Past and future changes in the Benguela upwelling system with global warming

Amr Talaat Salama[1], Marco Zavatarelli[1], Momme Butenschön[2], and Tomas Lovato[2]

[1]Department of Physics and Astronomy, University of Bologna, Italy.

[2]Euro-Mediterranean Center on Climate Change, Bologna, Italy.

1.Introduction

The Benguela upwelling system (**BUS**) is one of the most productive marine systems in the world. (Bakun,1990)[1] proposed that as global warming proceeds, upwelling favorable winds further intensify, leading to an increase in the upwelling intensity and duration. Consequently, an alteration in the primary production could occur in the BUS which has high fisheries values.

2. Objective

The present work aims to study the past physical and biogeochemical changes in the BUS regarding climate changes consequences like winds intensification and increasing temperature. As well as investigating the response of the system to some potential future global warming scenarios.

3. Methodology

- A 3D coupled physical-biogeochemical model is designed based on NEMO (NEMO, 2016)[2] and BFM (*Biogeochemical flux model*) (Vichi et al, 2015)[3] numerical models. Two-way online nesting approach is constructed to maintain high resolution and to provide better boundary conditions values for the BUS domain. As shown in (Fig. 1), The nesting grid (parent) cover the global ocean with a horizontal resolution of 1/4°, while the nested grid (child) for the BUS domain has a resolution of 1/16°, and both grids have 75 fixed vertical layers.
- Model set-up is described in Table. 1

Table. 1 : model configuration

Parameter	Description
▪Grid	ORCA025 tripolar grid
▪Surface boundary conditions	ERA5 re-analysis data
▪Bottom boundary conditions (Geothermal heat)	(Goutorbe et al., 2011)[4]
▪Initial conditions	World Ocean Atlas 2018
▪Surface runoff	GLOFAS v3.1
▪Bathymetry	GEBCO v2021
▪Spin-up	15 years from 1965 to 1980

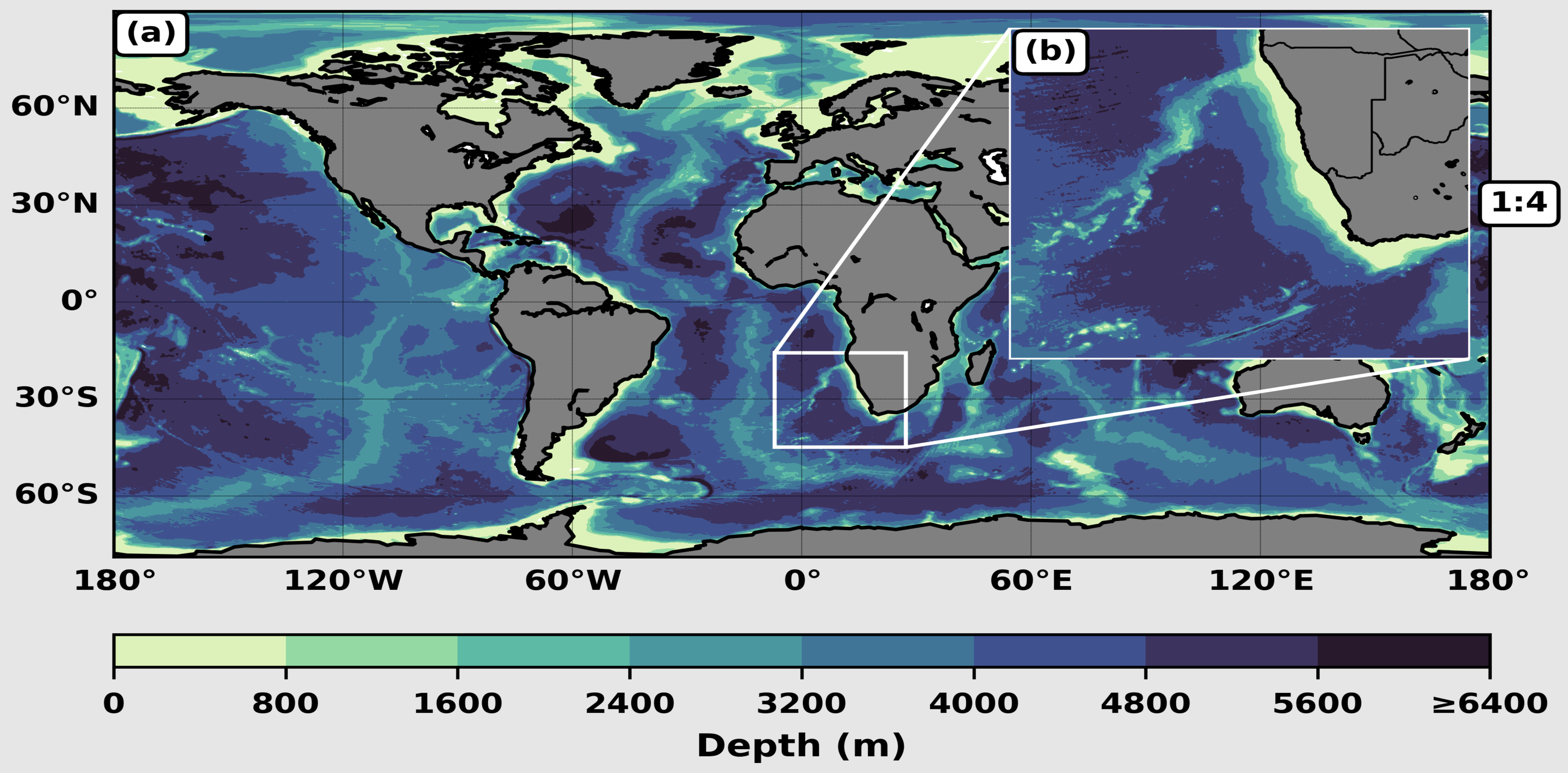

Fig. 1: Nesting (parent) model domain **(a)**, nested (child) BUS domain **(b)** with nesting ratio **1:4**

4. Initial results

4.1 parent domain

- A hindcast NEMO physics simulation was run over the period from 1980 to 2020.
- Comparison between simulated SST and satellite data from (ESA, 2019)[5] shows that the model has good agreement with observations, with a global mean difference of 0.08 °C (Fig. 2).
- The parent domain provides the BUS domain with precise boundary conditions, as there is low error in the vicinity of the Benguela domain, also the temporal correlation between with observation shows a high positive correlation coefficient values.

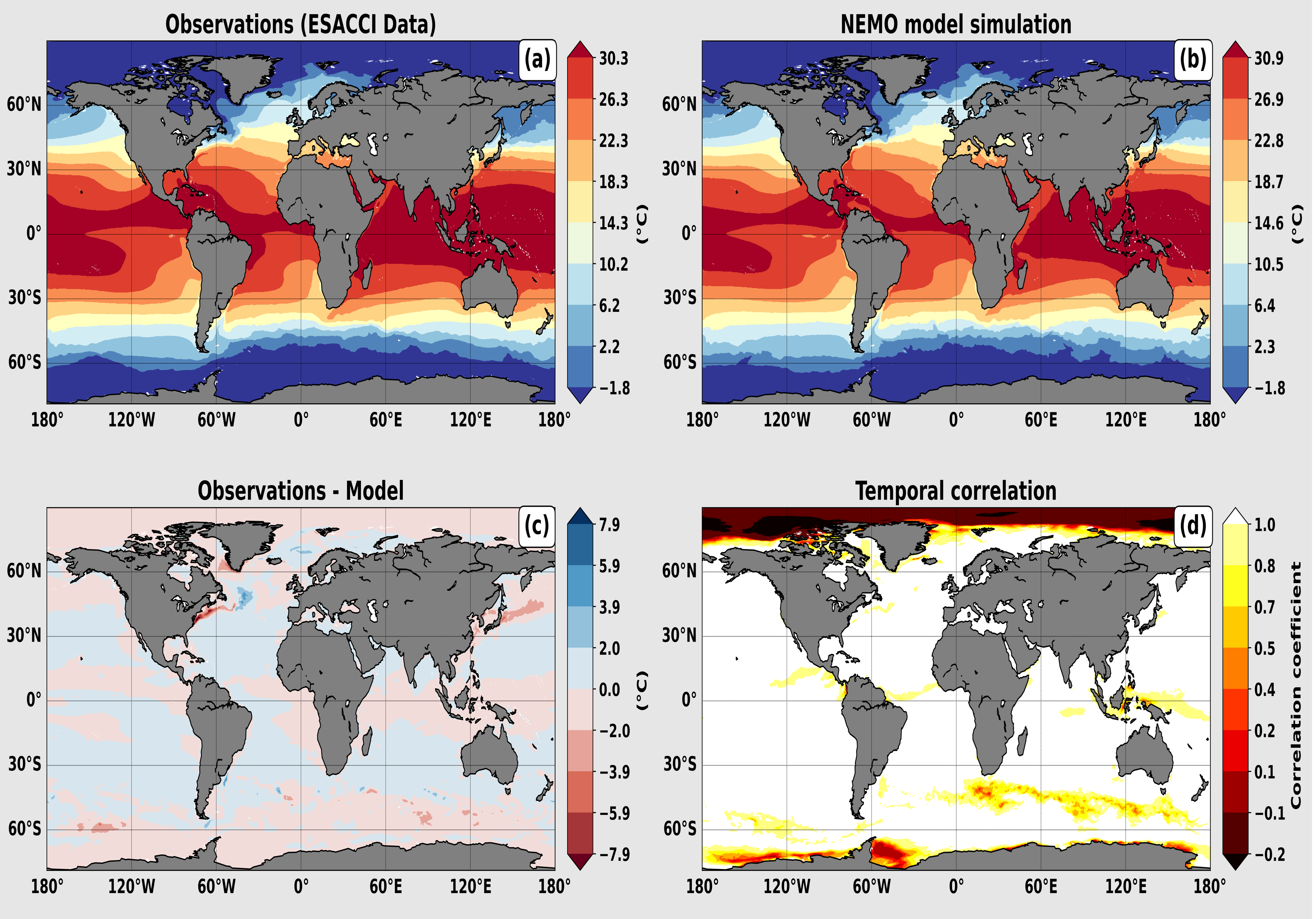

Fig. 2: Observed **(a)** and simulated **(b)** mean annual climatology of SST (1982 – 1998) and their difference **(c)**. **(d)** Temporal correlation coefficient between modelled and observed SST.

4.2 Benguela child domain

- The nested model shows high consistency with observational SST data (Fig. 3).
- Upwelling process is simulated efficiently, since offshore relatively lower SST values (which is an upwelling index) are being observed in the center of the BUS (e.g. Lüderitz). Furthermore, a horizontal transect at Lüderitz (~26.6 °S) shows a raising for the deep cold lower salinity water to the surface levels (Fig. 4).
- Besides the horizontal distribution, vertical profiles of modelled and observed temperature and salinity values show a high similarity with a relatively small error in the upper layers.

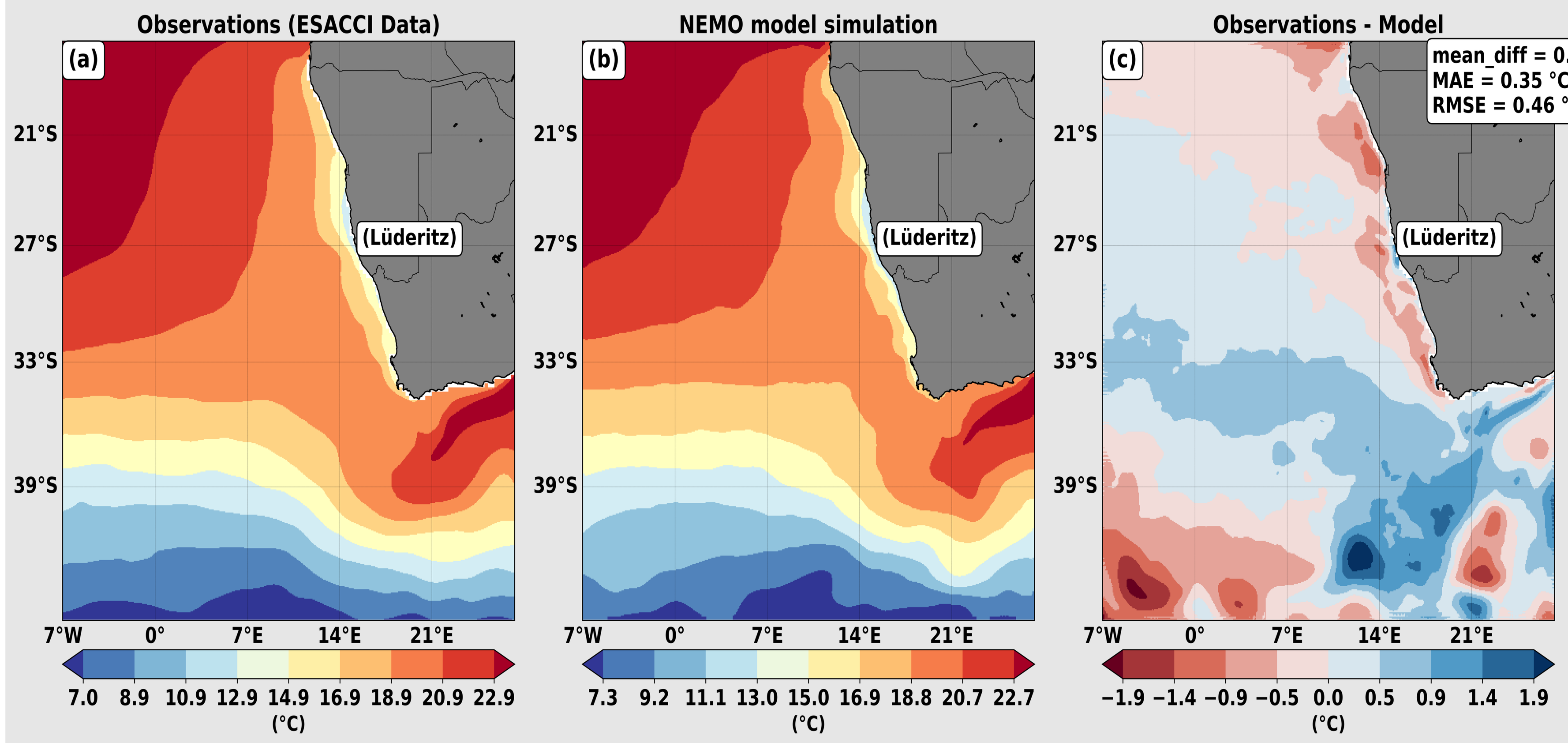

Fig. 3: Observed **(a)** and simulated **(b)** mean annual climatology of SST (1982 – 1998) and their difference **(c)** over the BUS domain.

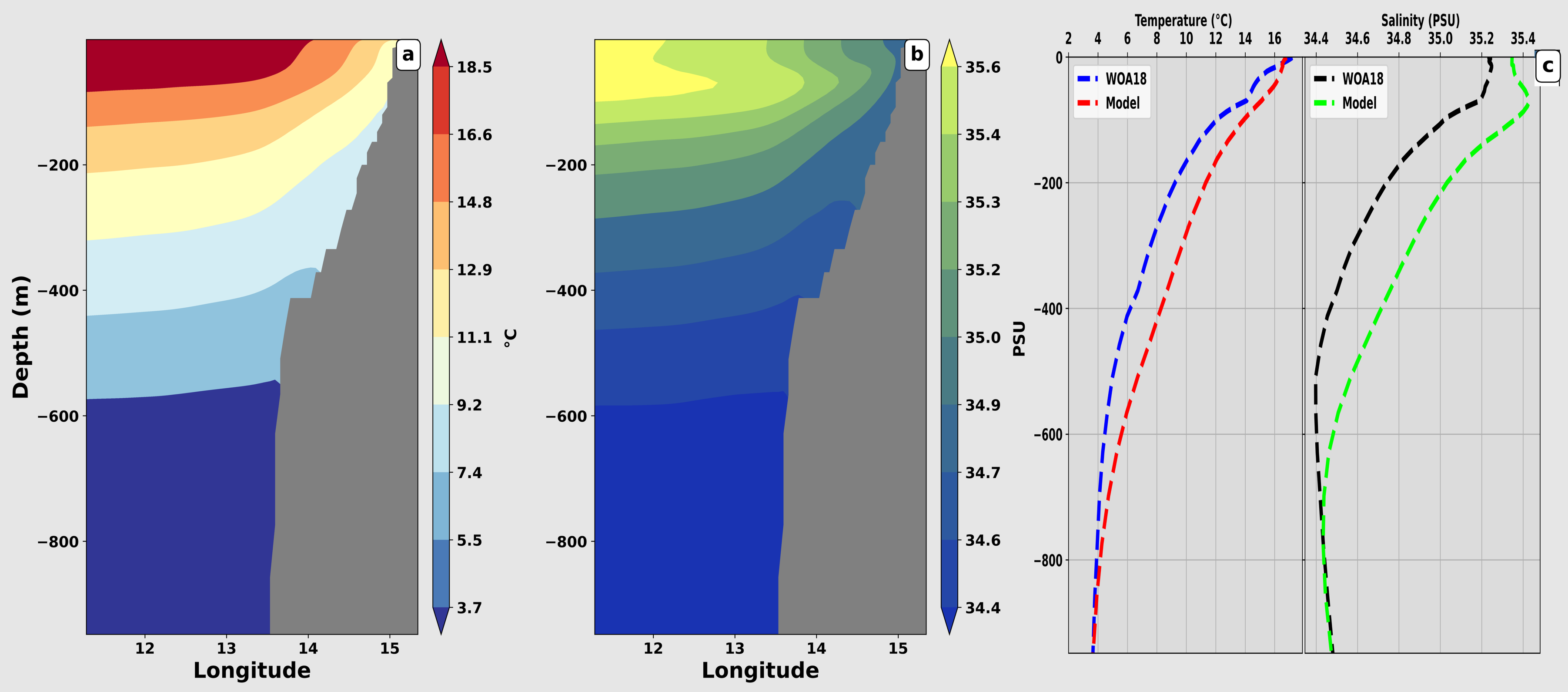

Fig. 4: Horizontal transect for observed temperature **(a)** and salinity **(b)** at latitude (26.6 °S) (11.28 to 15.34 °E). Observed (WOA-18) and simulated spatially averaged temp and salinity at Lüderitz transect **(c)**.

5. Past changes in the Benguela upwelling system

- The linear trend analysis of meridional alongshore wind stress (τ_y) over 40 years shows positive trend within the coastal area of BUS (Fig. 5).
- As a result of such intensification in (τ_y), cross-shore Ekman transport shows also positive trend values ranging from (1.5 to 65 m^3/s/km per decade), with higher values in the northern BUS.
- Based on the trend analysis, it seems that over the last few decades the upwelling favorable winds in the BUS have been intensified, which generally could affect the upwelling process in the study area.

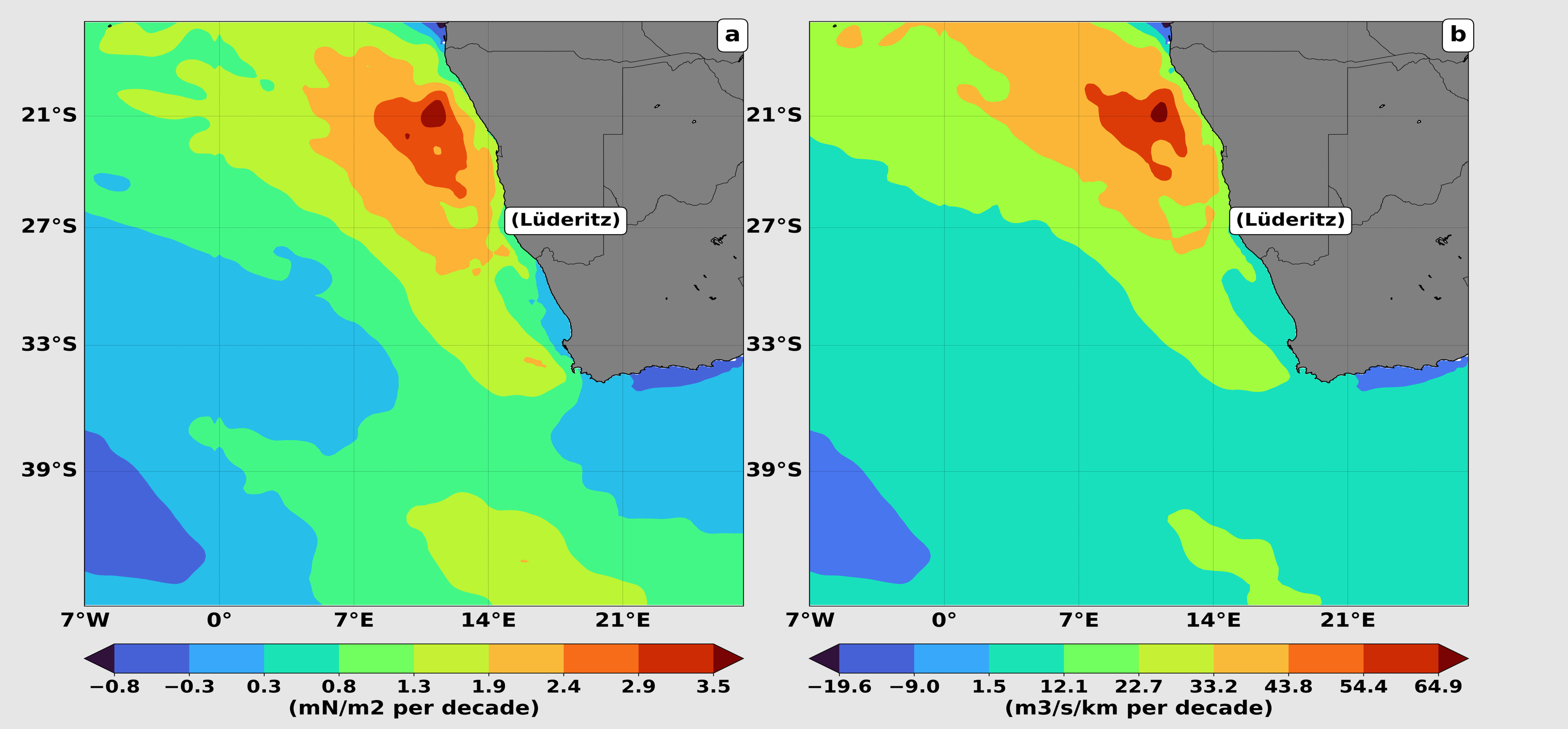

Fig. 5: Linear trend for meridional alongshore wind stress (τy) **(a)** and cross-shore Ekman transport (M_x) **(b)** over the period from 1980 to 2020.

6. Future work

- The next step in the current work is coupling the NEMO physical model results with **BFM** to simulate the biogeochemical dynamics in the Benguela upwelling system.

7. References

1. Bakun, Andrew. "Global climate change and intensification of coastal ocean upwelling." *Science* 247.4939 (1990): 198-201.
2. Madec, G., 2016. NEMO System Team: NEMO ocean engine. Scientific Notes of Climate Modelling Center, 27.
3. Vichi M., Lovato T., Lazzari P., Cossarini G., Gutierrez Mlot E., Mattia G., Masina S., McK- iver W. J., Pinardi N., Solidoro C., Tedesco L., Zavatarelli M. (2015). The Biogeochemical Flux Model (BFM): Equation Description and User Manual. BFM version 5.1. BFM Report series. http://bfm-community.eu, pp. 104.
4. Goutorbe, B., et al. "Global heat flow trends resolved from multiple geological and geophysical proxies." Geophysical Journal International 187.3 (2011): 1405-1419.
5. Good, S. A., et al. "ESA sea surface temperature climate change Initiative (SST_CCI): Level 4 analysis climate data record, version 2.1." Centre for Environmental Data Analysis 10 (2019).

Authors contact: amrtalaat.salama2@unibo.it | marco.zavatarelli@unibo.it | momme.butenschon@cmcc.it | tomas.lovato@cmcc.it