CHANGES IN THE EQUATORIAL MODE OF THE TROPICAL ATLANTIC IN TERMS OF THE BJERKNES FEEDBACK INDEX

Paulo Silva[1], Ilana Wainer[1], Myriam Khodri[2]

(1) Oceanographic Institute, University of São Paulo; (2) LOCEAN-IRD/IPSL, Sorbonne University

Introduction

The study of sea surface temperature (SST) variability is essential because of its strong influence on precipitation in the surrounding contintent and the consequent social and economic impacts (Lübbeckeand McPhaden 2013). In the Tropical Atlantic, one of the main modes of sea surface temperature variability is the Atlantic Equatorial Mode, which is associated with the variability of the Atlantic Cold Tongue. The region of largest interannual variability, where the Atlantic Cold Tongue forms, is also a region of consistent biases in climate models. In this study, we investigate the interannual variability of the Tropical Atlantic and its changes in the recent decades in terms of the Bjerknes Feedback Index (IBJ) in a set of seven ocean reanalyses for the periods 1980–1999 and 2000–2010.

Objectives

This study aimed to investigate the Equatorial Atlantic variability in the period 1980–2010 and assess the robustness of the Bjerknes Feedback across seven reanalysis products in the Atlantic, as well as potential changes in this feedback after 2000, in terms of the Bjerknes Feedback Index (Jin et al. 2006).

Methods

The expression for the Bjerknes Feedback Index (IBJ) derived by Jin et al. (2006) is shown below. The IBJ has frequency units and describes the growth rate of sea surface temperature (SST) anomalies in the eastern equatorial Atlantic region (Fig. 1).

$$2I_{BJ} = \underbrace{-\left(\frac{\langle\bar{u}\rangle_{ATL3}}{L_x} + \frac{\langle -2y\bar{v}\rangle_{ATL3}}{L_y^2} + \frac{\langle\bar{w}\rangle_{ATL3}}{H_m}\right)}_{\text{DD}} \overbrace{-\alpha}^{\text{TD}} \underbrace{+\mu_a\beta_u\left\langle\frac{-\partial\bar{T}}{\partial x}\right\rangle_{ATL3}}_{\text{ZAF}}$$
$$\underbrace{+\mu_a\beta_w\left\langle\frac{-\partial\bar{T}}{\partial z}\right\rangle_{ATL3}}_{\text{EF}} \underbrace{+\mu_a\beta_h\left\langle\frac{H(\bar{w})\bar{w}}{H_m}a_h\right\rangle_{ATL3}}_{\text{TF}}$$

Eq 1. Bjerknes Feeback Index (IBJ) as derived by Jin et al (2006).

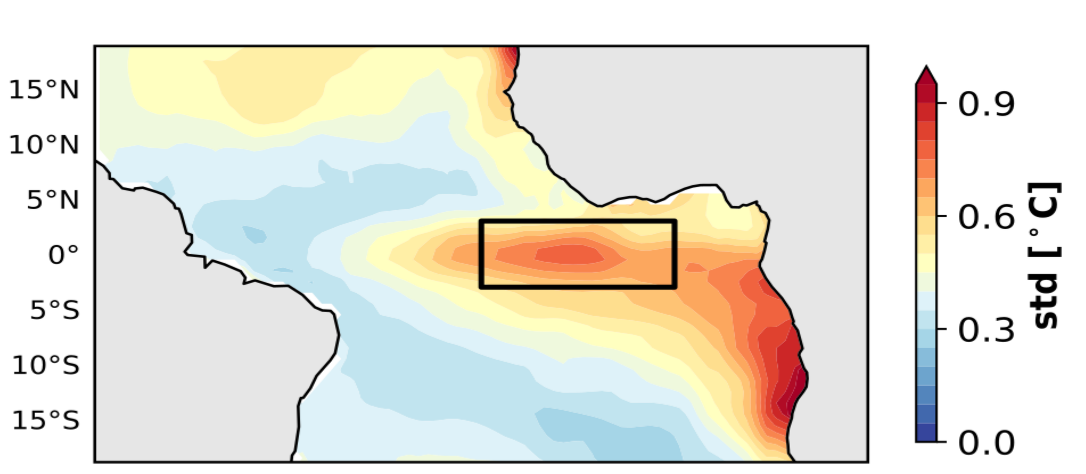

Fig 1. JJA standard deviation of SST and ATL3 region (3°N–3°S; 20°W–0°), which is used as the index region of the equatorial mode.

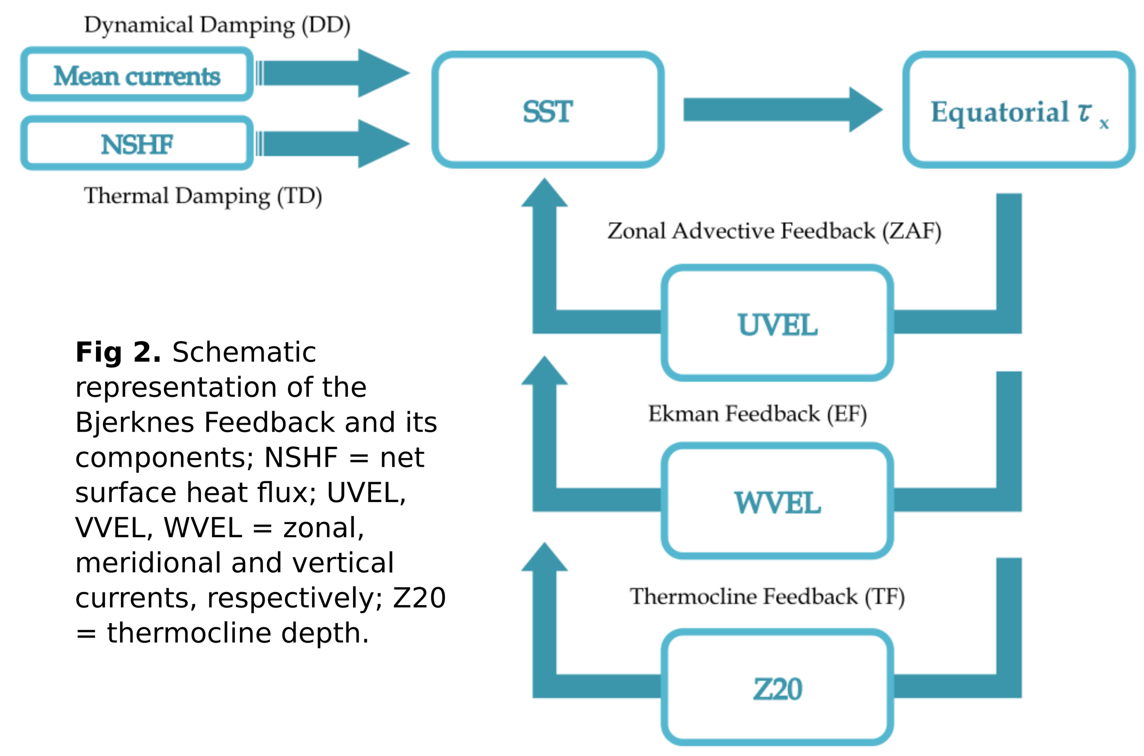

Fig 2. Schematic representation of the Bjerknes Feedback and its components; NSHF = net surface heat flux; UVEL, VVEL, WVEL = zonal, meridional and vertical currents, respectively; Z20 = thermocline depth.

Results and Discussion

The analysis of the individual terms of the Bjerknes Feedback Index (IBJ) for the two time periods (Fig. 2) reveals a consistent weakening of the TD and TF terms across all reanalysis products. The total IBJ is more damped (negative but larger absolute value) in 2000-2010 than in 1980-1999, although within the error bounds; this occurs due to the abnormally large DD in SODA, which in turn is associated with an equatorial undercurrent extending all the way up to the surface in this reanalysis product. If all reanalyses but SODA are considered, the ensemble means for P1 and P2 are −0.44 ± 0.11 year^{-1} and −1.45 ± 0.35 year^{-1}; in this case, the error bars do not overlap and the difference in the total IBJ between P1 and P2 is statistically significant at the 95% level.

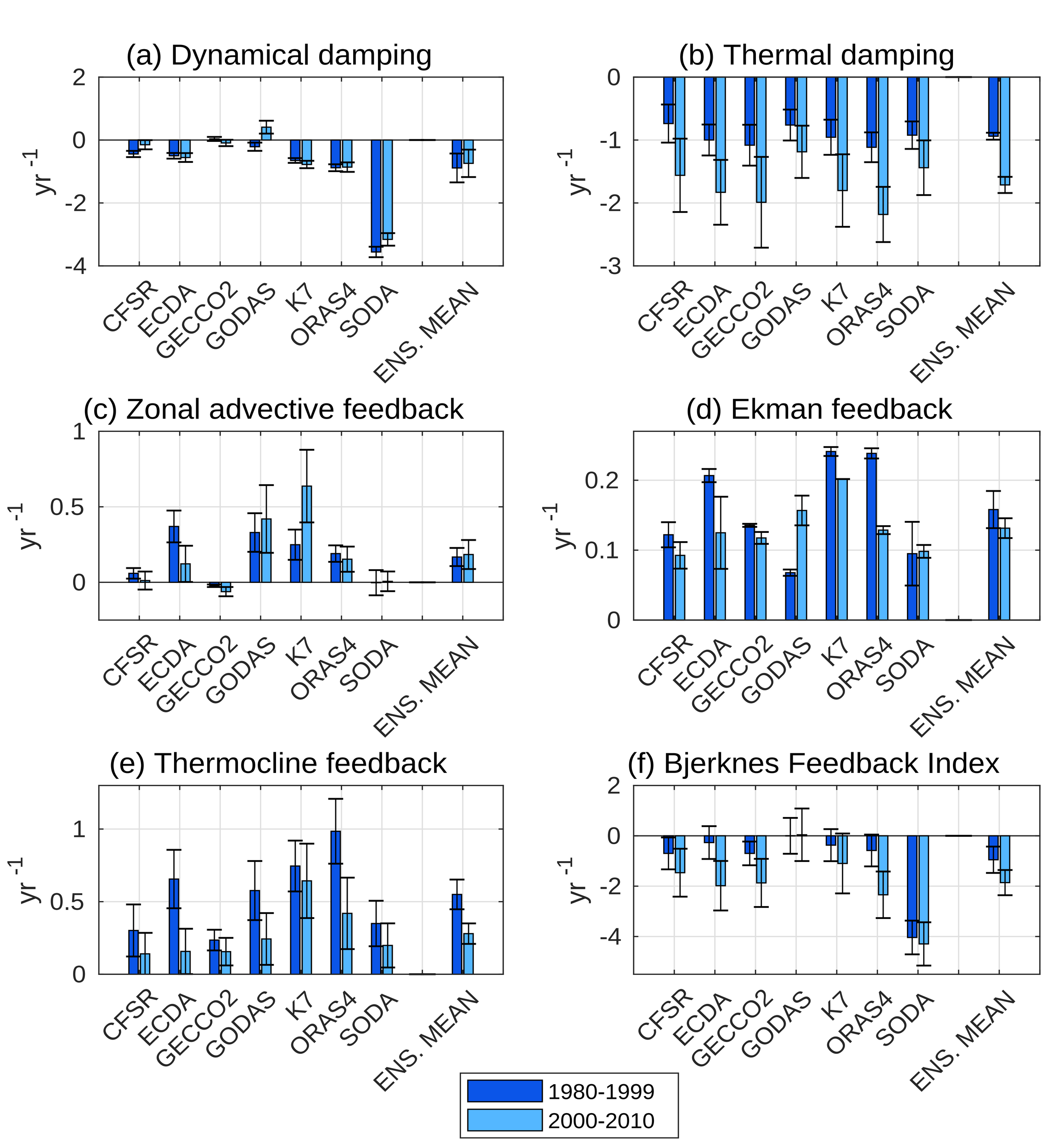

Fig 3. Individual components and total IBJ for each reanalysis and their ensemble mean, for P1: 1980-1999 and P2: 2000-2010.

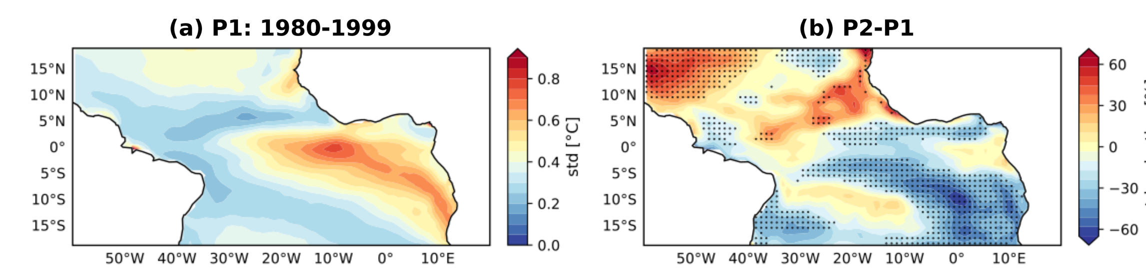

Fig 4. JJA standard deviation of SSTs in P1 (a) and the percentual reduction in P2 compared to P1 (b). Stippling in (b) indicates regions where the difference between the two periods is significant at the 95% level of a Welch's t-test

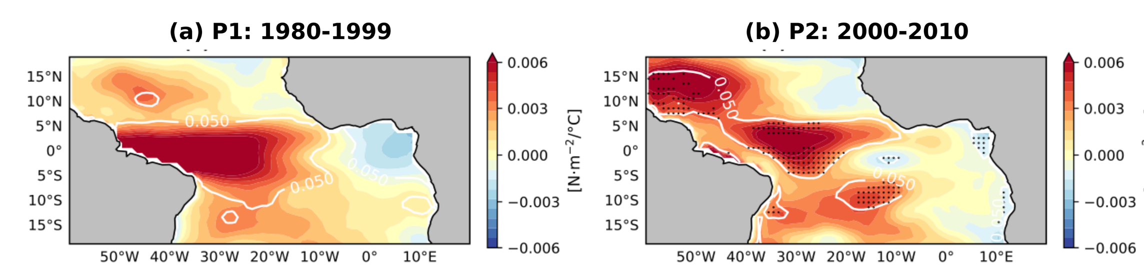

Fig 5. Regression of ATL3 SST anomalies and zonal wind stress elsewhere in the basin, for (a) 1980-1999 and (b) 2000-2010. White contours denote the regions where regressions are significant at the 95% level and stippling in (b) indicates regions where the difference between P1 and P2 is significant at the 90% level.

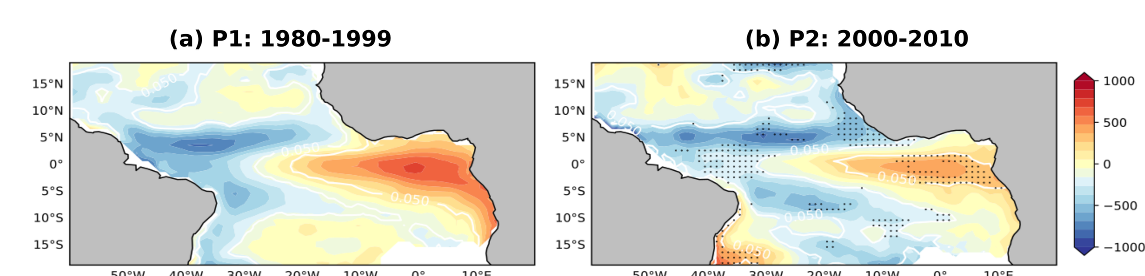

Fig 6. Regression of mean equatorial zonal wind stress and thermocline depth (Z20), for (a) 1980-1999 and (b) 2000-2010. White contours denote the regions where regressions are significant at the 95% level.

The weaker Bjerknes Feedback in P2 is then a result of increased thermal damping (TD) and weaker thermocline feedback (TF). Consistent with the more damped IBJ, there is a decrease in the standard deviations of JJA SST anomalies in P2 (Figure 4). An analysis by Prigent et al. (2020) indicates that the increased thermal damping is mainly due to an increased latent heat flux.The weaker thermocline feedback, on the other hand, is found to be related to a weaker response of western zonal wind stress anomalies to ATL3 SST anomalies (Figure 5) and weaker response of the equatorial thermocline to anomalous equatorial zonal wind stress (Figure 6). The weaker wind-SST response in P2 could be related to a warmer northern Tropical Atlantic and a northward shift in the ITCZ (e.g., Amaya et al., 2017; Prigent et al., 2020). The reason why there is a decrease in the ATL3 thermocline response to anomalous wind stress is not clear, since no changes in ATL3 thermocline anomalies or its mean state are found for P2 in our data.

Conclusions

- The Bjerknes Feedback Index indicates a more damped equatorial mode in the recent period, consistent with previous studies reporting a decrease in SST variability in the equatorial Atlantic.

- The weaker feedback is due to stronger thermal damping and weaker thermocline feedback.

- Nonetheless, the IBJ is a linear simplification of the underlying dynamics and may not fully capture the complexity of variability in this region. Further studies should consider a mixed layer heat budget analysis of the weaker variability after 2000.

References

Amaya, D. J., DeFlorio, M. J., Miller, A. J., & Xie, S. P. (2017). WES feedback and the Atlantic meridional mode: Observations and CMIP5 comparisons. Climate Dynamics, 49(5), 1665-1679.

Jin, F.-F., Kim, S. T., and Bejarano, L. (2006), A coupled-stability index for ENSO, Geophys. Res. Lett., 33, L23708, doi:10.1029/2006GL027221.

Lübbecke, J. F., & McPhaden, M. J. (2013). A comparative stability analysis of Atlantic and Pacific Niño modes. Journal of Climate, 26(16), 5965-5980.

Prigent, A., Lübbecke, J. F., Bayr, T., Latif, M., & Wengel, C. (2020). Weakened SST variability in the tropical Atlantic Ocean since 2000. Climate Dynamics, 54(5), 2731-2744.

Silva, P., Wainer, I., & Khodri, M. (2021). Changes in the equatorial mode of the Tropical Atlantic in terms of the Bjerknes Feedback Index. Climate Dynamics, 1-20.

Acknowledgements

This study was supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) grant 001.

Ilana Wainer was supported by grants FAPESP (Fundação de Amparo à Pesquisa do Estado de S. Paulo) 215/17659-0 and 18/14789-9 CNPq:301726/2013-2, 405869/2013-4 and CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico)-MCT-INCT-594 CRIOSFERA 573720/2008-8.

For further information, please contact: paulo2.silva@usp.br

Universidade de São Paulo

UNIVERSIDADE DE SÃO PAULO Instituto Oceanográfico

C2 Oceanografia Física, Clima e Criosfera - USP