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1 **Causes for the Recent Increase in Sea Surface Salinity in the north-eastern**
2 **Gulf of Guinea**

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25 **Abstract**

26 In situ Sea Surface Salinity (SSS) observations showed an increase $> +0.5$ over the period
27 2002-2009 in the Gulf of Guinea, off the Niger Delta. Observed changes in the Niger River
28 runoff were not consistent with this increase in SSS, but the increase was reproduced in a
29 regional numerical simulation with climatological river runoff. The simulated mixed-layer
30 salinity budget was used to identify the mechanisms responsible for the increase. When
31 comparing the period 2002-2009 with the period 1993-2001, significant changes in the salt
32 budget were identified. The increase in SSS in the more recent period appeared to be driven
33 by changes in the atmospheric freshwater flux, mainly attributed to a regional decrease in
34 precipitation. Horizontal advection partly compensated for the effect of freshwater flux
35 through changes in zonal currents and zonal SSS gradients.

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40 **Keywords:** Mixed-layer salt budget, Precipitation, SSS trend

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46 **Introduction**

47 Sea Surface Salinity (SSS) is a key indicator of changes in the hydrological cycle at
48 the ocean surface, where most of Earth's freshwater fluxes occur (Yu 2011). Quantifying
49 salinity variability is important, therefore, for understanding global climate change. Curry et
50 al. (2003) showed that SSS increased between the 1960s and the 1990s in the tropical and
51 subtropical North Atlantic, at a rate of 0.02 decade^{-1} . The authors suggested that this SSS
52 increase was caused by increased evaporation associated with global warming of the ocean.
53 Using in-situ observations, Boyer et al. (2005) found that, over the same four decades, the
54 Atlantic Ocean exhibited a large, positive salinity trend (exceeding 0.03 decade^{-1}) in the
55 subtropics and tropics in both the Northern and Southern hemispheres. Grodsky et al. (2006),
56 using a dataset combining the same historical data as the previous studies but with additional
57 data sources that extended to 2004, suggested that the near-surface waters in the tropical
58 Atlantic underwent a major salinification during the period 1960-1985 at a rate of 0.1 decade^{-1} ,
59 followed by the reverse trend. Whereas they found that year-to-year changes in salinity
60 were related to precipitation, they attributed decadal salinity changes to wind changes in the
61 deep tropics altering upwelling intensity and, possibly, evaporation rates.

62 In this study, we use a new in situ SSS gridded dataset for the Atlantic basin (Da-
63 Allada et al. 2013) to show a recent increase in SSS in the Gulf of Guinea. This increase was
64 also present in a regional simulation of the Tropical Atlantic Ocean from an ocean general
65 circulation model (OGCM) (Jouanno et al 2013). We used the simulated mixed-layer salinity
66 (MLS) budget to identify the mechanisms responsible for this salinification.

67 We describe (1) the SSS data used in the study and the numerical model employed,
68 and (2) how the model was validated and how it explores changes in the salt budget,
69 freshwater flux and horizontal advection.

70



71 **Material and methods**

72 **Data and model**

73 **In situ SSS dataset**

74 The observed-SSS product is an updated version of the dataset of Reverdin et al.
75 (2007) described in Da-Allada et al. (2013). The monthly SSS are gridded using an objective
76 mapping (Bretherton et al. 1976) at $1^\circ \times 1^\circ$ spatial resolution, by compiling a variety of data
77 sources, primarily from underway thermosalinographs on research vessels and voluntary
78 observing ships, from the Prediction and Research Moored Array in the Tropical Atlantic
79 (PIRATA) moorings, from surface drifters and from Argo floats. Figure 1 shows the temporal
80 and spatial resolution over the region 15°N - 15°S , 20°W - 15°E for the period 1993-2009. The
81 data distribution increased after 2005 as a result of the deployment of ARGO floats in the
82 region. The overall density of observations presents a marked contrast between areas of poor
83 data coverage (e.g. the south-east region of the Gulf of Guinea) and areas of high density that
84 occur along well-used shipping lines. We chose this SSS product as a reference for model
85 evaluation as it is, to our knowledge, the most complete and up-to-date SSS product available
86 for the Tropical Atlantic basin; salinity has been measured using the practical salinity scale.

87 **Model**

88 The model configuration is based on the Nucleus for European Modelling of the
89 Ocean (NEMO) general ocean circulation modelling system (Madec 2008). It solves the three
90 dimensional primitive equations in spherical coordinates discretised on a C-grid and fixed
91 vertical levels. The model design is a regional configuration of the tropical Atlantic at $\frac{1}{4}^\circ$
92 horizontal resolution. There are 75 levels in the vertical, with 12 in the upper 20 meters and
93 24 in the upper 100 meters. The model is forced at its boundaries (20°S - 20°N and 60°W -
94 15°E) using a radiative open boundary condition provided by outputs from the global
95 interannual experiment ORCA025-MJM95 developed by the DRAKKAR team (Barnier et al.

96 2006). The vertical turbulent mixing is parameterized using a level-1.5 turbulence closure
97 scheme, with a prognostic equation for turbulence kinetic energy (TKE) and a diagnostic
98 equation for length scale (Blanke and Delecluse 1993).

99 The atmospheric fluxes of momentum, heat and freshwater were provided by bulk
100 formulae (Large and Yeager 2004) and ERA-Interim reanalysis from the European Centre for
101 Medium-Range Weather Forecasts (ECMWF) (3-hour fields of wind, atmospheric
102 temperature and humidity, and daily fields of long and shortwave radiation and precipitation).
103 This product appears to be the most appropriate in terms of freshwater budget in the Tropical
104 Atlantic (Da-Allada et al. 2013). The short wave radiation forcing is modulated by a
105 theoretical diurnal cycle. A monthly climatology of continental runoffs from Dai and
106 Trenberth (2002) is prescribed near the rivers mouths as a surface freshwater flux. To justify
107 the use of monthly runoff, we tested different simulations (with climatology, yearly and
108 constant river flow) and found that interannual variability of river flow does not have much
109 effect on the interannual SSS in the eastern tropical Atlantic Ocean. It should be noted,
110 however, that uncertainty of the runoff data at interannual time scale is high in this region.

111 The model was initialized on 1 January 1990, using temperature and salinity outputs
112 from the ORCA025-MJM95 global experiment for the same date, and then integrated over the
113 period 1990-2009. Note that there was no restoring term toward a climatological SSS. Three
114 day averages values of SSS from 1993 to 2009 were used in the present analysis. Jouanno et
115 al. (2013) provide further details on the parameterization and some elements of validation,
116 including comparisons with surface and in-situ observations of temperature in the Gulf of
117 Guinea. Our focus was on the causes of salinification detected in the north-eastern part of the
118 Gulf of Guinea.

119 **Salinity Budget**



120 To investigate the processes of SSS variability at interannual time scales, as described
 121 in Ferry and Reverdin (2004), we used a salinity budget in the ocean mixed layer. This
 122 approach has been widely used in the tropical Atlantic to investigate the processes controlling
 123 the mixed-layer temperature at seasonal time scales (Peter et al. 2006).

124 Following the study of Vialard et al. (2001), the equation for mixed-layer salinity
 125 evolution can be written as follows:

$$\begin{aligned}
 127 \quad \partial_t SSS = & - \underbrace{\langle u \partial_x S \rangle}_{UADV} - \underbrace{\langle v \partial_y S \rangle}_{VADV} - \underbrace{\langle w \partial_z S \rangle}_{WADV} + \underbrace{\langle D_l(S) \rangle}_{DIFL} - \underbrace{\frac{(k \partial_z S)_{z=-h}}{h}}_{ZDF} - \underbrace{\frac{1}{h} \frac{\partial h}{\partial t} (SSS - S_{z=-h})}_{ENT} + \underbrace{\frac{(E - P - R)SSS}{h}}_{FWF} \\
 128 \quad & \text{(Eq.1)}
 \end{aligned}$$

129
 130
 131 where S is the model salinity, u and v are the eastward and northward components,
 132 respectively, of the horizontal velocity, w is the upward vertical velocity, $D_l(S)$ is the lateral
 133 diffusion operator, k is the vertical diffusion coefficient, h is the time varying mixed-layer
 134 depth, E is evaporation, P is precipitation and R is river runoff.

135 The terms in Eq.1 represent, from left to right, mixed-layer salinity tendency,
 136 horizontal advection (H ADV; H ADV=U ADV+ V ADV), vertical advection (W ADV),
 137 horizontal diffusion (DIFL), vertical diffusion (ZDF) at the mixed-layer base, mixed-layer
 138 salinity tendency due to variation of the mixed-layer depth, (ENT) and freshwater flux terms
 139 (FWF).

140 The mixed-layer salinity budget was computed online to quantify precisely the
 141 contributions of the different processes to the mixed-layer salinity tendency. The mixed layer
 142 depth was defined by a density criterion (0.03 kg.m^{-3} , de Boyer Montégut et al. 2004), in
 143 order to take into account both temperature and salinity stratifications. As Foltz et al. (2004).

144 We assumed that mixed-layer salinity is very close to SSS (Foltz et al. 2004). Therefore,
145 simulated mixed-layer salinity was compared to observed SSS to validate the model.

146

147 **Results**

148 **Model validation**

149 The model output of annual mean SSS for the period 1993-2009 was very similar to
150 the observed annual mean (Figure 2a-b). South of 5°S, both the model output and the
151 observations showed high values of SSS in the subtropical gyre, which was probably the
152 result of intense evaporation in this region. Elsewhere, low SSS values are a result of either
153 the Intertropical Convergence Zone (ITCZ) along 5°N, or the runoff from major rivers on the
154 west African coast (e.g. the Niger and Congo rivers, which are located in the vicinity of 5°N
155 and 5°S respectively).

156 With regard to the SSS seasonal cycle in the Gulf of Guinea, the model correctly
157 reproduced the amplitude and phase of the mixed-layer salinity. In particular, in the northern
158 region of the Gulf of Guinea, the use of an OGCM, which explicitly calculates vertical
159 diffusion, produced model output that more closely matched the observed values than did a
160 simplified mixed-layer model as used by Da-Allada et al. (2013), highlighting the important
161 role of vertical diffusion in the Gulf of Guinea.

162 Observed and simulated linear trends in SSS are compared in Figure 2 c-d over the
163 period 2002-2009. The model exhibited a large, positive, salinity trend in the eastern tropical
164 Atlantic, with maximum values up to 0.8 occurring in the low salinity regions of the Gulf of
165 Guinea, i.e. off the Niger Delta and along the equator (Figure 2d). Negative salinity trends
166 occurred in small regions, however. The map of the observed data (Figure 2c) shows regions
167 with negative trends (e.g. along the north coast of the Gulf of Guinea, which had negative
168 trends of around -0.2) and with positive trends (that were most prominent off the Niger Delta



169 (0.8)) and less pronounced at the equator. Both observations and model results showed the
170 greatest increase near the Niger Delta (1°S-5°N, 6°-10°E) where the trend was significant
171 (Welch test; $p < 0.05$). Elsewhere trends are lower in amplitude and significance is
172 questionable. Therefore our analysis was focused on this region (see boxes in Figure 2 c-d),
173 referred to hereafter as the focal area.

174 Interannual SSS anomalies, spatially averaged in the focal area from both the
175 observations and the model output, are shown in Figure 3a. Both time series presented a
176 similar evolution, which showed two periods. The first period was characterized by an
177 absence of notable salinity trend in either the observations or the model output and was
178 termed the 'period of reference' (REF). The second exhibited a fairly large, positive SSS trend
179 of about + 0.5 for the period 2002-2009 (Student's t-test; $p < 0.1$), in both the model output
180 and observations, and was termed the 'period of change' (CHA). The close agreement between
181 the modelled and observed SSS suggests that the model can be used to explore changes in the
182 salt budget responsible for the SSS increase.

183 **Changes in salt budget**

184 Applying the model of Alory and Meyers (2009) to salinity, we compared the mean
185 balance of the salt budget between the periods REF and CHA to investigate possible changes.
186 Figure 3b shows, for both periods and for both the model output and the observations: (1)
187 mean anomalies (and standard deviation) of SSS changes (dS); (2) linear trend of SSS; and
188 (3) the model salt budget terms, computed using a five-year running mean. The use of running
189 means allows the standard deviation to be estimated for each term, which assists with the
190 identification of significant changes in terms of the salt budget.

191 Change in SSS and the linear trend of SSS in the model were positive for the recent
192 period, CHA, and confirmed an SSS increase in the focal area, which was also detected in the
193 observations data (Figure 3b). In the model output, there was a significant change in SSS

194 (Welch test; $p < 0.05$) between the two periods, REF and CHA. To identify the primary
195 mechanisms responsible for the SSS change, salinity balance terms were plotted in Figure 3b.
196 Horizontal diffusion and entrainment terms were negligible and were therefore not shown in
197 the figure. Freshwater flux (FWF) and horizontal advection (H ADV) changed significantly
198 (Welch test; $p < 0.05$). Freshwater flux was strongly negative during REF and became
199 strongly positive during CHA, which would explain the increase in SSS. Horizontal advection
200 was slightly positive during REF and became strongly negative during CHA. Hence it
201 contributed to decrease in SSS and tended to compensate for the effect of changes in
202 freshwater flux. Vertical advection (W ADV) and vertical diffusion (ZDF) also changed, but
203 not significantly.

204 **Changes in freshwater flux**

205 Likely causes of the change in freshwater flux were explored. Freshwater flux includes
206 three components: evaporation (E), precipitation (P) and runoff (R). Increasing SSS in the
207 model was not related to a change in river runoff because only climatological run-off was
208 used in Eq.1. Moreover, the interannual variability of the Niger runoff, determined from
209 altimetry according to the method developed by Papa et al (2010), did not exhibit any
210 significant changes during the period 2003-2009, other than a slight increase in 2009 (data not
211 shown).

212 Mean evaporation from ERA-Interim and from the model (computed through bulk
213 formulae) are presented in Figure 4a-b. Evaporation values were high south of 5°S and low
214 elsewhere in the basin. Changes in evaporation between CHA and REF are shown in Figure
215 4d. Increase in evaporation was weak in the focal area as well as south of equator. The mean
216 contribution of evaporation to the salt budget (ES/H , where S is salinity and H is mixed-layer
217 depth) was positive (about 18 yr^{-1} ; Figure 4e), with a pattern slightly different than that for
218 evaporation itself due to spatial variation in the mixed-layer depth (data not shown). The

219 changes in ES/H between the two periods, CHA and REF, were positive (+1) in the focal area
220 (Figure 4f), indicating that changes in evaporation contributed only slightly to the increase in
221 SSS in recent years .

222 ERA-Interim precipitation was at a maximum at around 5°N due to the ITCZ, and
223 weakened on either side of the ITCZ (Figure 4c). There was a large precipitation decrease
224 between the two periods in our focal area. Precipitation changes over the ocean seem to be
225 linked to precipitation changes over the continent, with a deficit in precipitation around 10°N
226 and an increase south of 5°N, centred on 12°E (Figures 4c and 4g). However, rainfall products
227 are subject to uncertainties. Comparing of ERA-Interim with GPCP (Global Precipitation
228 Climatology Project) version 2.1 (Adler et al., 2003), based on observations, showed some
229 differences, especially on land. However, both products showed a decrease in precipitation in
230 the focal area (Figure 5a) although it was more pronounced in ERA-Interim. The higher-
231 resolution TRMM-3B43 satellite product (Adler et al., 2000) is limited to a shorter period that
232 which precluded a direct comparison between the CHA and REF periods, but there appeared
233 to be negative precipitation trend over the period 1998-2010 in the same focal area (Figure
234 5b), which is consistent with changes in other products and tends to support our results.

235 The mean contribution of precipitation to the salt budget was negative (-PS/H; -30 yr^{-1})
236 ¹), with a spatial pattern very similar to that for precipitation (Figure 4h). The change in this
237 term between the two periods, CHA and REF, was positive (+3) in the focal area, suggesting
238 that its contribution increased SSS in the salt budget.

239 Hence it appears that, off the Niger Delta in recent years, precipitation decrease was
240 the dominant term with regard to freshwater-flux, and its contribution to the salt budget led to
241 an increase in SSS.

242 **Changes in horizontal advection**

243 The contribution of the horizontal advection to the salt budget off the Niger River
244 delta changed significantly between the two periods, and tended to decrease SSS in the recent
245 period (Figure 3b), partly compensating the salinification effect of the freshwater fluxes. The
246 mean horizontal advection also contributed to a decrease in SSS in the whole basin (Figure
247 6a). Changes in horizontal advection had both positive and negative values, depending on
248 regions (Figure 6b), but, on average, were negative in the focal area. This was due mainly to
249 changes in zonal advection because changes in meridional advection contributed only slightly
250 to an increase in SSS (data not shown).

251 To identify whether changes in zonal currents or zonal SSS gradients were responsible
252 for the changes in H ADV, the mean zonal current, changes in zonal current, mean zonal SSS
253 gradient and changes in zonal SSS gradient were mapped (Figure 6). In the Gulf of Guinea,
254 the mean zonal SSS gradient is mainly negative over the basin, as SSS weakens towards the
255 African coast, and the mean current system consists of the eastward flowing Guinea Current
256 (GC) along the northern coast of the Gulf of Guinea and the westward flowing South
257 Equatorial Current (SEC), with its two branches located on each side of the equator. The
258 model suggests that the strength of both GC and SEC increased in the recent years. In the
259 focal area, comparison between the two periods showed weakening eastward flow and
260 strengthening westward flow, in addition to a mean negative SSS gradient. This contributed to
261 the negative advection term, which partly compensated for the freshwater flux contribution.

262 **Discussion**

263 Interannual variations of SSS during the period 1993-2009 were analysed using a
264 regional numerical simulation and observations. Both model and observations showed a
265 positive, linear trend of SSS since 2002 in the Gulf of Guinea, specifically in a focal area near
266 the mouth of the Niger River delta. The interannual SSS anomalies spatially averaged in this
267 region can be split into two periods: a period of reference (1993-2001), in which SSS was

268 stable, and a period of change (2002-2009), in which SSS increased significantly. Hosoda et al
269 (2009), when comparing SSS in the world ocean between the period 2003-2007 and the
270 period 1960-1989, also found positive salinity anomalies in the eastern part of the Gulf of
271 Guinea (which were actually the largest in the tropical Atlantic, see their figure 1c), which is
272 consistent with our findings.

273 We used a simulated mixed-layer salinity budget to identify the changes in the salt
274 budget by comparing the mean balance of the salt budget between the two periods. We have
275 found that SSS increases significantly in the model. In the salt budget, only freshwater flux
276 and horizontal advection changed significantly. Freshwater flux was strongly positive in the
277 recent period, explaining the increase in SSS. Horizontal advection was strongly negative
278 during this period and acted to compensate partially for the effect of freshwater flux. The
279 remaining salt balance terms did not change significantly.

280 We investigated the causes of these significant changes in freshwater flux and
281 horizontal advection. SSS increase was not related to changes in rivers runoff as we used
282 climatological river runoff in the simulation. Changes in freshwater flux were mainly due to
283 decreasing precipitation in the focal area. These local changes in precipitation may have been
284 related to changes in continental precipitation in neighboring areas. In their investigation of
285 SSS differences between the 1960s and the 1990s at a large spatial scale in the tropical
286 Atlantic, Curry et al. (2003) and Grodsky et al. (2006) also found that atmospheric freshwater
287 fluxes contributed to an increase SSS. In our study, changes in both zonal current and in zonal
288 SSS gradient led to significant changes in horizontal advection. Hence we conclude that this
289 effect dominates the ocean processes and tends to attenuate the effect of freshwater changes.

290 Grodsky et al. (2006) had previously noted a salinification in the Gulf of Guinea but of
291 a smaller than that found in the current study, probably because they considered a larger
292 region and longer period (1960-1999). Grodsky et al. (2006) also noted a decadal variability

293 in SSS in addition to an increasing salinity trend in this region, but we cannot conclude if the
294 trend found in our study was part of a decadal signal of SSS or a signature of a longer-time
295 trend. Interestingly, a global analysis also suggested that some of the largest increase in SSS
296 over the period 1950-2008 were found in the Gulf of Guinea (Durack and Wijffels, 2010).
297 Whereas at large scales the hydrological cycle is expected to strengthen in a warming climate
298 and consequently decrease salinity in the wet tropics (Terray et al. 2012), the observed
299 salinification in the Gulf of Guinea suggests that regional changes are driven by more
300 complex processes. The recently available satellite products for SSS (SMOS, Aquarius;
301 Lagerloef 2012; Reul et al. 2012) and the recent increases in ARGO observations in the Gulf
302 of Guinea, will be useful to better understand these processes.

303

304

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390 **Figure Captions:**

391 **Figure 1.** Sea surface salinity data distribution indicating the number of $1^\circ \times 1^\circ$ grid points
392 with data in a month as a function of year (top panel). Spatial distribution of the number of
393 months with data in $1^\circ \times 1^\circ$ box for 1993-2009 (bottom panel).

394 **Figure 2.** Annual mean sea surface salinity (SSS) for (a) observations and (b) model ; mean
395 linear trend of SSS build from a 5-year running mean over the period 2002-2009 for (c)
396 observations and (d) model.

397 **Figure 3.** (a) Time series interannual anomalies of SSS: Observations (black), model (red),
398 model trend (dashed blue) and observation trend (dashed purple) for the period REF, and the
399 model trend (blue) and observation trend (purple) for the period CHA. Time series are
400 averaged over the focal area (1°S - 5°N , 6° - 10°E). The mean seasonal cycle is removed and a
401 1-year running mean is applied; (b) SSS changes and SSS trend in model and observation
402 (respectively dS_M , trend M, dS_O and trend O), and model salt budget terms, averaged over
403 the study box (FWF: freshwater fluxes; H ADV: horizontal advection; W ADV: vertical
404 advection; ZDF: vertical diffusion). A 5- year running mean anomalies for the period of
405 reference (REF) is in blue and the period of change (CHA) is in red.

406 **Figure 4.** Annual mean for (a) model evaporation (in $\text{mm}\cdot\text{day}^{-1}$), (b) ERA Interim
407 evaporation (in $\text{mm}\cdot\text{day}^{-1}$); (c) ERA Interim precipitation ((in $\text{mm}\cdot\text{day}^{-1}$),; (d) changes in
408 model evaporation (in mm); (e) annual mean contribution to the salt budget for ES/H (E
409 evaporation, S salinity, H mixed layer depth); (f) Changes in ES/H; (g) Changes in ERA-
410 Interim precipitation (in mm); (h) annual mean contribution to the salt budget for $-PS/H$ (P
411 precipitation); (i) changes in $-PS/H$.

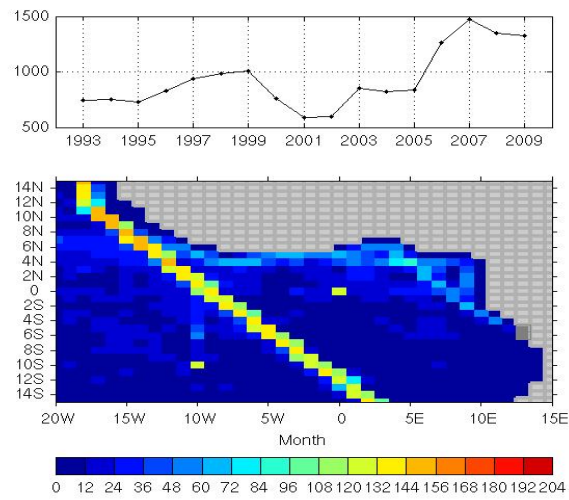
412 Changes are calculated between the period of change (CHA) and the period of reference
413 (REF) build using a 5-year running window. Changes in precipitation and evaporation are

414 calculated using cumulative values for each period. Wind vectors (c) and wind changes
415 vectors (values multiplied by 5) (g) are in m/s.

416 **Figure 5.** a) Changes in GPCP precipitation between CHA and REF periods (in mm) and b)
417 Linear trend over the 1998-2010 period in TRMM-3B43 precipitation (in mm/day/year). The
418 region of study is indicated.

419 **Figure 6.** Horizontal advection annual mean (a) and changes (b); zonal current annual mean
420 (c) and changes (d) in ms^{-1} ; zonal SSS gradient annual mean (e) and changes (f) in m^{-1} .
421 Changes are the difference between the period of change (CHA) and the period of reference
422 (REF) build using a 5-year running window.





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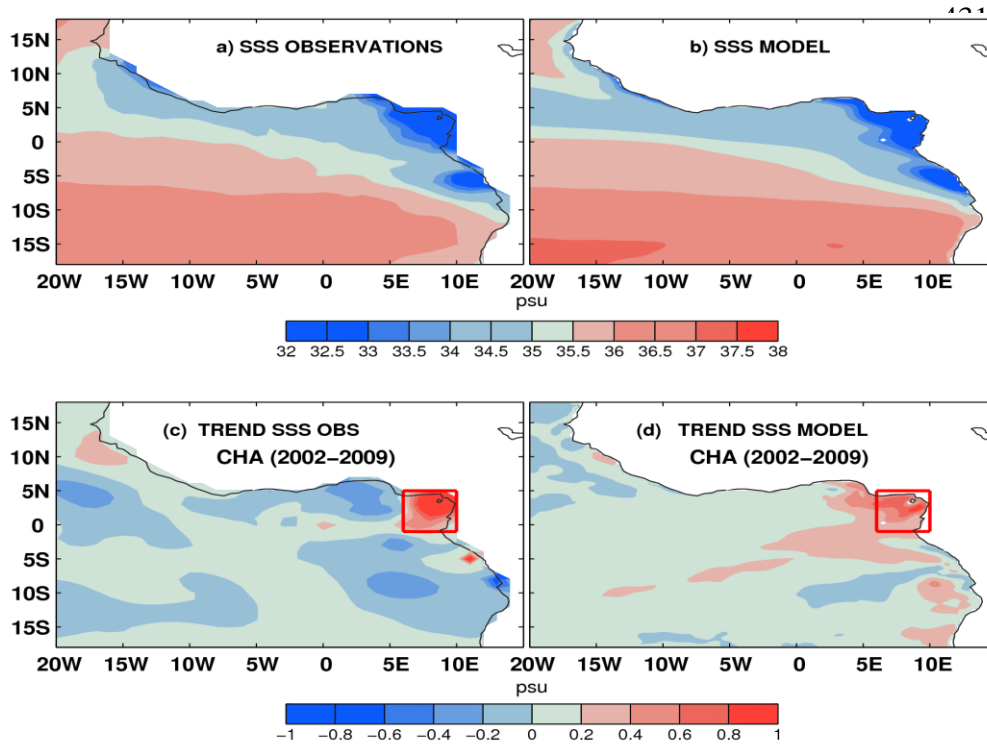
426 **Figure 1:** Sea surface salinity data distribution indicating the number of $1^\circ \times 1^\circ$ grid points

427 with data in a month as a function of year (top panel). Spatial distribution of the number of

428 months with data in $1^\circ \times 1^\circ$ box for 1993- 2009 (bottom panel).

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442 **Figure 2.** Annual mean sea surface salinity (SSS) for (a) observations and (b) model ; mean
443 linear trend of SSS build from a 5-year running mean over the period 2002-2009 for (c)
444 observations and (d) model.

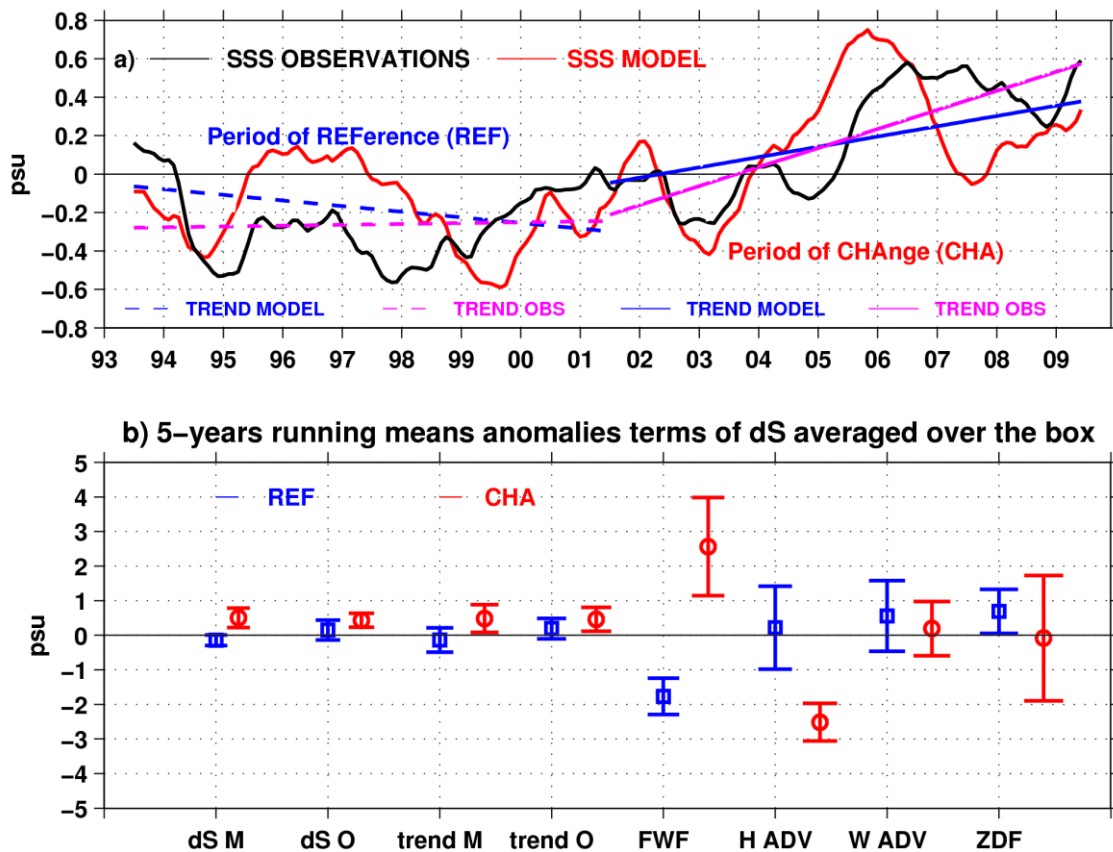
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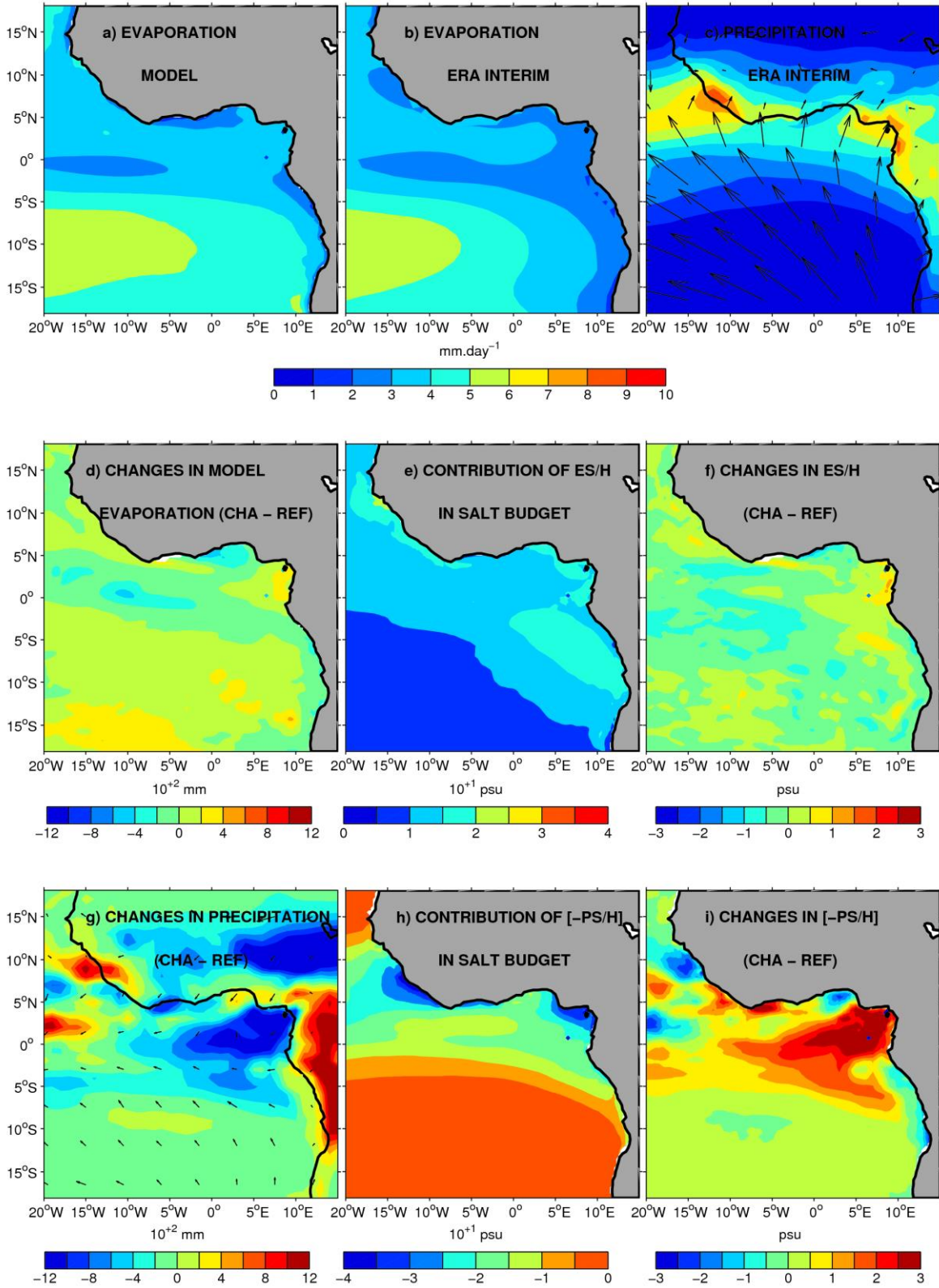
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451 **Figure 3.** (a) Time series of SSS interannual anomalies: Observations (black), model (red),
 452 model trend (dashed blue) and observation trend (dashed purple) for the period REF, and the
 453 model trend (blue) and observation trend (purple) for the period CHA. Time series are
 454 averaged over the study box (1°S-5°N, 6°-10°E). The mean seasonal cycle is removed and a
 455 1-year running mean is applied; (b) SSS changes and SSS trend in model and observation
 456 (respectively dS M, trend M, dS O and trend O), and model salt budget terms, averaged over
 457 the study box (FWF: freshwater fluxes; H ADV: horizontal advection; W ADV: vertical
 458 advection; ZDF: vertical diffusion). A 5- year running mean anomalies for the period of
 459 reference (REF) is in blue and the period of change (CHA) is in red. Units are psu.

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463 **Figure 4.** Annual mean for (a) model evaporation (in mm.day^{-1}), (b) ERA Interim
 464 evaporation (in mm.day^{-1}); (c) ERA Interim precipitation ((in mm.day^{-1}); (d) changes in

465 model evaporation (in mm); (e) annual mean contribution to the salt budget for ES/H (E
466 evaporation, S salinity, H mixed layer depth) (in psu); (f) Changes in ES/H; (g) Changes in
467 ERA-Interim precipitation (in mm); (h) annual mean contribution to the salt budget for –
468 PS/H (P precipitation); (i) changes in –PS/H. ES/H and PS/H are the contributions of
469 evaporation and precipitation respectively to the salinity balance.

470 Changes are calculated between the period of change (CHA) and the period of reference
471 (REF) build using a 5-year running window. Changes in precipitation and evaporation are
472 calculated using cumulative values for each period. Wind vectors (c) and wind changes
473 vectors (values multiplied by 5) (g) are in m/s.

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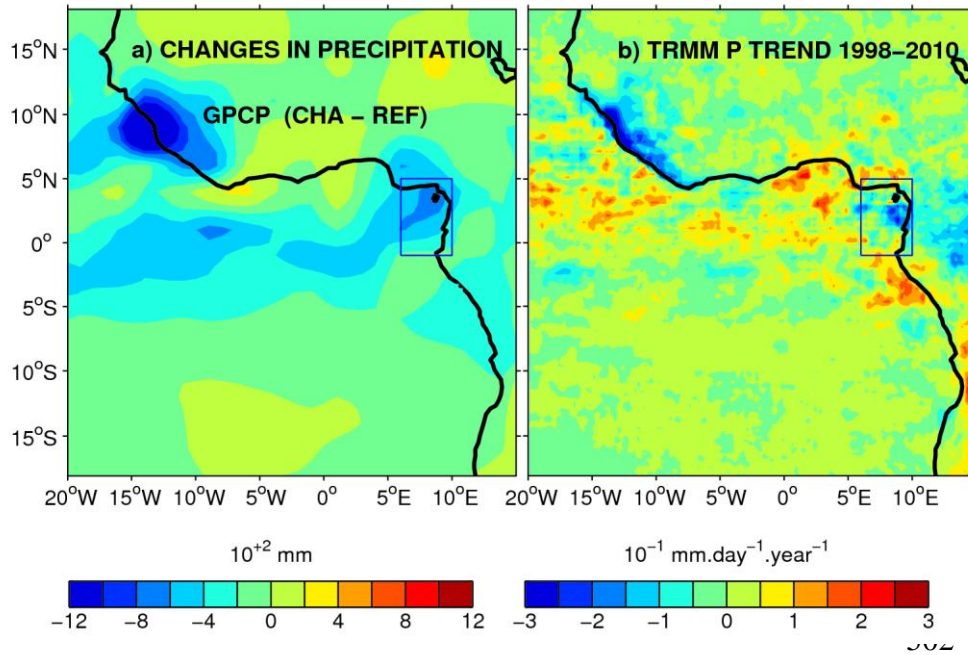
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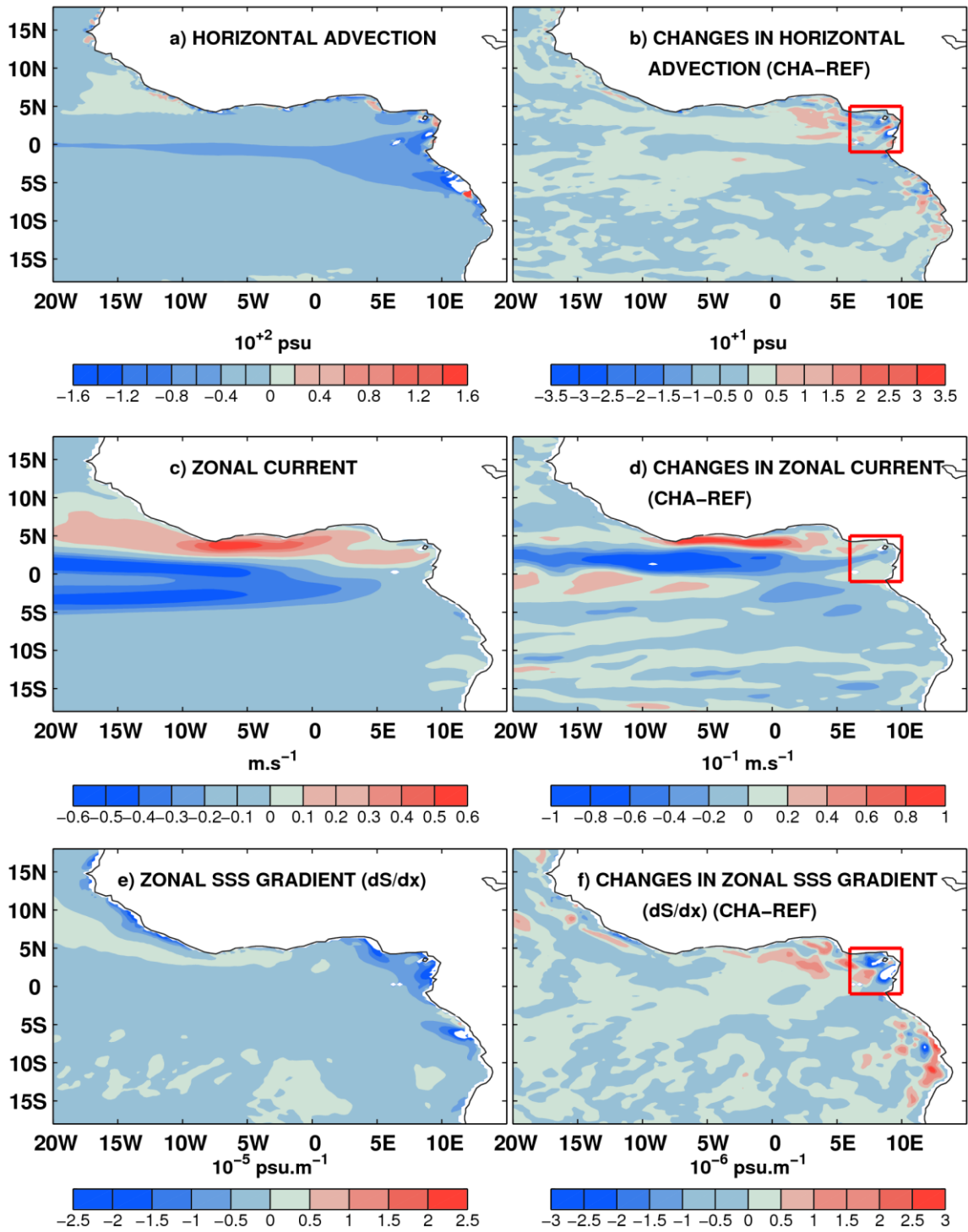
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503 **Figure 5.** a) Changes in GPCP precipitation between CHA and REF periods (in mm) and b)
504 Linear trend over the 1998-2010 period in TRMM-3B43 precipitation (in mm/day/year). The
505 region of study is indicated.
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510 **Figure 6.** Horizontal advection annual mean (a) and changes (b) in psu; zonal current annual
 511 mean (c) and changes (d) in ms^{-1} ; zonal SSS gradient annual mean (e) and changes (f) in

512 psu.m⁻¹. Changes are the difference between the period of change (CHA) and the period of
513 reference (REF) build using a 5-year running window.
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