Eastward propagating surface salinity anomalies in the tropical North Atlantic

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Ocean areas with expected eastward anomaly propagation

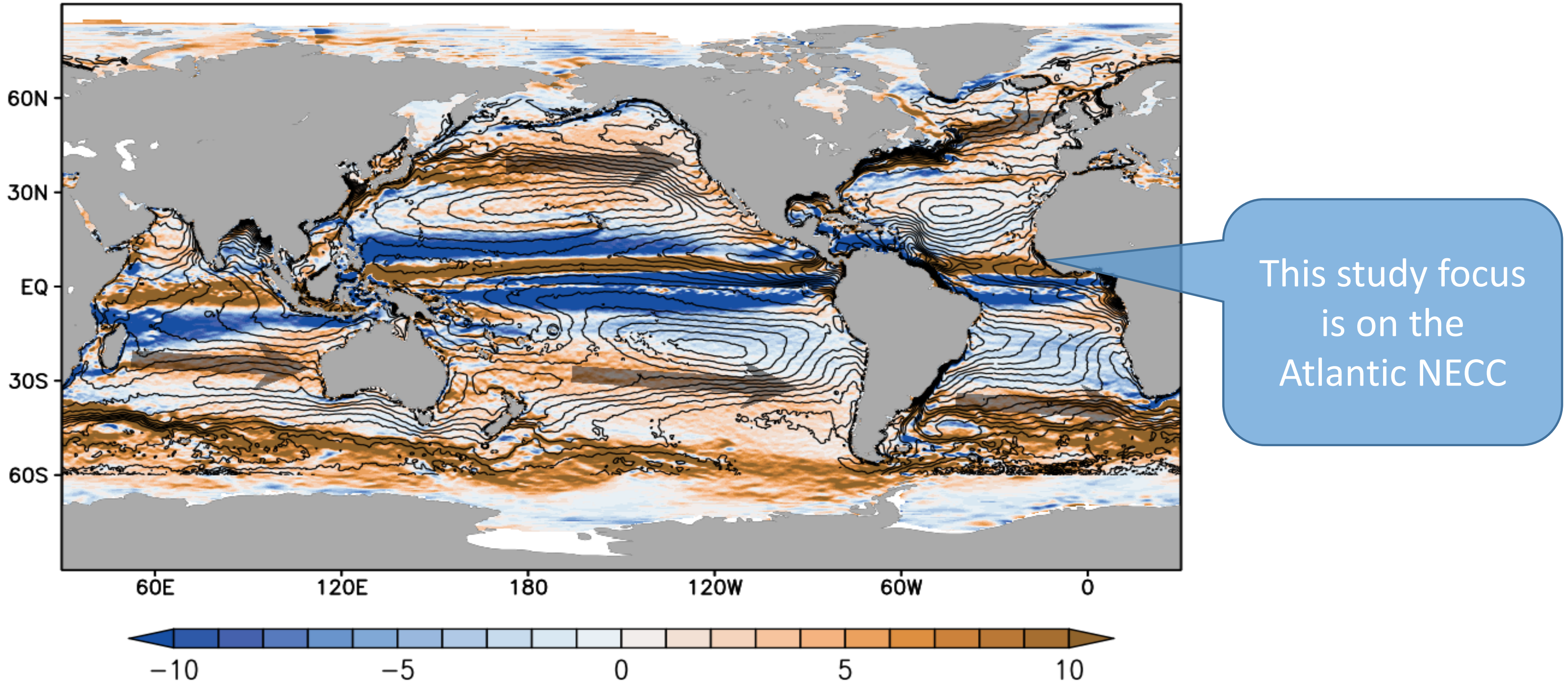

Figure 1. Time mean altimeter zonal geostrophic velocity (shaded, cm/s) and satellite SSS (contours, CINT=0.25 psu). Gray arrows illustrate poleward edges of subtropical gyres where eastward advective salinity signals are expected. They are also expected in the ACC and equatorial contercurrents.

In contrast to the westward ocean signal propagation by Rossby waves, the eastward advective propagation may be common in zonally-oriented salinity fronts located on poleward sides of subtropical gyres, in the ACC, and equatorial countercurrents. The North Equatorial Countercurrent (NECC) in the tropical north Atlantic is an ideal system for observing such eastward salinity signals produced by highly variable western boundary current dynamics that impact Amazon plume water and its export into the eastward NECC via the NBC retroflection.

Abstract

Upper ocean in the tropical Atlantic is strongly seasonal due to the corresponding seasonality in surface forcing and continental runoff. This implies that many regional anomaly features may also be seasonally locked. In the boreal summer and autumn, remote sensing sea surface salinity (SSS) shows the presence of eastward propagating anomalies concurrent with the seasonal development of fresh Amazon plume and acceleration of the eastward North Equatorial Countercurrent (NECC).

Interannual variations of eastward cross-Atlantic SSS signals are investigated in connection with their forcing by wind and circulation patterns. Satellite data show that they are advected zonally across the entire Atlantic. It is suggested that they originate due to wind-induced changes in the Amazon plume areal extent, which are notorious in the North Brazil Current retroflection.

Satellite SSS is instrumental for exploring such signals because in-situ observations do not always capture them due to the limitation in resolved meridional and temporal scales.

Figure 2 illustrates the August climatological SMAP SSS and geostrophic zonal currents in the tropical Atlantic. The Amazon freshwater plume configuration, with SSS≤35 psu, reflects the Amazon runoff entering the ocean at approximately 0°N and its transport northwestward along the western boundary. Importantly, a connected area of relatively fresh 33< SSS <35 psu also extends eastward along the NECC (between **4°N−10°N**). It reflects the combined impact of ITCZ rainfall and eastward Amazon plume advection. But in contrast with the August rainfall that is stronger east of 40ºW (not shown), the fresh SSS distribution is weighted towards the west that is consistent with the expected impact of advection from the plume.

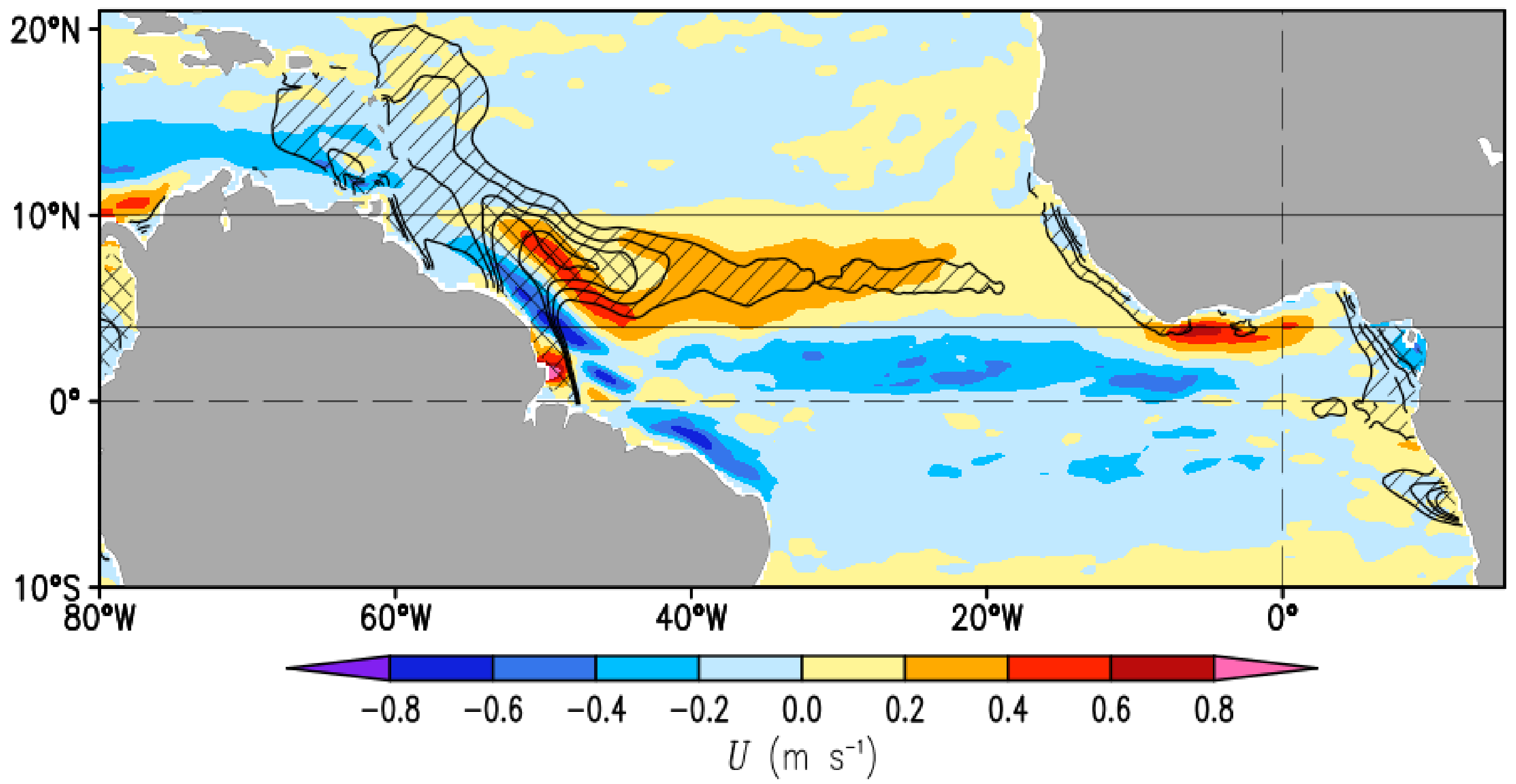

Figure 2. August climatological zonal geostrophic velocity (*U*, shaded, positive - eastward) and sea surface salinity (SSS) contoured at 32, 33, 34, and 35 psu. SSS≤33 psu is cross-hatched and 33<SSS<=35 psu is hatched. The latitudinal range (4°N−10°N) of the eastward North Equatorial Countercurrent, NECC, is delineated by solid lines.

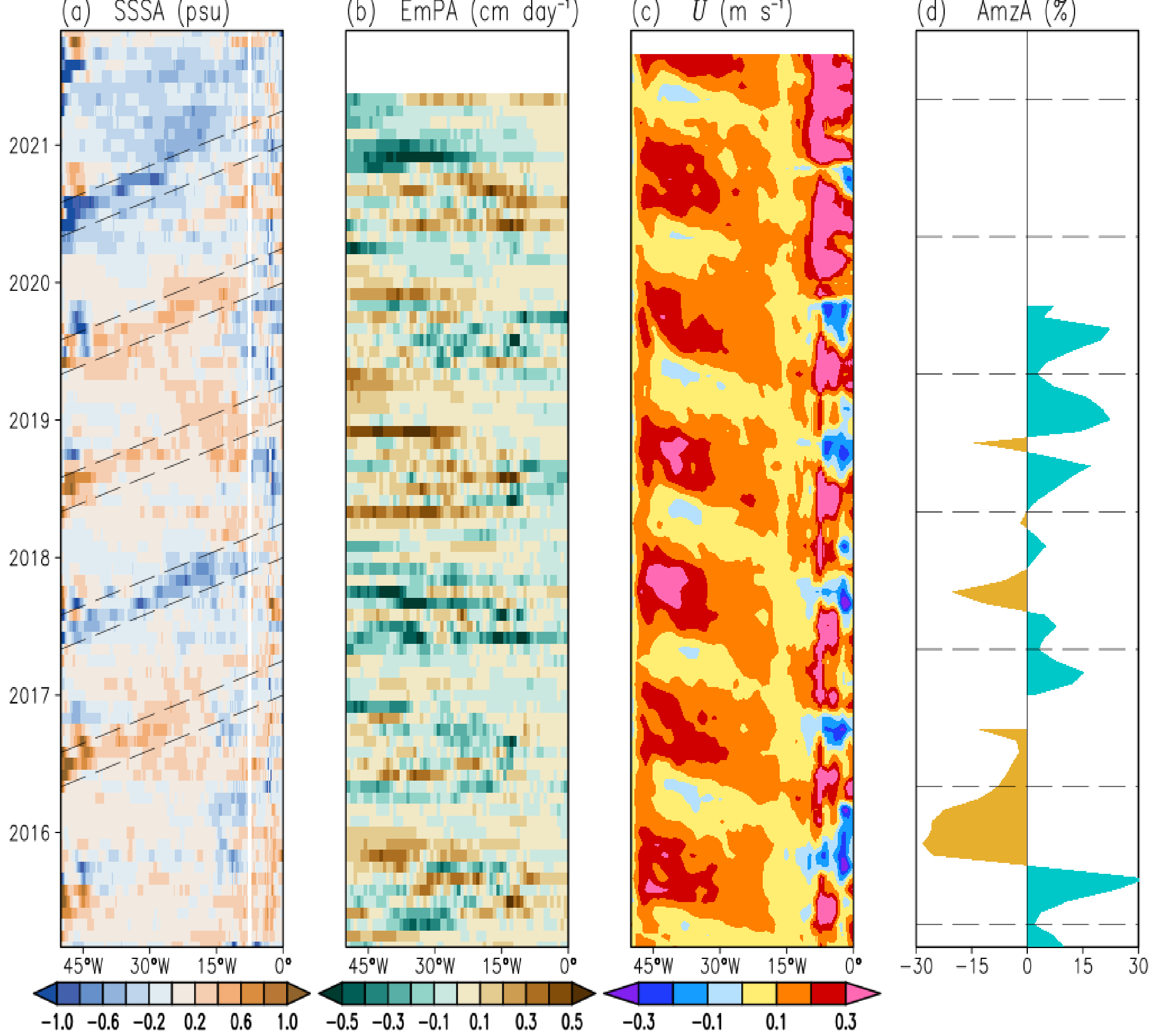

Figure 3. Monthly mean 4º-10ºN averages of (a) sea surface salinity anomaly (SSSA), (b) Evaporation-minus-Precipitation anomaly (EmPA), (c) total zonal geostrophic velocity (U), and (d) relative anomaly ($\text{AmzA} = (R - R_S)/R_S$) of Amazon runoff ($R$) from its seasonal cycle (R_S). Horizontal lines in (d) are drawn 1-st of May each year when Amazon runoff maximizes. Diagonal lines in (a) show 25 cm s^{-1} propagation speed.

SSS anomaly (SSSA) within the zonal NECC belt across 4°N–10°N reveals an eastward propagation , with SSSA ~0.5 psu crossing the *entire* tropical Atlantic (a). They develop seasonally along with the NECC, originate in the west by late spring to early summer, and cross the Atlantic by year-end.

These eastward SSSA are not likely forced by local air-sea interactions, as illustrated by Evaporation-minus-Precipitation, EmP, anomalies, which do not seem to display a similar eastward propagation (b). SSSA characteristic propagation speed ~0.2 m s^{-1} (a) corresponds to NECC zonal geostrophic velocity (c). But, NECC acceleration events observed in 2017 and 2018 (c) correspond to two opposite sign salinity events with fresh and salty NECC states (a), respectively. This, in turn, suggests that SSS anomalies exiting the plume area via the NBC retroflection are further advected eastward by the mean NECC ($\bar{u}S'$ transport term) while the salinity transport by anomalous zonal velocity ($u'\bar{S}$ transport term) is not at play.

It is anticipated that the Amazon runoff anomaly may also contribute. But only in 2016 can the saltier NECC state be linked to preceding below-normal Amazon runoff (d), (runoff data from, https://hybam.obs-mip.fr/ are available only through the 2019). During other years, the sign of SSS anomaly does not correlate with the sign of Amazon runoff anomaly.

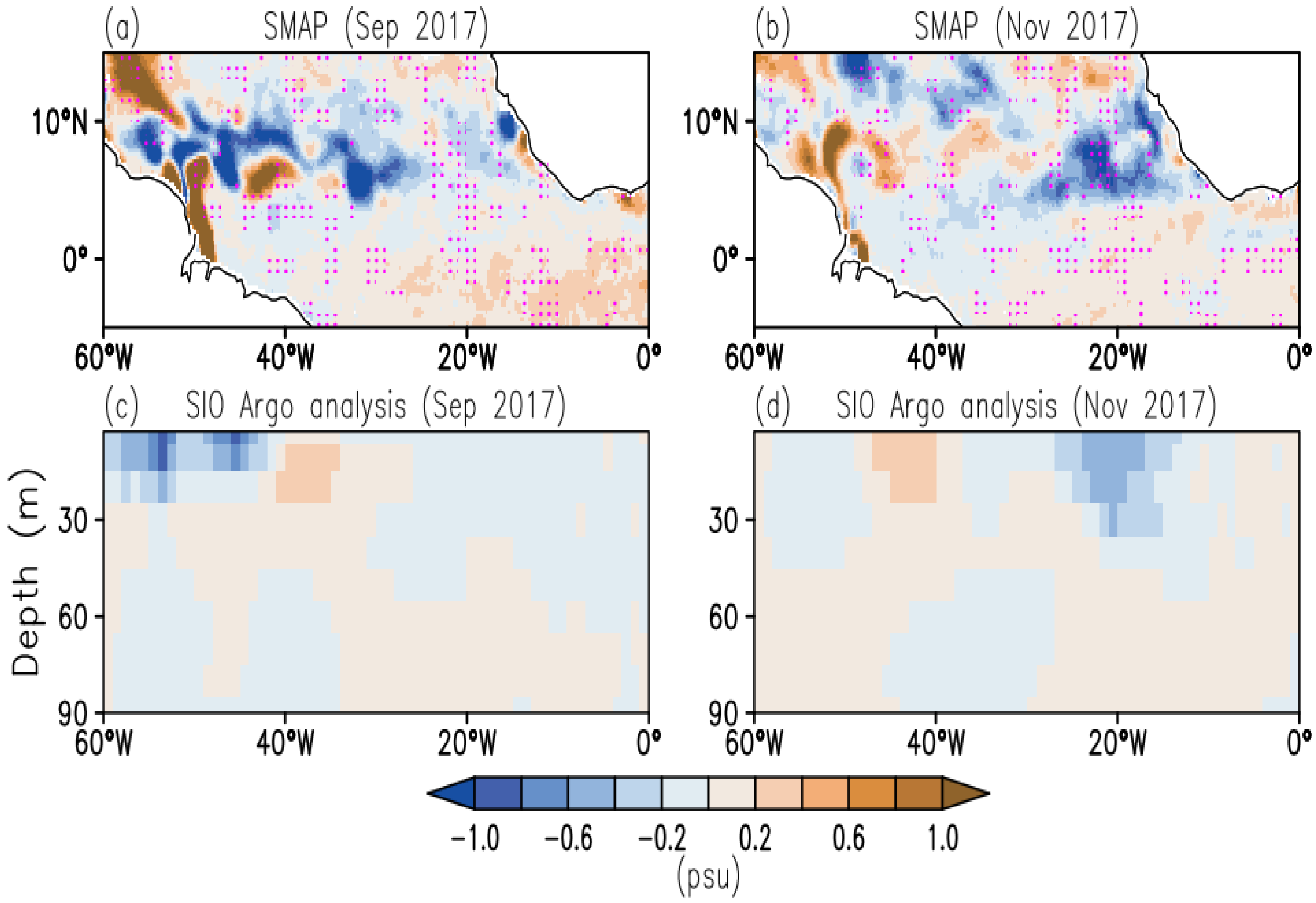

Figure 4. Sample SMAP satellite monthly SSS anomaly (shaded) for (a) September 2017 and (b) November 2017 with Argo data coverage hatched by purple dots. (c, d) Corresponding Argo depth-longitude salinity anomaly averaged 4°N-10°N from the Scripps Institute of Oceanography analysis (Roemmich and Gilson 2009).

In spite of their cross-Atlantic zonal extent, the eastward SSSA signals have a smaller meridional size and are not firmly captured by the existing in-situ observations, which do not always sample them due to the limitation in resolved meridional and temporal scales. As an example, panels (a) and (b) show spatial patterns of fresh SMAP SSSA for two sample months of 2017. In November 2017, the Argo float network (d) captures the fresh SMAP-observed SSSA pattern located at ~20ºW (b, d). But there is a large discrepancy in September 2017 when Argo salinity anomaly (c) grossly misses the satellite-observed SSSA (a).

If captured, the gridded Argo analysis does represent the expected vertical characteristics associated with these eastward SSSA signals, increasing from ~20 m to ~40 m as they propagate from the west into the tropical eastern Atlantic (c, d). In the west and close to the plume, their vertical scale corresponds to the vertical scale of barrier layers in the plume, ~20 m. In the east, it deepens to ~ 40 m that may be interpreted as a result of the vertical diffusion of salinity anomalies as they are advected eastward by the NECC and propagate away from the plume.

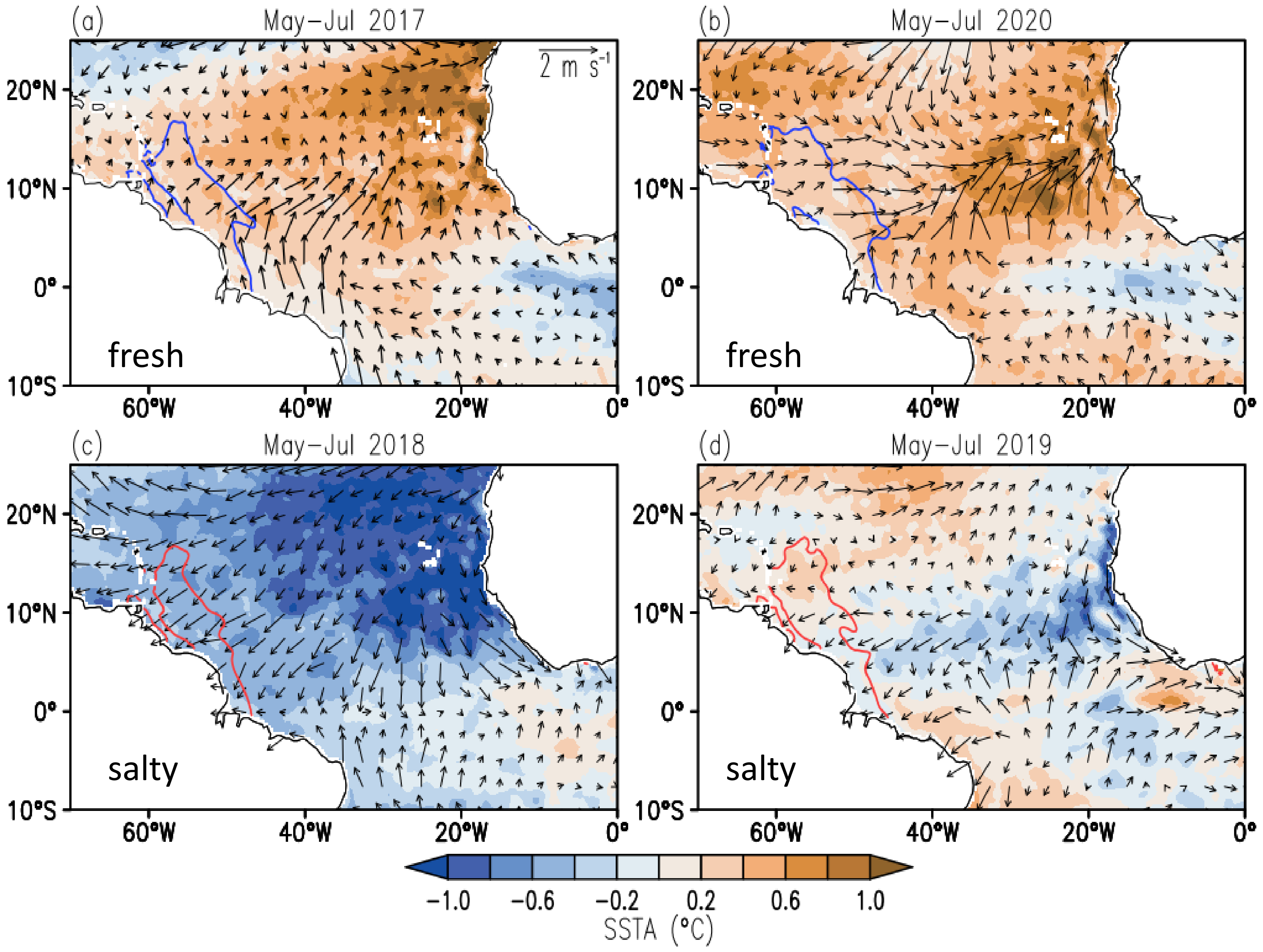

Figure 5. (shaded) Sea surface temperature anomaly (SSTA), (arrows) scatterometer surface wind anomaly, and (solid lines) SSS=34 psu contours during May-July period of years with (a, b) fresh and (c, d) salty NECC states. SSS contour color is (top row) blue (bottom row) red for better contrast with SSTA shading.

Previous research has hypothesized that the strength of cross-shore winds over the tropical northwestern Atlantic can regulate the cross-shore plume extent by modifying its dispersal by mesoscale currents (Molleri, Novo, and Kampel 2010). Such indirect wind-induced changes of plume extent, in turn, modify the salinity of the water that enters the NECC through the NBC retroflection. Scatterometer winds during months (May-July) corresponding to the annual development of salinity anomalies in the western NECC for years with fresh (a, b) and salty (c, d) NECC states support the above hypothesis. In 2017 and 2020, the wind anomalies were offshore (a, b). This favoured Amazon plume dispersal off the shelf and allowed for fresher water to be retroflected into the western NECC. Conversely, May-July wind anomalies in 2018 and 2019 were onshore (c, d). This squeezed the plume area and place it nearer to the coast, ultimately resulting in anomalous salinification of the western NECC.

Changes in the strength of cross-shore winds are related to larger-scale changes in the northeasterly trade winds, in turn, linked to the meridional-mode-like SST patterns (Fournier et al. 2017), with weaker winds corresponding to warmer tropical North Atlantic SST and vice versa.

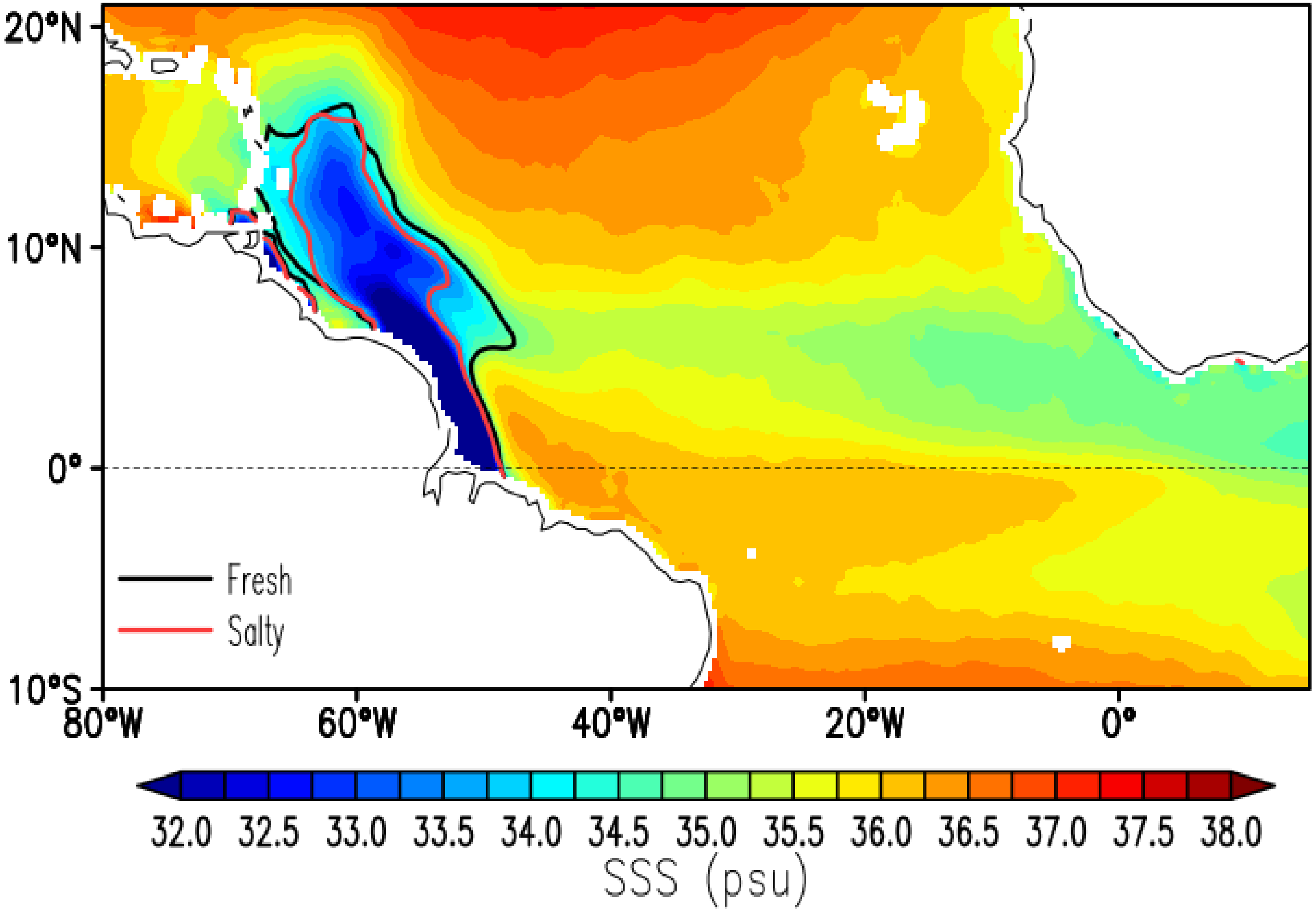

Figure 6. May-July climatological SSS (shaded) with SSS=34 psu contour (solid lines) for years of fresh (2017 and 2020, black) and salty (2016, 2018, and 2019, red) state in the NECC.

Amazon plume extent composites are compared using satellite SMAP SSS separately for years of salty (2016, 2018, and 2019) and fresh (2017 and 2020) NECC states. Even given the limited statistics available from only 5 full years of SMAP data, this comparison illustrates that the plume area contracts somewhat during years of stronger onshore winds, which corresponds to the salty NECC state. The strongest plume contraction is present in the retroflection area and this implies less Amazon freshwater transport into the western NECC during anomalously onshore wind conditions. Variations in this freshwater transport are a key factor of upper ocean salinity variability in the tropical northwestern Atlantic

Summary

- SMAP SSS data reveal eastward advective propagation of ~0.5 psu SSS anomalies that cross the entire tropical Atlantic within the North Equatorial Countercurrent (NECC) belt between 4°N and 10°N. They develop seasonally along with the seasonal acceleration of the NECC, originate in the west by late spring to early summer, and reach the eastern tropical Atlantic by year-end. Their characteristic propagation speed (~0.2 m s^{-1}) corresponds to the NECC zonal geostrophic velocity. These salinity anomalies produce year-to-year changes of SSS in the NECC belt, with alternating years of salty and fresh states.
- During six years of SMAP SSS observations, only the 2016 salty NECC anomaly may be attributed to the lack of Amazon runoff, while other years do not show this expected relationship. Instead, the sign of NECC salinity anomalies is consistent with the strength of cross-shore winds over the tropical northwestern Atlantic that regulates the cross-shore plume extent by modifying its dispersal by mesoscale currents. Such indirect wind-induced changes of plume extent, in turn, modify the salinity of the water that enters the western NECC through the NBC retroflection and is further advected eastward. Examining scatterometer winds during months (May-July) corresponding to the annual development of salinity anomalies in the western NECC confirms the presence of below normal and above normal onshore wind velocity anomalies during years of fresh and salty NECC states, respectively.
- Satellite salinity measurements are instrumental for exploring these eastward propagating salinity signals because in-situ measurements do not always capture them due to the limitation in resolved spatial and temporal scales.