Do the Amazon and Orinoco freshwater plumes really matter for hurricane-induced ocean surface cooling ?

Olga Hernandez, Julien Jouanno, and Fabien Durand.
LEGOS, Univ. Paul Sabatier, Toulouse, France
Corresponding author : olga.hernandez@legos.obs-mip.fr

1. Background :

Tropical cyclones (TC) often pass directly over the Amazon-Orinoco freshwater plume (see Figure 1). Ffield [2007] has shown that 68% of all category 5 Atlantic hurricanes during the 1960-2000 time period passed directly over the historical region of the plume, suggesting that the majority of the most destructive hurricanes may be influenced by ocean–atmosphere interaction within the plume just prior to reaching the Caribbean, and that the freshwater inputs from the Amazon and Orinoco could be active players of TC intensification in the region.

Two causal relationships between the river plumes and tropical cyclogenesis are generally proposed :

a) The presence of particularly warm SSTs over river plumescould favor their development (e.g. Vizy and Cook [2010] show a great sensitivity of summertime climate and hurricane intensity and frequency to temperature anomalies over the Amazon-Orinoco plume region).

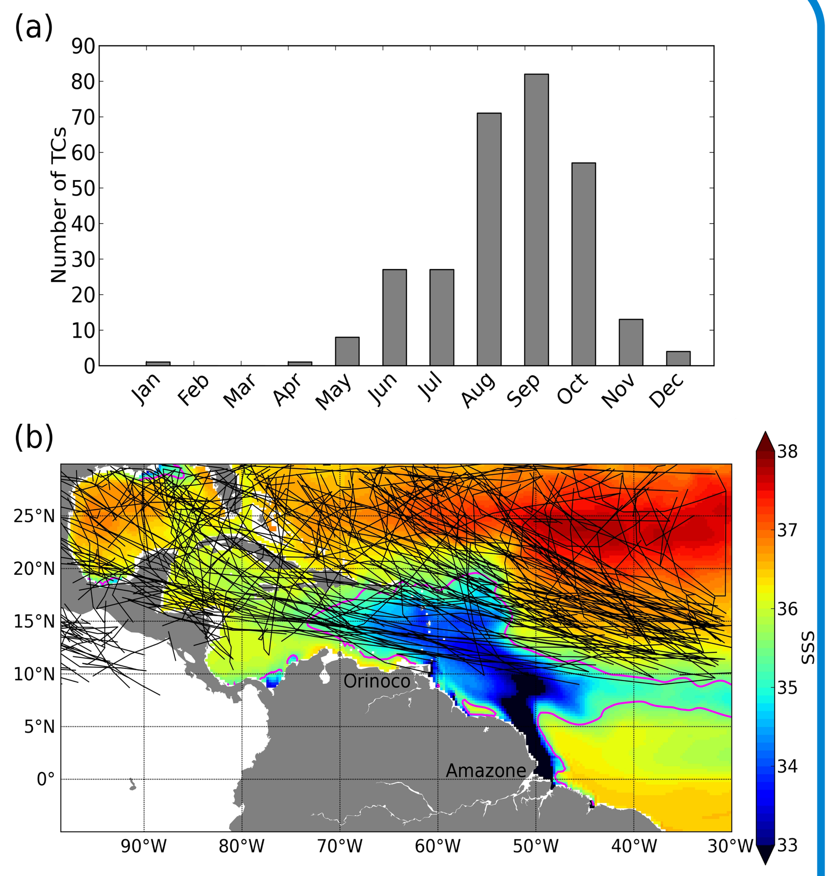


Fig. 1: (a) Seasonal evolution of the number of TCS in the Amazon-Orinoco River plume region. (b) Climatological June-November SSS from experiment REF. The magenta curve is the 35.4 sea surface salinity contour. Black lines indicate the cyclones trajectories obtained from the International Best Track Archive for Climate Steward (IBTrACS). All the figures have been made using data from 1998 to 2012.

b) Inhibition of TC-induced surface cooling by the presence of strong haline stratification and barrier layers could favors TC intensification by weakening the cool wake and its impact on the hurricane growth potential [Schade and Emanuel 1999, Balaguru 2012a].

2. Scientific objectives :

a) clarify and quantify the impact of the Amazon and Orinoco plumes on the background oceanic conditions and on the TC response

b) detail the processes setting the characteristics of the sea surface cooling induced by the TC

c) explain the difference of cooling between the plume region and the open ocean region.

3. Regional model

Code : NEMO 3.6

Grid : ORCA025 (1/4°) 75 levels (~1m near the surface)

Boundaries: Daily /Global reanalysis GLORYS2V3

Atm. forcing: DFS5.2 + Large and Yeager [2009] bulk

Period analyzed: 1998 – 2012 **Outputs**: 1 day average

Two experiments :

- REF (Dai and Trenberth 2002 runoff forcing)
- NO-RUNOFF

The hurricane forcing strategy follows Vincent et al. (2012) :

- Hurricanes position and intensity are from IBTRaCS (6h and 10mn-sustained wind product)

-The residual TC signature (11-day running mean within 600km around each vortex) is filtered out.

-At each time model time step (300 seconds) a TC wind pattern is superimposed (a Willoughby et al. [2006] idealized vortex)

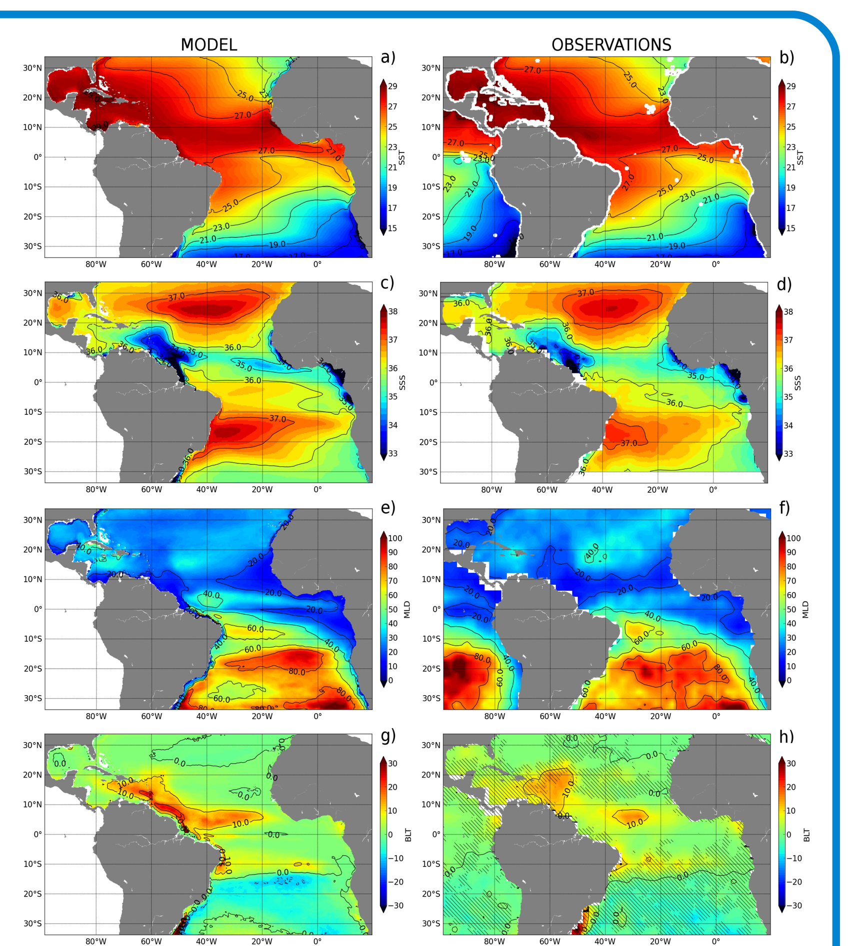


Fig. 2: Climatological a,b) SST (°C), c,d) SSS, e,g) BLT (m), and g,h) MLD (m) averaged from June to November in model (left) and observations (right) averaged from 1998 to 2012 (at the exception of the observed MLD and BLT). Observed SST are from OI microwave dataset, observed SSS are from Reverdin et al. (2007), and observed MLD and BLT are from de Boyer Montegut (2004, 2007).

4. Impact of the runoff on the background oceanic conditions

The absence of runoff induces a **ML thickening and a barrier layer disappearance**, but it has almost **no impact on the SST.**

This is in agreement with earlier modeling results by Masson and Delecluse [2001], Balaguru et al. [2012b], White and Toumi [2014], Newinger and Toumi [2015], who found no significant SST change in response to the presence or absence of large tropical rivers such as the Amazon, Orinoco or Congo rivers.

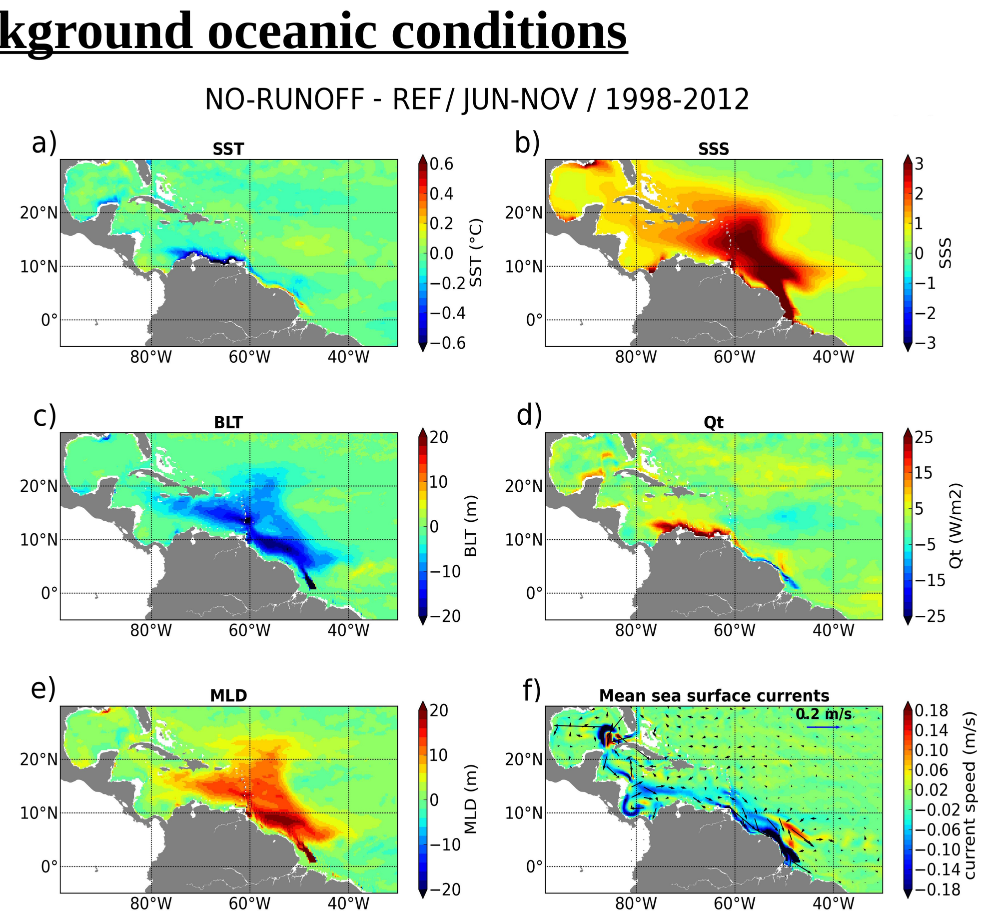


Fig. 3: Differences between the simulation without precipitation (NO-RUNOFF) and the model reference simulation (REF) of June-November averaged a) SST (°C), b) SSS, c) BLT (m), d) net air-sea heat flux Qt (W m^{-2}), e) MLD (m) and f) surface currents (m s^{-1}).

5. Hurricane Katia : a case study

Hurricane Katia crossed the Amazon plume in early fall 2011. It attained its peak intensity as a Category 4, with sustained winds reaching 220 km/h. The response to this cyclone was thoroughly documented in Grosdsky et al., (2012) using satellite and in-situ observations.

Our simulations show little impact of the freshwater plume on the surface cooling.

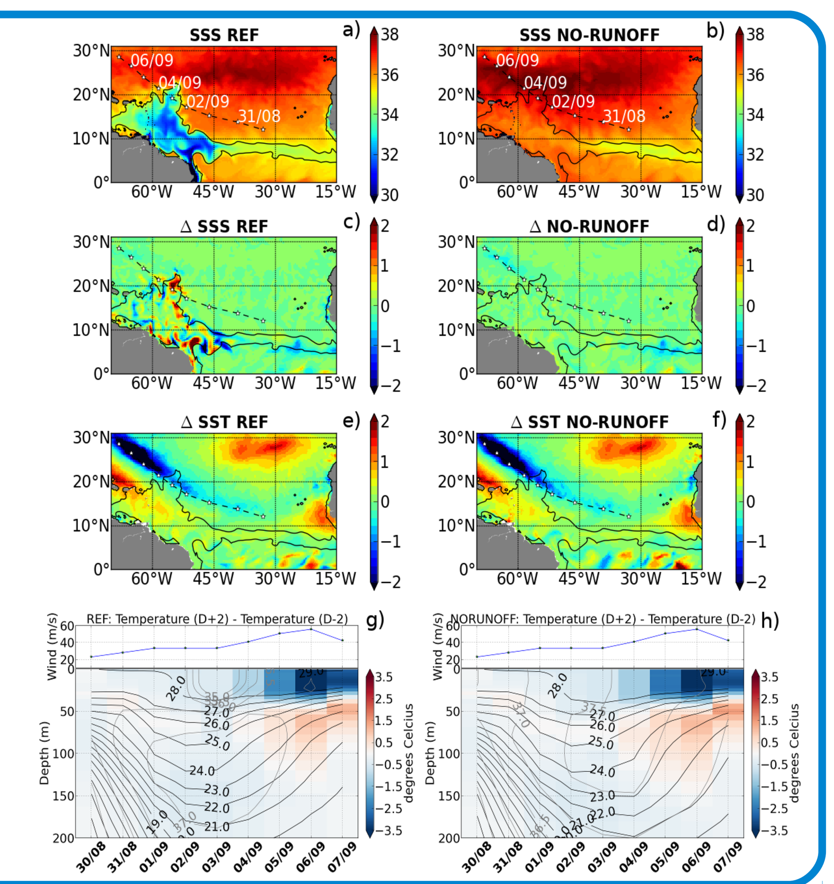


Fig. 4: SSS for experiments REF (a) and NORUNOFF (b) at day 30/08/2011 just prior to the development of hurricane Katia. Difference of SSS (c,d) and SST (e,f) between the period just after the passage of Katia (September 5 to 10) and the period before (August 25 to September 1). The salinity contour 35 psu is overlaid in order to indicate the position of the river plume. Difference of temperature along the trajectory of the cyclone between two profiles taken two days after and two days before the passage of the cyclone, for the REF (g) and NORUNOFF (h) experiments. The isotherms (black contours) and isohalines (grey contours) show the oceanic conditions two days before the passage of Katia. On top, the evolution of 10-min averaged maximum wind speed is shown.

6. Cooling amplitude observed over the plume waters and open ocean waters.

TC-induced surface cooling is analyzed within 200 km of all TC tracks over the plume waters and the open-ocean waters. Compared to the region out of the plume (referred to as open ocean waters), the cooling amplitude in plume waters is reduced by 0.3°C (50%) in observations and 0.4°C (59%) in the model. **Comparison between RUNOFF and REF indicate that haline stratification has a weak impact on the cooling (a cooling reduction of 10% only).**

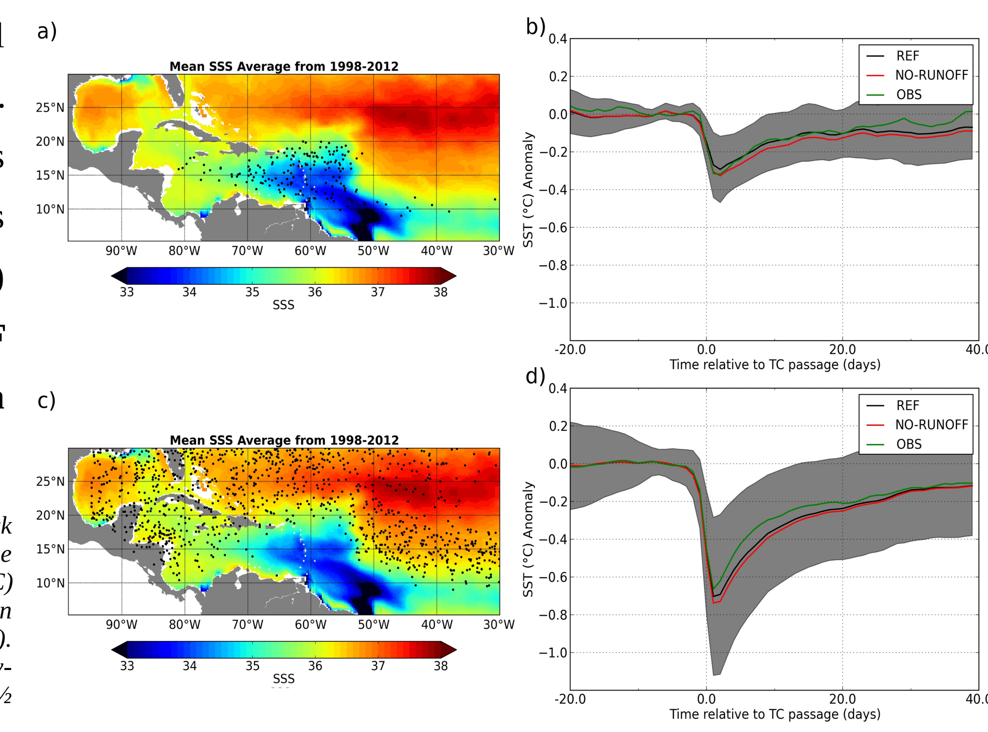


Fig. 5: Climatological model SSS from the model during June-November with black dots indicating the daily positions of TC selected in the "plume waters" (a) and in the "open ocean waters" (c). Temporal evolution of TC-induced SST cooling (in °C) within 200 km of all TCs tracks in model simulations (REF, NO-RUNOFF) and in observations (OBS) in the "plume waters" (b) and in the "open ocean waters" (d). SST anomalies are calculated with respect to pre-storm SST (averaged SST from day-10 to day-3), using the entire 1998-2012 period. Color shading indicates the ½ standard deviation around the mean composite value for REF experiment.

7. Processes contributing to the cooling

The various terms contributing to the mixed-layer heat budget are calculated online following Menkes et al. (2006) :

$$\partial_t T = -\underbrace{<u\partial_x T + v\partial_y T + w\partial_z T>}_{ADV} + \underbrace{<D_t(T)>}_{LMIX} + \underbrace{\frac{1}{h}\frac{\partial h}{\partial t}\left(T - T_{z=-h}\right) + \frac{\left(K_z \partial_z T\right)_{z=-h}}{h}}_{VMIX} + \underbrace{\frac{Q_{ns} + Q_s\left(1 - F_{z=-h}\right)}{\rho_0 C_p h}}_{FOR}$$

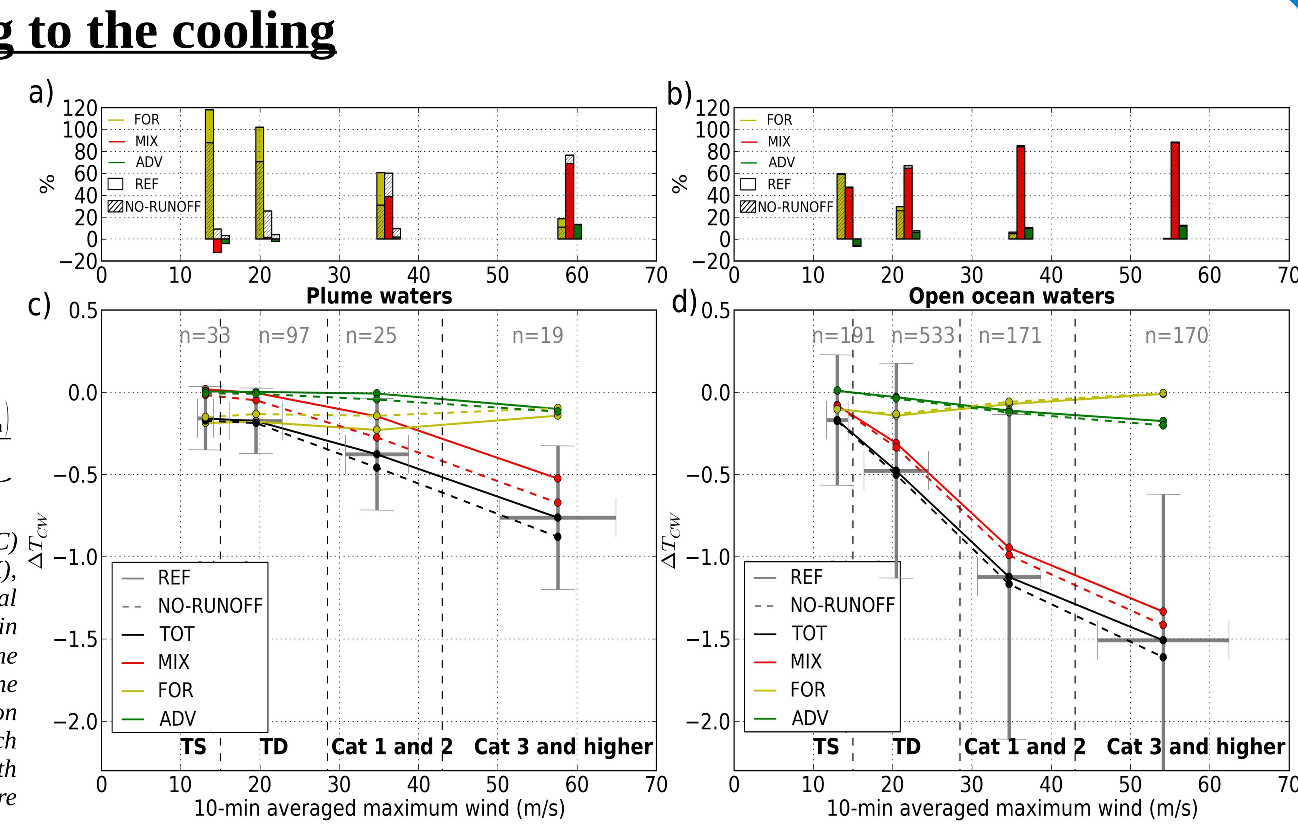


Fig. 7: Mean amplitude of TC induced cooling (in °C) and respective contribution of vertical mixing (MIX), heat fluxes (FOR), and advection (ADV) to the total cooling as a function of 4 winds categories of 10-min averaged maximum wind speed (in m.s^{-1}) for the plume waters (a, c) and the ocean open waters (b,d). The contributions (in °C) of each process (c, d) are shown on the bottom and the relative contributions (%) of each process in the top (a, b). Results for REF are shown with continuous lines and results for NO-RUNOFF are shown with dashed lines.

8. Why ML cooling due to vertical mixing is weaker in the plume ?

Cooling Inhibition index (CI; Vincent et al. 2012)

$$CI = \left[\Delta E_p\left(-1^\circ C\right)\right]^{1/3}$$

$$\Delta E_p(\Delta T) = \int_0^{h_f} \left(\rho_f - \rho_i(z)\right) gz dz$$

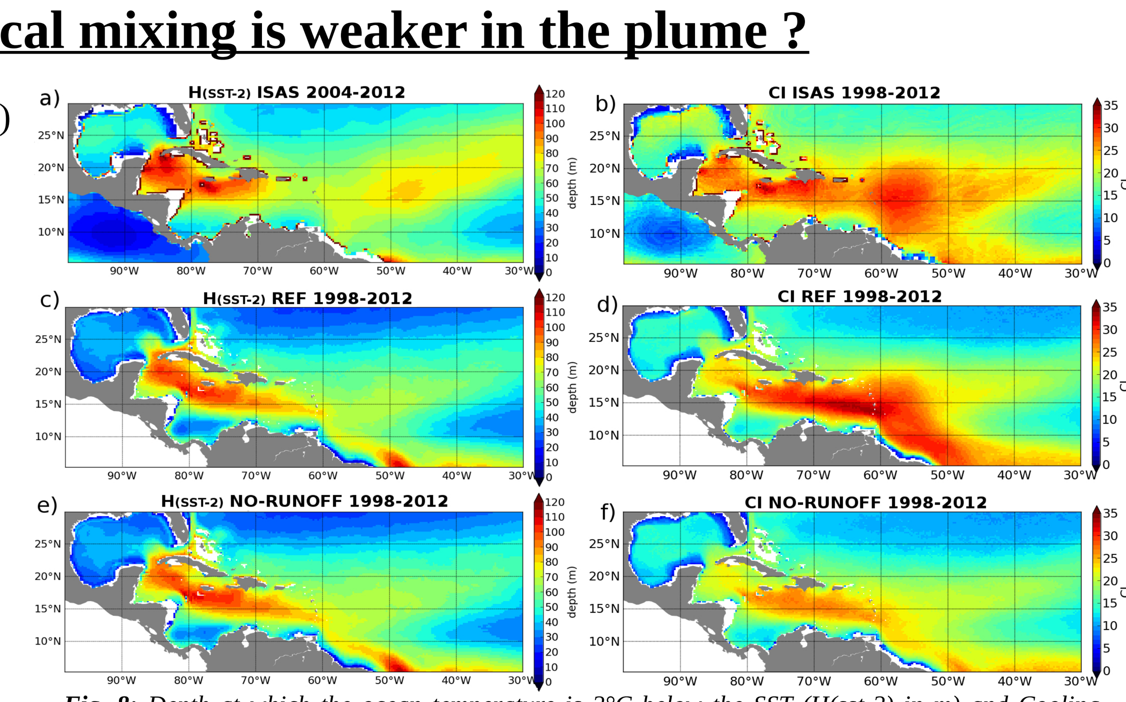
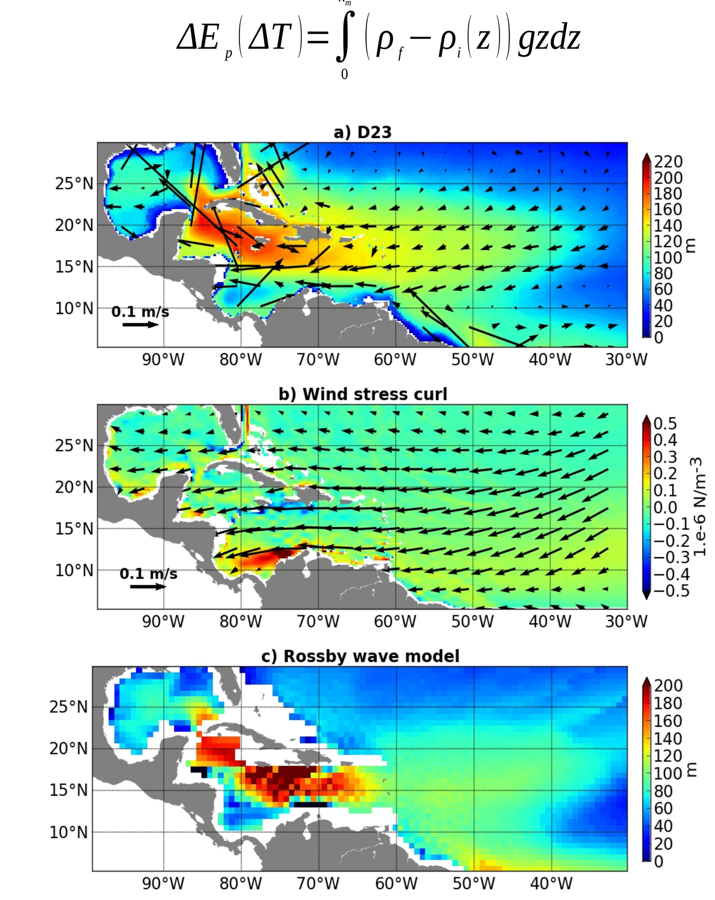


Fig. 8: Depth at which the ocean temperature is 2°C below the SST (H(sst-2) in m) and Cooling Inhibition Index (CI in (J/m^2)$^{1/3}$) calculated from ISAS observations (a,b), simulation REF (c, d) and simulation NO-RUNOFF (e, f) from June to November during the period 1998-2012.



→ **Weak sensitivity of H(sst-2) to river runoff !**

→ **20% decrease of CI without runoff**

Larger thermal content in the plume area than north of 20°N

→ Deep thermal structure in the plume region and associated large value of CI occurs at first order as a linear **response to the wind stress curl of the trade winds.**

Fig. 9: (a) Depth of the 23ºC isotherm (D23, in m), (b) wind stress curl (N/m^3) of the trade winds and (c) thermocline depth (m) estimated from the long Rossby wave linear model averaged from June to November during the period 1998–2012. (a) Currents (m/s) between 100 and 200 m are superimposed to D23 and (b) winds stress (N/m^2) is superimposed to winds stress curl. The Rossby model is similar to the one described in Kessler [2006]. We used a gravity wave speed c=2 m/s and a damping time scale of 18 months.

8. Conclusions:

This study argues for a **weaker than thought cooling inhibition effect of salinity stratification and barrier layers in the Amazon-Orinoco plume region**. Indeed, results suggest that haline stratification and barrier layers caused by the river runoff may explain only ~10% of the cooling difference between plume waters and open ocean waters. Instead, the analysis of the background oceanic conditions suggests that the **regional distribution of the thermal stratification is at leading order, the main factor controlling the amplitude of cooling in the plume region.**

Ackowndledgements:

This study was supported by EU FP7/2007-2013 under Grant Agreement No. 603521, project PREFACE. Computing facilities were provided by GENCI project GEN7298. We aknowledge the ISAS team for making freely available the temperature and salinity climatology. Sea surface salinity data derived from thermosalinograph instrumentsinstalled onboard voluntary observing ships were collected, validated, archived, and made freely available by the French Sea Surface Salinity Observation Service (http://www.legos.obs-mip.fr/observations/sss/). We acknowledge discussions with G. Reffray, R. Bourdalle-Badie, G. Madec, J. Vialard, G. Samson, and S. Jullien.

References

***Balaguru** K, et al. (2012b). "The Barrier Layer of the Atlantic Warmpool: Formation Mechanism and Influence on the Mean Climate." Tellus Series A. Dynamic Meteorology and Oceanography 64. **de Boyer Montégut,** et al. (2004), Mixed layer depth over the global ocean: an examination of profile data and a profile-based climatology, J. Geophys. Res., 109. **Ffield**, A. (2007): Amazon and Orinoco River plumes and NBC Rings: bystanders or participants in hurricane events? J. Clim., 20, 316-333. **Grodsky**, S. A., et al. (2012), Haline hurricane wake in the Amazon/Orinoco plume: AQUARIUS/SACD and SMOS observations, Geophys. Res. Lett., 39. **Large**, W. G. and S. Yeager, (2009): The global climatology of an interannually varying air-sea ux data set. Climate Dynamics, 33, 341-364. **Madec** G. (2014), "NEMO ocean engine" (Draft edition r5171). Note du Pôle de modélisation, Institut Pierre-Simon Laplace (IPSL), France, No 27 ISSN No 1288-1619. **Masson**, S., and P. Delecluse (2001), Influence of the Amazon river runoff on the tropical Atlantic, Phys. Chem. Earth, Ser. B, 26, 137–142. **Newinger**, C., and R. Toumi (2015), Potential impact of the colored Amazon and Orinoco plume on tropical cyclone intensity, J. Geophys. Res. Oceans, 120, 1296–1317. **Reverdin** G., et al. (2007) Surface salinity in the Atlantic Ocean (30° S-50° N), Prog. Oceanogr. **Schade**, L. R., & Emanuel, K. A. (1999). The ocean's effect on the intensity of tropical cyclones: Results from a simple coupled atmosphere-ocean model. J. Atm. Sciences, 56(4), 642-651. **Vincent**, E. M.,et al. (2012b), Assessing the oceanic control on the amplitude of sea surface cooling induced by tropical cyclones, J. Geophys. Res., 117, C05023. **Vizy,** E. K., and K. H. Cook (2010), Influence of the Amazon/Orinoco Plume on the summertime, Atlantic climate, J. Geophys. Res., 115. **Willoughby**, H., R. Darling, and M. Rahn (2006), Parametric representation of the primary hurricane vortex. part II: A new family of sectionally continuous profiles, Monthly Weather Rev., 134(4), 1102-1120*

More details in: ***Hernandez, O., J. Jouanno, and F. Durand (2016), Do the Amazon and Orinoco freshwater plumes really matter for hurricane-induced ocean surface cooling?, J. Geophys. Res. Oceans, 121, 2119–2141***