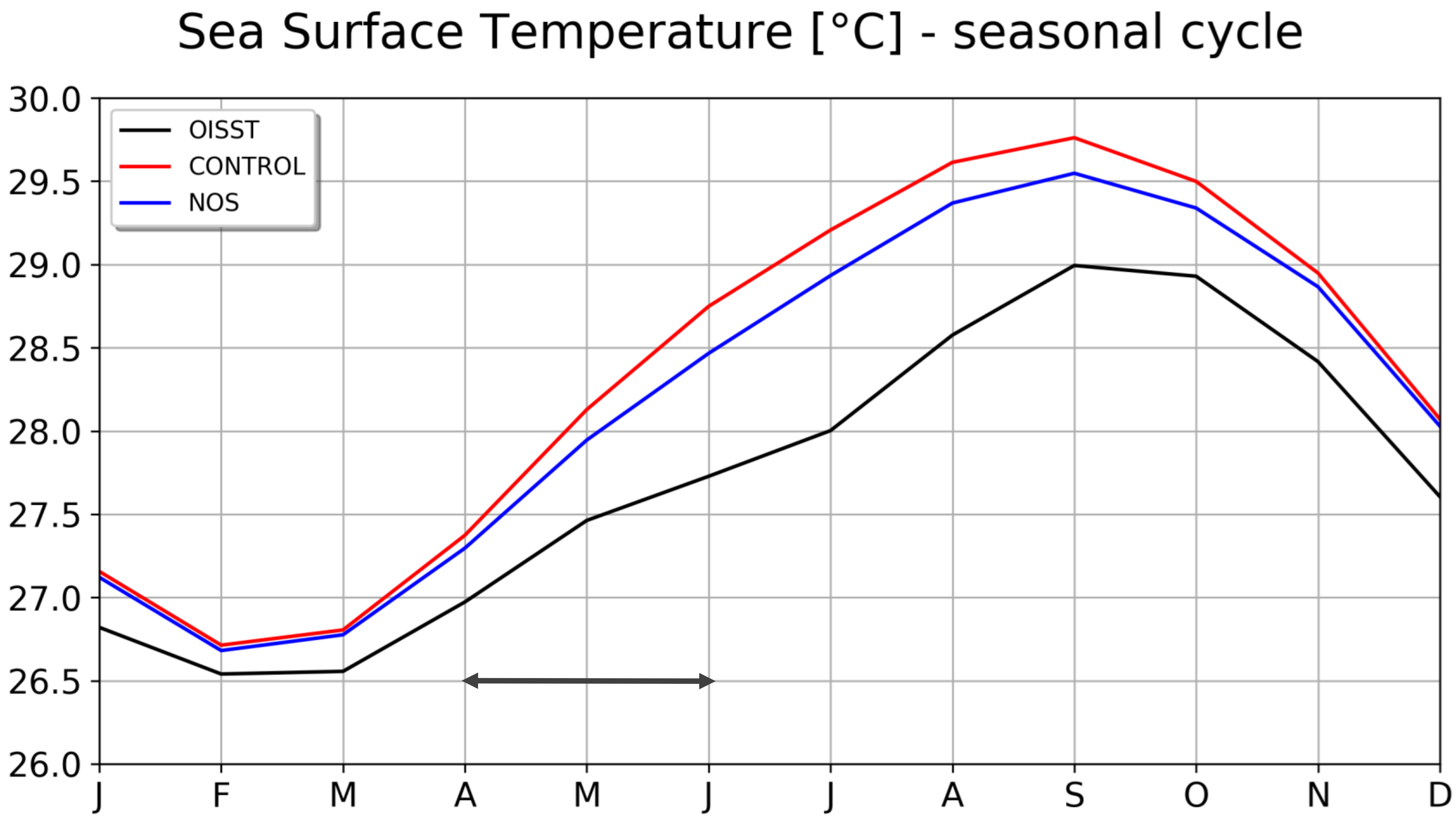
- The higher the OSS_{100m} the larger the SST anomalies

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

- Mean from April to June (growing SST difference)



Mixed Layer heat budget

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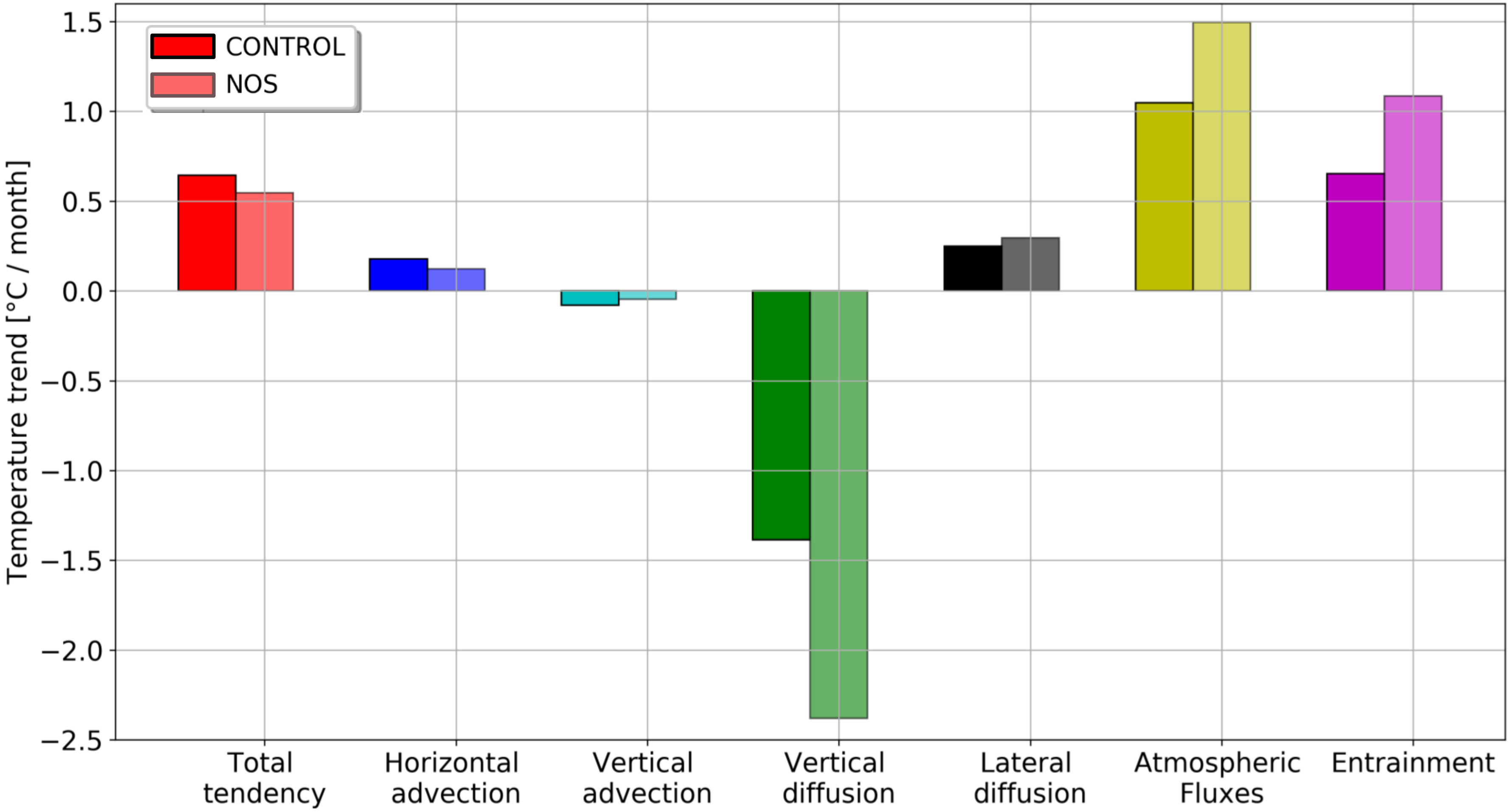
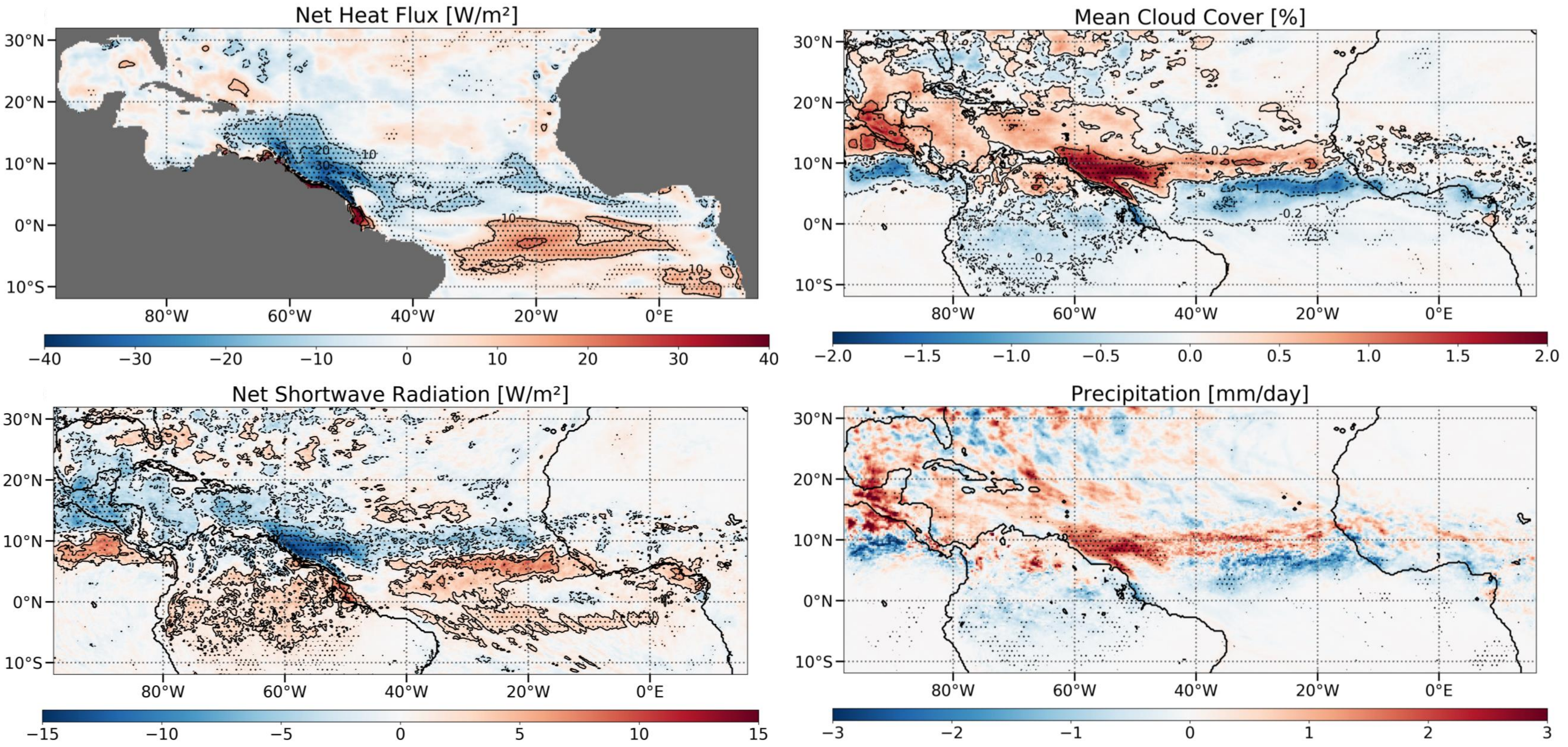
with $\langle \blacksquare \rangle = \frac{1}{h}\int_{-h}^{0} \blacksquare\, dz$

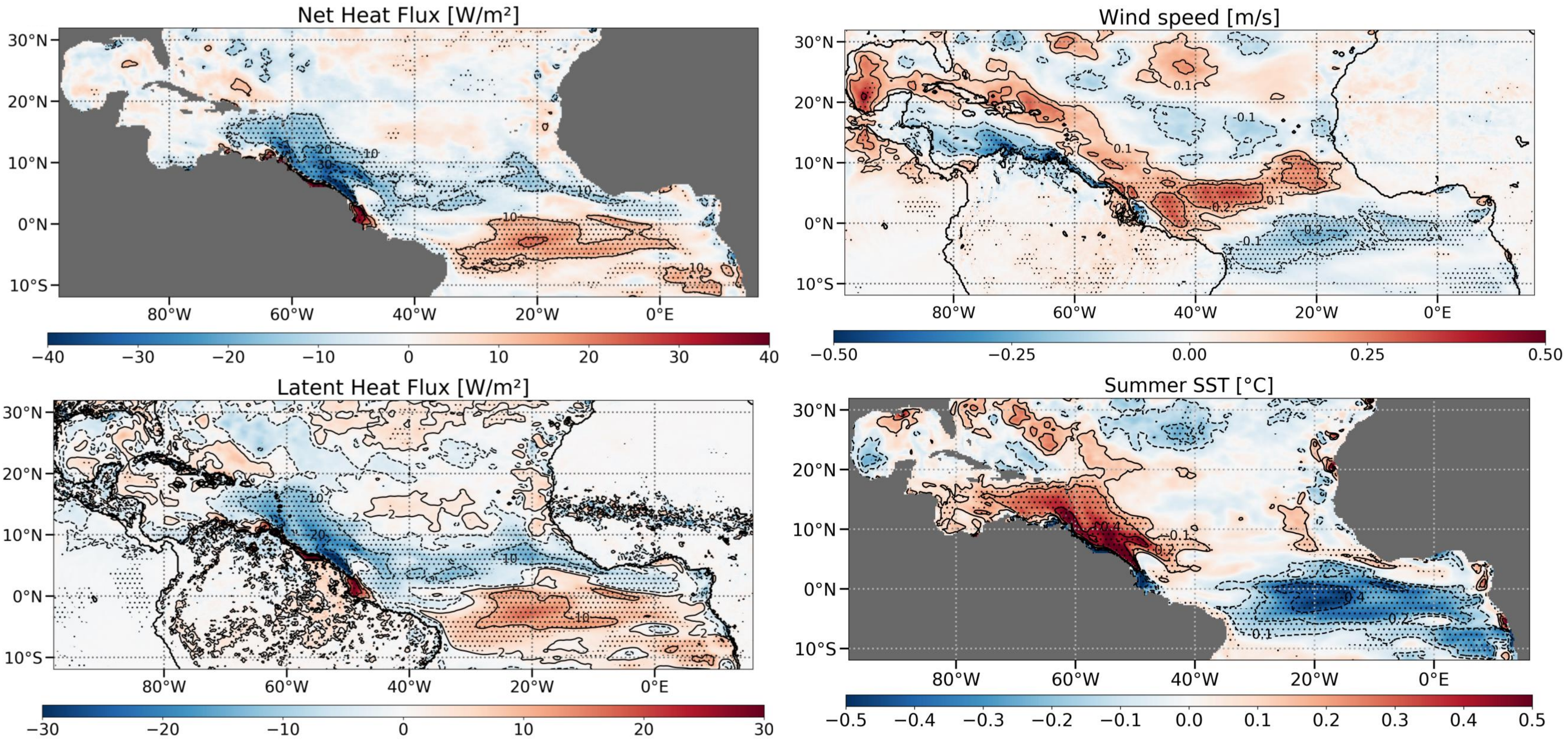
- Increase of temperature by inhibition of vertical mixing
- Damping by atmospheric fluxes and entrainment



Atmospheric response



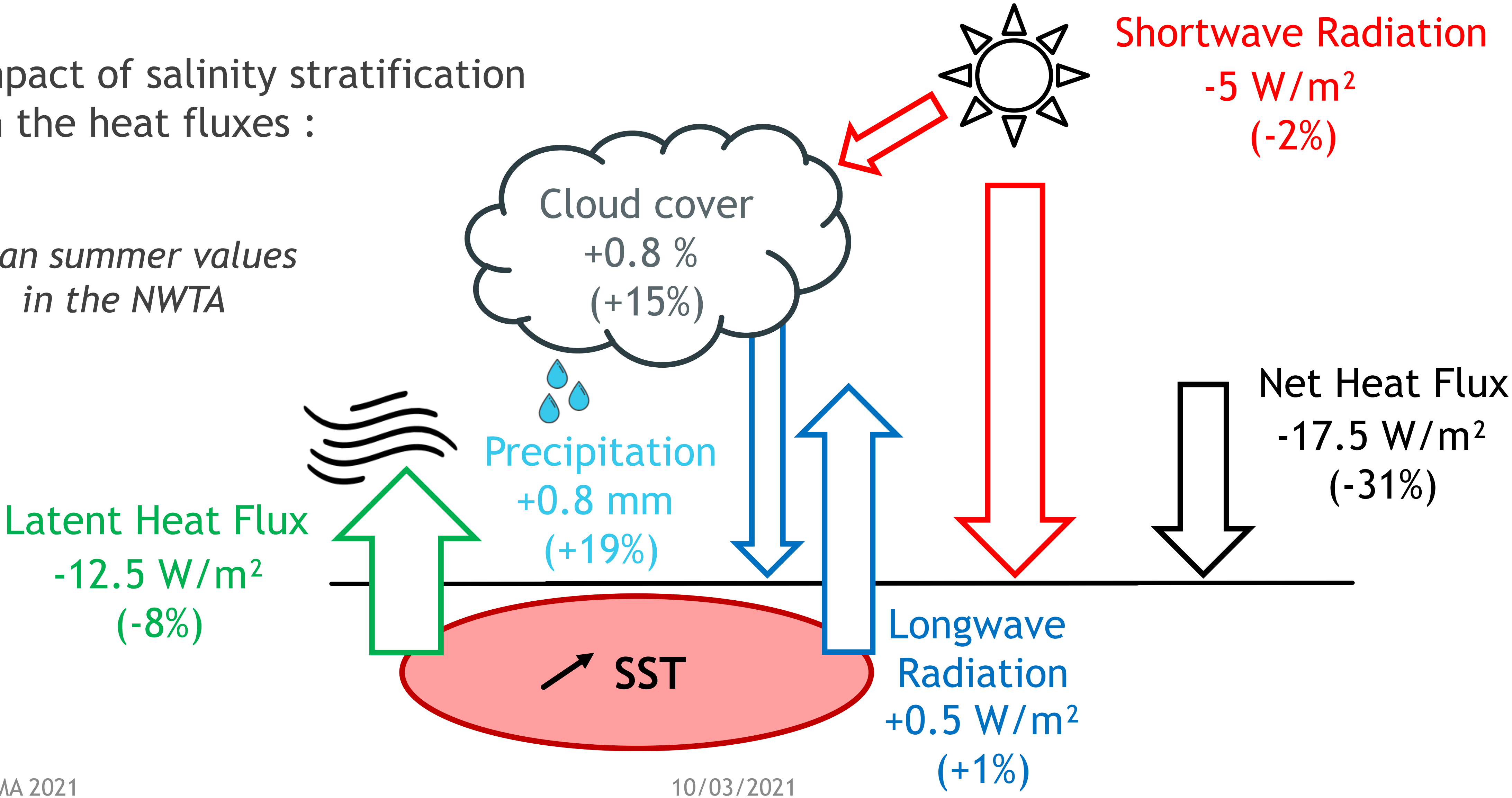
Atmospheric response



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
- Decrease of cooling due to vertical mixing, damped by a decrease of warming due to atmospheric fluxes and entrainment
- Negative feedback from the atmosphere : SST increase leads to a decrease in latent heat flux and shortwave radiation, limiting the surface warming

Supplementary material

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

Development of the coupled configuration

NEMO: already used in several publications
(Jouanno et al., 2017 ; Hernandez et al., 2016, 2017 ; Giffard et al., 2019)

WRF: need for sensitivity tests

4 parameters tested:

- Convection
- Longwave radiation
- Shortwave radiation
- Planetary Boundary Layer

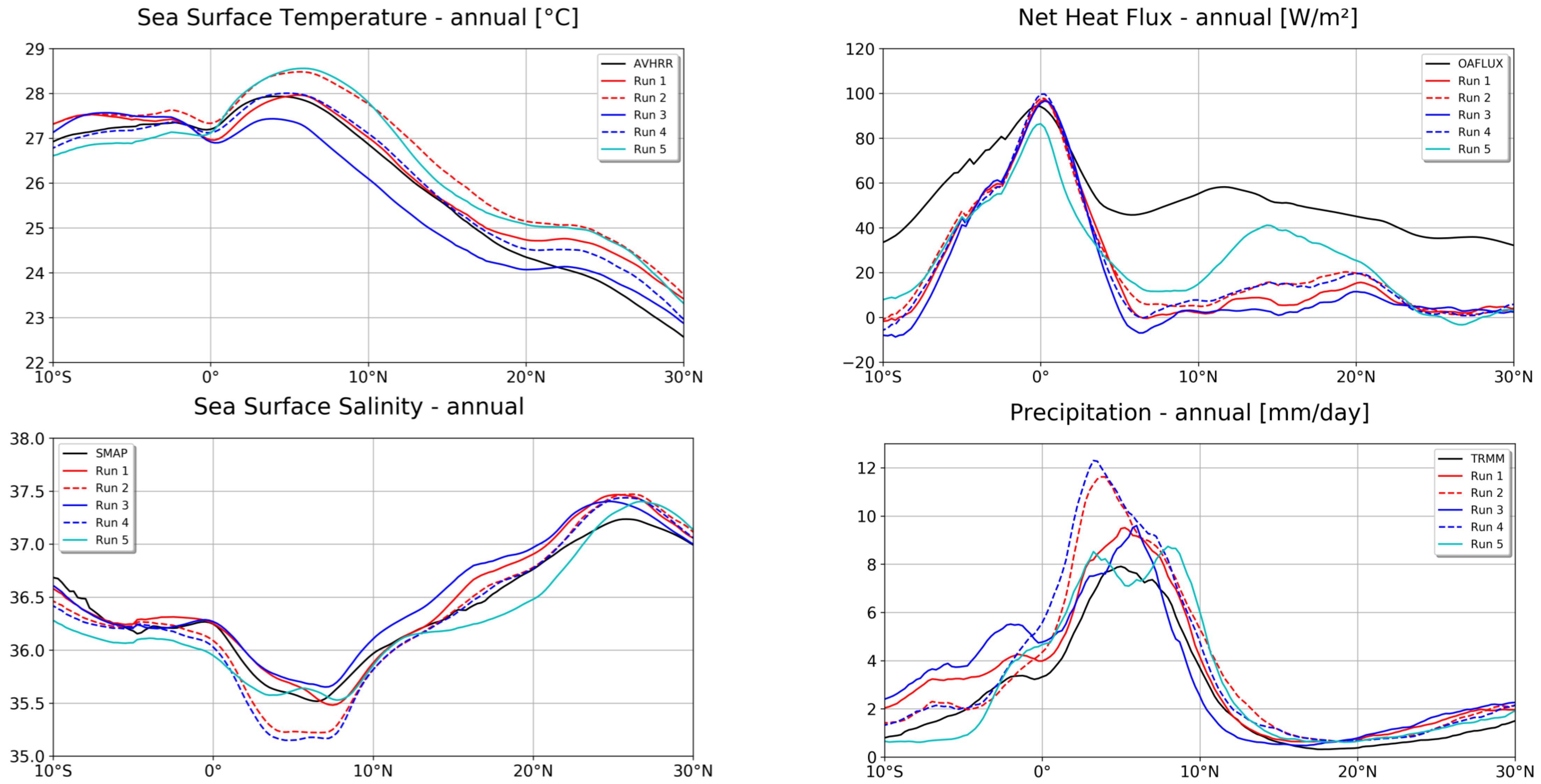
Parameters not tested: (Meynadier et al., 2015)

- Microphysics (WSM6)
- Land Surface (Noah Land Surface Model)
- Surface Layer (MM5)

Choice : parameters giving the best heat fluxes and including a feedback of clouds on the radiative schemes

WRF Sensitivity tests

South-North sections
mean between 40°W and 20°W

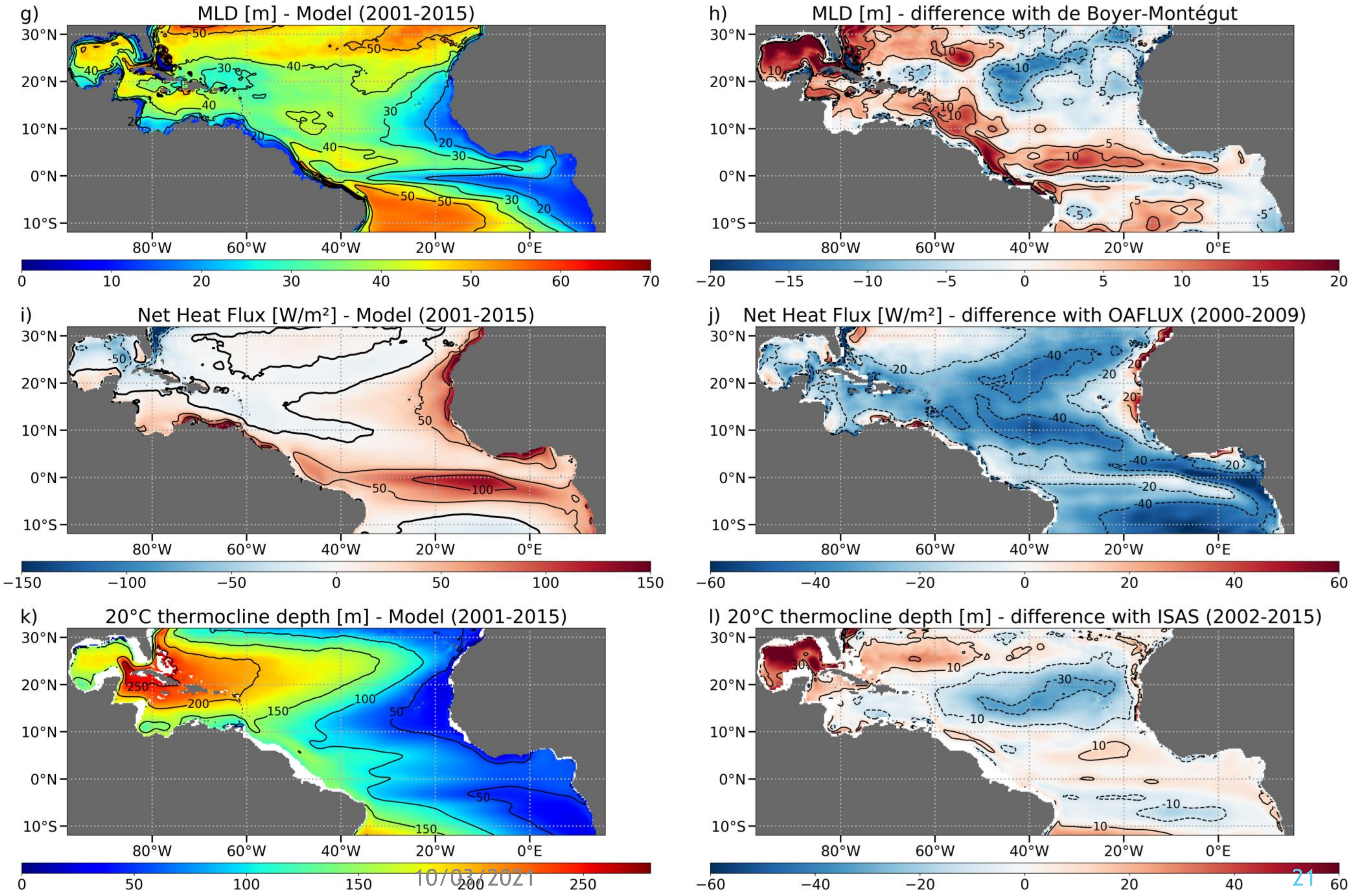


Validation

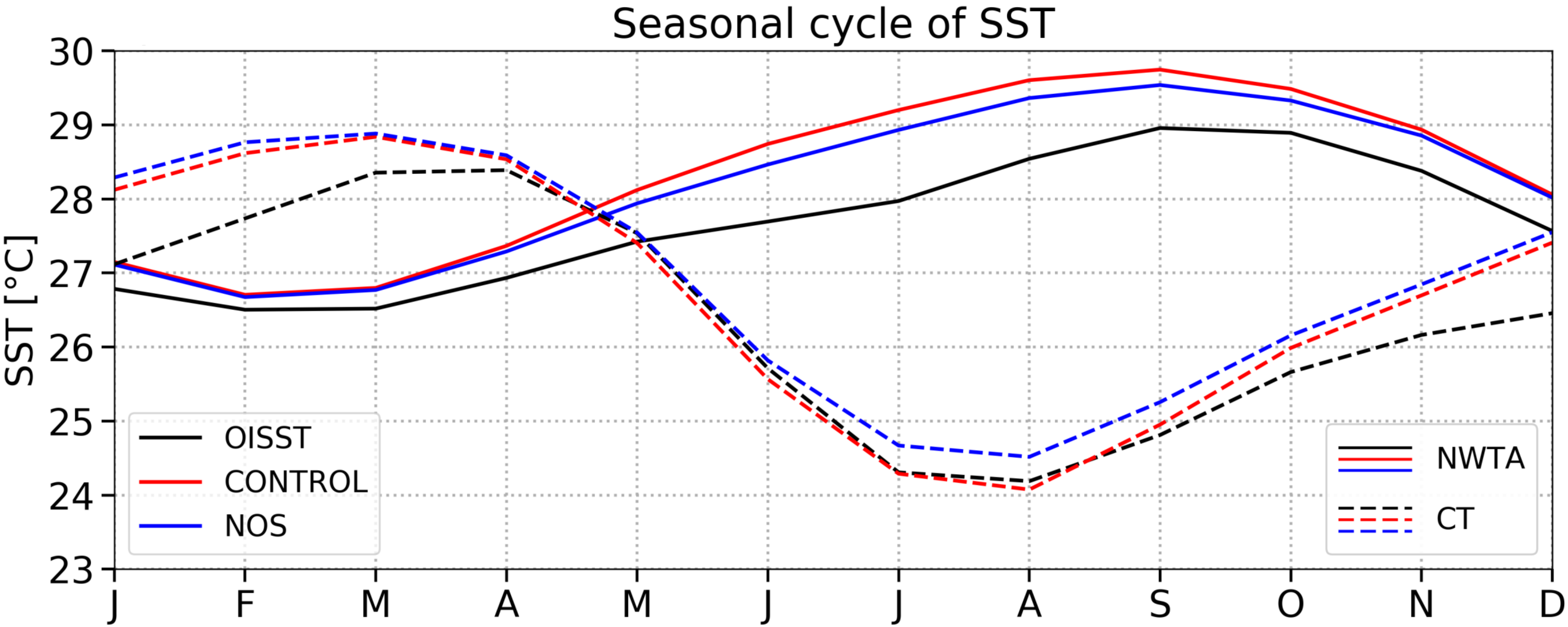
Mixed Layer Depth [m]

Net Heat Flux [W/m²]

20°C isotherm depth [m]

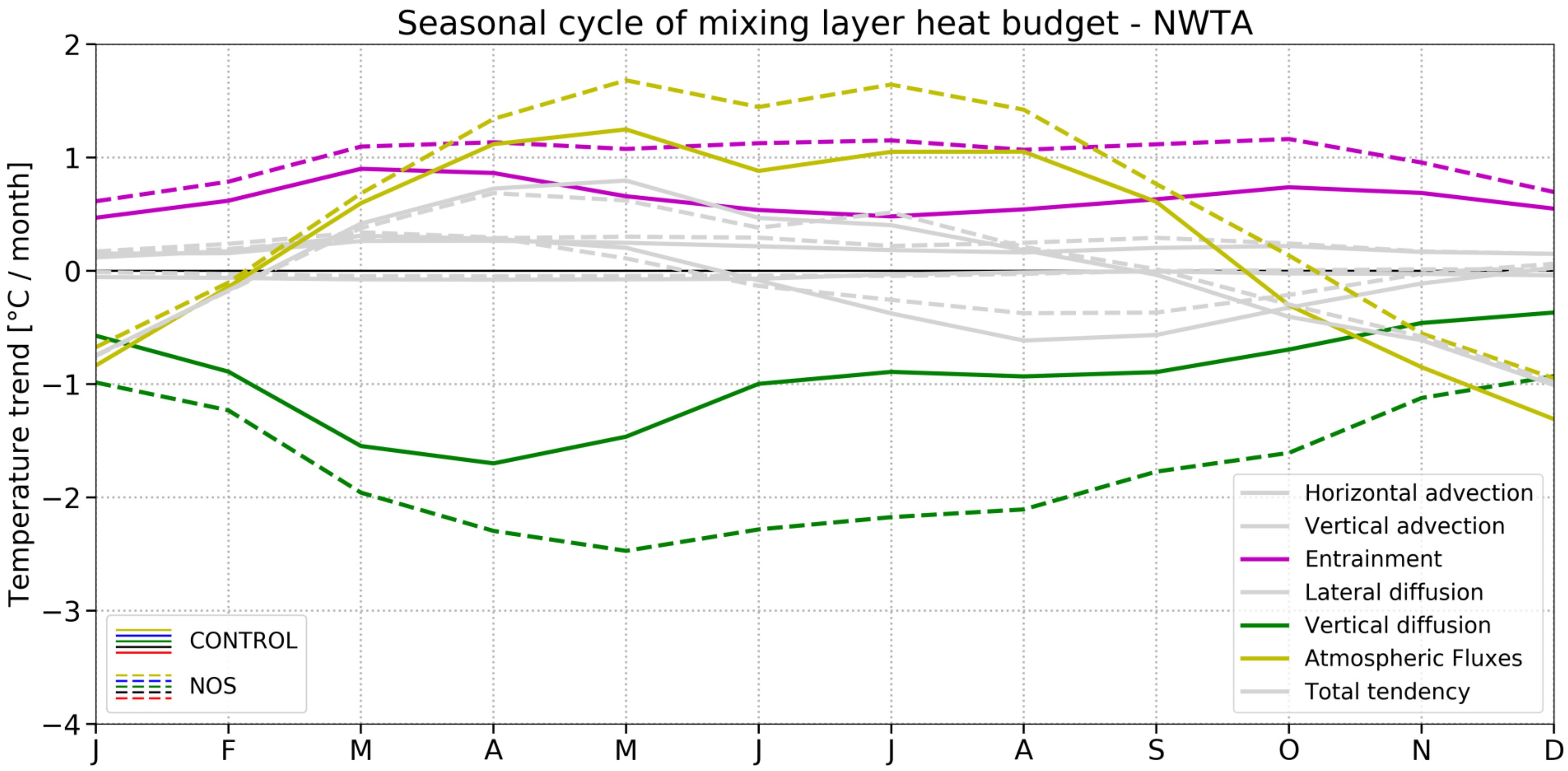


Seasonal cycle of SST



Change in entrainment in the NWTA (MLD heat budget)

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



Change in entrainment in the NWTA (MLD heat budget)

- 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