# A NUMERICAL STUDY OF THE AMAZON AND CONGO PLUMES

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## INTRODUCTION

The recent addition of SSS to the suite of remotely sensed oceanic variables revealed previously poorly known features of the tropical Atlantic. Aquarius SSS shows high salinity (SSS > 37 PSU) pools south of 10°S and north of 15°N in dry regions where annual mean evaporation exceeds precipitation (**Fig. 1**). Between these dry zones the SSS is generally below 36 PSU in the moist tropics. Two additional SSS minima are located between 7°S-2°S in summer and 10ºN-15°N in winter (**Fig. 1**). Both are probably not linked to local concurrent precipitation and are possibly related to river freshwater input. West of 40ºW (in the equatorial Atlantic) the mixed layer salinity is freshened by the spread of near-surface water from the Amazon (whose discharge peaks in boreal summer; annual mean of ~ 209,000 $m^3$/s) and the Orinoco (annual mean of ~ 33,000 $m^3$/s with a peak in July). On the eastern tropical Atlantic at 6S, the Congo (the second largest world's river by discharge; Dai *et al.*, 2009) inputs an annual mean of ~ 41,200 $m^3$/s.

The dynamics of these freshwater plumes, therefore, is critical to the freshwater balance of the equatorial Atlantic. Future changes in the drainage basin of the Amzon, Orinoco and Congo (i.e de-forestation) are likely to promote dramatic changes in river discharge which may be ultimately conveyed to the region of deep water formation in the North Atlantic with a result of an enhanced/reduced AMOC. In spite of their importance there are very few observational studies on the spreading of these tropical plumes and scarce modeling studies on their dynamics. In this work we use Aquarius data and the results of a suite of process-oriented numerical experiments to investigate the dynamical mechanisms controlling the spreading of the Amazon, Orinoco and Congo plumes.

## NUMERICAL MODEL:

We employ ROMS (Shchekeptin and Mc Williams, 2005). We conducted experiments in highly idealized domains as well as experiments in realistic settings with 1/12 degree horizontal resolution and 30 vertical " s" levels.

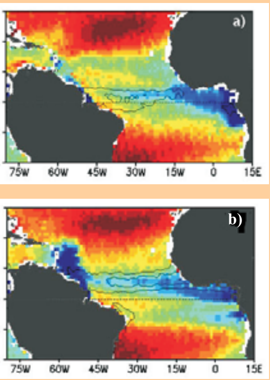

**Figure 1:** Sea Surface Salinity from Aquarius. (a) February and (b) June. Black contours mark ITCZ rainfall larger than 5 mm/day. In northern winter (a), a fresh zonal band is present between 10-15N well north of concurrent ITCZ. In summer, a fresh zone is present between 7S-2S, again south of concurrent ITCZ. We speculate that these bands are due to the effect of the major rivers outflows.

## Idealized Experiments

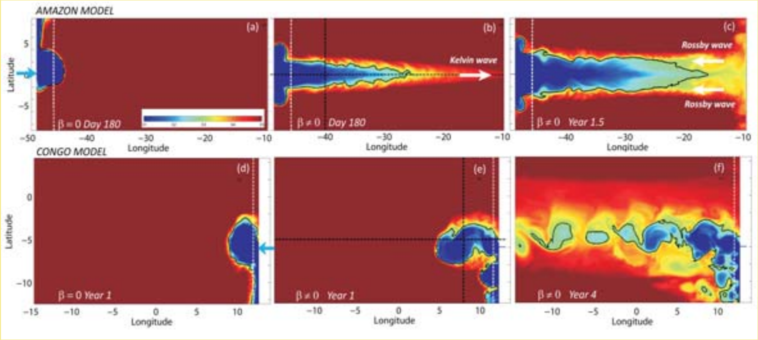

**Figure 2:** Highly idealized simulations of the Amazon and Congo river plumes. The ocean is a rectangular, constant depth basin with a continental shelf near the river's mouth. Horizontal resolution is 1/12 of a degree. The blue arrow indicates the inflow location, the white dashed line is the shelf break. Top panels: Snapshots of SSS from the Amazon River experiment . (a) Experiment with $\beta=0$ showing the development of a buldge. (b) SSS structure associated with the eastward propagation of Kelvin waves. (c) Modifications of the SSS structure brought by the reflection of Rossby waves. Bottom panels: Snapshots of the SSS for the Congo River experiment. (d) Experiment with $\beta=0$ showing the development of a buldge (no eddies) (e) Experiment with $\beta \neq 0$ showing the detachment of the buldge. (f) SSS structure at a later time showing a well developed train of eddies. Analytical results have shown that for mid-latitude outflows on an $f$-plane ($f \neq 0$ *but* $\beta=0$), the discharge produces a forever growing gyre near the point where it debouches into the ocean. (Nof and Pichevin 2001). With $f \neq 0$ and $\beta \neq 0$ (i.e., outflows in mid-latitude subject to both rotation and β) and the discharge located at an eastern coast, the problem produces westward propagating nonlinear anticyclonic eddies (Nof *et al.*, 2002 and 2004 ).

**REALISTIC EXPERIMENTS I:** These experiments include realistic bathymetry and coastlines at 1/12 degree resolution. The ocean is initialized with constant density and there are no externally imposed mean currents or wind forcing .

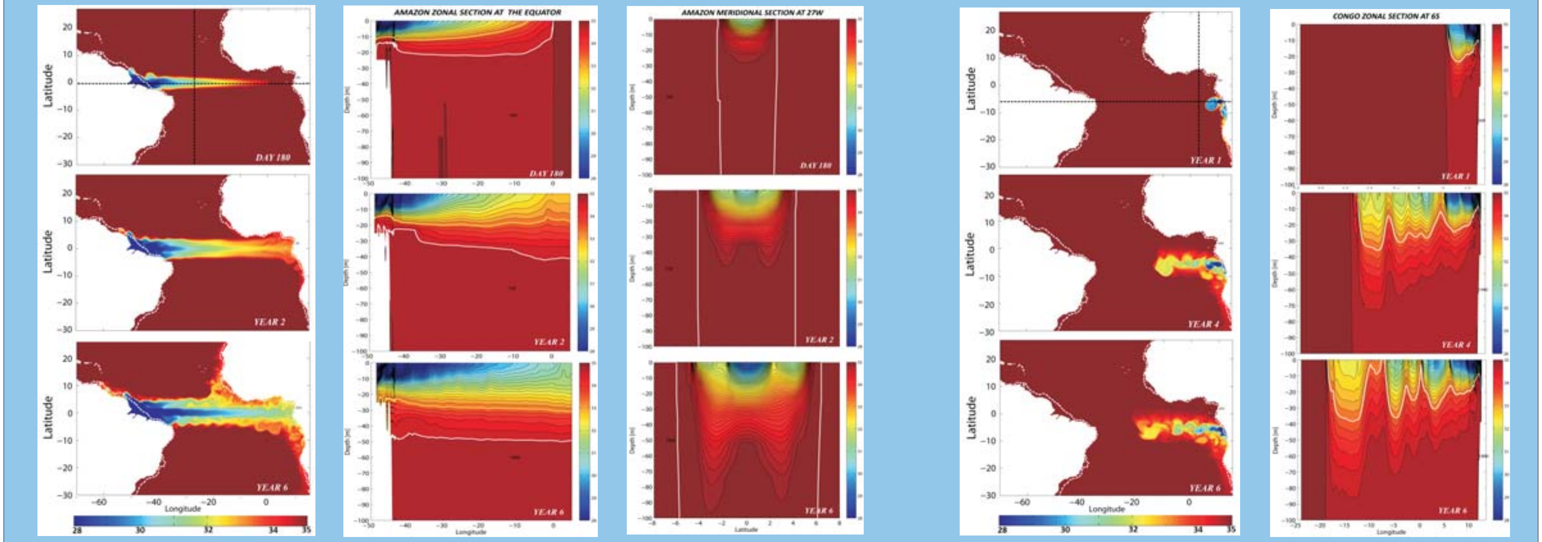

**Figure 3:** Ocean Salinity structure . The first three panels shows the SSS anomalies and salinity profiles generated by the Amazon River and the last two panels shows the SSS anomalies and salinity profiles generated by the Congo River. The tilting of the coastline breaks the inter-hemispheric symmetry of the Amazon plume in the coastal region (compared with the idealized simulations) and favors an earlier separation from the coast in the northern hemisphere. The lack of resemblance between this plume and the Aquarius observations reflects the importance of the mean ocean circulation and the wind in the spreading of the discharge. In contrast, the Congo River outflow generates a train of westward propagating eddies and a low-salinity plume that resembles the idealized results (Fig. 2), Nof, et al. (2002) prediction for the spreading of an outflow situated several degrees south of the equator, and the Aquarius observations (Fig. 1b).

**REALISTIC EXPERIMENTS II**: These experiments were started from rest and run until dynamical equilibrium using climatological forcing [ERA-Interim winds (Dee *et al*., 2011) and the heat and freshwater fluxes from COADS (Da Silva *et al.*, 1994)] At the northern and southern boundaries we impose a modified radiation open boundary condition (Marchesiello *et al.*, 2001) with nudging to the monthly values of a global, eddy-resolving (1/10˚) global ocean general circulation model (OFES, Sasaki *et al.*, 2008). The mean and seasonally varying discharges of the Amazon, Orinoco, and Congo rivers are derived from observations (Dai *et al.*, 2009).

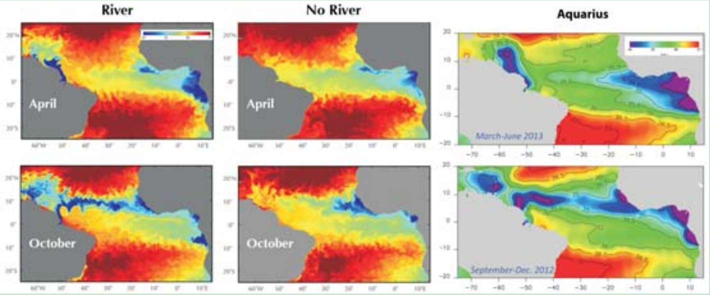

**Figure 4:** Snapshots of the model SSS show structures similar to those reported by the Aquarius observations . During the NH spring season (April) the Amazon and Orinoco river plumes are advected towards the tropics. The situation changes dramatically during the fall season (October), when the northward displacement of the ITCZ leads to the development of the North Equatorial Counter Current, which advects much of the Amazon waters towards the east creating the distinctive SSS signature captured by the Aquarius observations. To assess whether the observed seasonal variations of the SSS were due to river discharge or to seasonal variations of the precipitation rate we repeated the experiment excluding all the river discharges. Although this experiment is still under the influence of increased precipitation fluxes during the fall season, the absence of rivers discharges produces a dramatic change of the SSS field, which no longer shows the low-salinity tongues of the previous case.

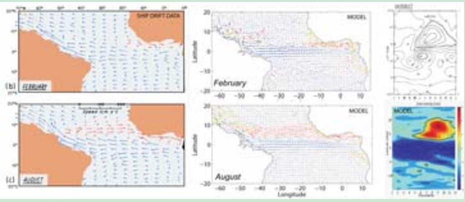

**Figure 5:** Left panels: Surface currents in the equatorial region as derived from ship drift data. [Adapted from Tomczak and Godfrey (2002)]. Middle panels : Model surface currents. Right panels: Time evolution of the surface velocities showing the seasonal appearence of the North Equatorial Counter-Current (NECC). Ship data is redrawn from Philander (1990).

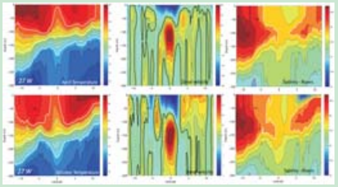

**Figure 6:**: Meridional sections of temperature, zonal velocity and salinity at 27W for the realistic experiment including the river's discharge. Note the presence of the Equatorial Undercurrent (middle panels) and the surface freshwater pool near 8N in October (right panels).

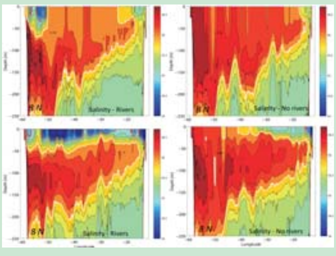

**Figure 7:**: **Zonal** sections of salinity at 8N for the realistic experiments with (left) and without (right) the river's discharge.

## SUMMARY

Highly idealized experiments are particularly useful to advance our understanding of the tropical plumes´ dynamics. Our results shows that while the adjustment of a freshwater discharge at the western boundary is dominated by (Kelvin/Rossby) wave propagation (Amazon River) the adjustment at the eastern boundary is dominated by eddy generation (Congo River).

Numerical experiments with realistic coastlines and bottom topography (initialized with constant salinity and without external forcing) shows that the tilting of the coastline breaks the inter-hemispheric symmetry of the Amazon plume in the coastal region and favors an earlier separation. In contrast, the Congo River discharge generates a train of westward propagating eddies very similar to the idealized experiments.

Preliminary results obtained from our most realistic experiments suggests that the banded salinity structure of the equatorial Atlantic is not primarily driven by E-P fluxes but by river discharges and the wind stress curl, which, during the fall season, leads to the development of the North Equatorial Counter Current.

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