STUDY OF THE EQUATORIAL ATLANTIC OCEANIC MIXING LAYER USING A ONE-DIMENSIONAL TURBULENCE MODEL

***Udo Tersiano Skielka*[1], *Jacyra Soares*[1], *Amauri Pereira de Oliveira*[1], *Jacques Servain*[2]**

[1]Laboratório de Interação Ar-Mar, IAG, USP. Rua do Matão 1226, Cidade Universitária, São Paulo - SP, Brasil.
udo@model.iag.usp.br, jacyra@usp.br, apdolive@usp.br
[2]Institut de Recherche pour le Développement (IRD), UMR-182, Paris, France. Atualmente como cientista visitante da *FUNCEME. jacques.servain@gmail.com*

RESUMO: Aqui são mostrados alguns resultados da aplicação de um modelo de turbulência unidimensional (GOTM) no estudo da evolução da camada de mistura oceânica (CMO), utilizando, como condições iniciais e de contorno, dados de uma bóia PIRATA situada no Oceano Atlântico equatorial. O *General Ocean Turbulence Model (GOTM) – www.gotm.net,* desenvolvido recentemente por cientistas europeus, é um modelo unidimensional que simula mistura turbulenta para o oceano, resolvendo o escoamento médio através da aplicação da média de Reynolds às equações primitivas e o escoamento turbulento utilizando um modelo k-ε com fechamento turbulento de 2^a ordem algébrico. Os resultados mostram que o modelo simplificado usado neste trabalho é capaz de simular a mistura turbulenta devido à presença de ventos de superfície. Entretanto, alguns ajustes ainda são necessários, como a inclusão do fluxo de água doce na superfície para melhorar os cálculos da salinidade e densidade. A estimativa do balanço de calor na superfície também deve ser aprimorado futuramente.

ABSTRACT: Here are shown some results of an one-dimensional turbulence closure model application to study the oceanic mixing layer variability using PIRATA data, as initial and boundary conditions, located on the equatorial Atlantic Ocean. The *General Ocean Turbulence Model (GOTM) – www.gotm.net*, developed recently by an European oceanic research team, simulate the oceanic mixing by solving the mean flow using the Reynolds averaged primitive equations and using a k-ε model with an algebraic second-moment closure for the turbulent quantities. The results show that the simplified model used in this work is able to simulate turbulent mixing due to surface stress. However, some adjusts are still need, as for instance, the inclusion of the surface freshwater flux for a better estimation of the salinity and density. The surface heat balance estimate also should be improved in the future.

Key words: oceanic mixing layer, GOTM, turbulence, air-sea interaction.

INTRODUCTION

The tropical Atlantic Ocean occupies a narrow basin surrounded by continents where usually there is intense convection. The position and intensity of convection over tropical oceans are sensitive to changes of sea surface temperature (SST). The SST over the Atlantic tropical is related to regional climate anomalies and to the displacement of the inter-tropical convergence zone (ITCZ) (e.g. Hastenrath, 1991).

Over the tropical Atlantic, the southeasterly and northeasterly trade winds are separated by the ITCZ. Its seasonal displacement is such that it is always on warmer waters. When this convergence zone shifts to the north – responding to the seasonal variation of the surface heating – the southeasterly trade winds cross the equator and intensify. The ITCZ reaches it most northern position, approximately at 10^oN, between August and September. When the superficial seawater becomes colder at the southern hemisphere, approximately between March and April, the ITCZ reaches its most southern position (Wang and Carton, 2003), when the rains season occur over the northeast of Brazil.

Carton et al. (1996) studied the role of many variables which control the meridional gradient of SST and found that the latent heat flux variations has an important role, which are associated with fluctuations of the surface winds.

Chang et al. (2000) suggested that the northwest region of the tropical Atlantic presents an intense positive feedback between the ocean and the atmosphere due to changes in wind speed and SST: relaxation of the winds reduces the cooling of the SST due to evaporation, leading to higher SST, which, in turn, lead to relaxing the winds. Furthermore, they found a negative feedback at the northeast region of the tropical Atlantic. According to Wang and Carton (2003), mostly of general circulations models produce an excessive latent heat as consequence of errors associated to prognostics of humidity in the atmospheric boundary layer.

The oceanic mixing layer (OML) is the upper layer of the ocean. Its depths vary from tens to a few hundreds of meters, where the density is approximately the same as the surface. The OML exists due to turbulence mixing, which is caused by the surface stress and waves. An effect of mixing is to turn the seawaters properties (temperature and salinity) homogeneous, and so, the density. The depth of the OML depends mainly from the seawater stability and the energy provided by the wind. Greater the seawater stability, thinner is OML depth. The stability of the water close to the ocean surface is controlled basically by the surfaces fluxes. Many physical processes (e.g. heat, momentum and gases budget between the ocean and the atmosphere), chemical (e.g. CO_2 dissolution from the atmosphere) and biologic (e.g. phytoplankton blooms) occur in the OML, been an important component for climatic, pollution, and biologic studies, among others. Indeed, understand the dynamics and quantify the magnitude of the surface turbulent fluxes is fundamental for improve climate, atmospheric and oceanic modeling.

The main goal of this work is to study the relevant physical processes on the development of the tropical Atlantic mixing layer at 0^o 23^oW, when the ITCZ is at its most southern position (between march and may approximately). To do so, a one-dimensional turbulence closure model has being used, the *General Ocean Turbulence Model – GOTM*. This model has been widely used on studies of turbulent processes over many water environments: open ocean, costal ocean, lake, etc (e.g. Burchard, 2002). One-dimensional models are simpler and allow for a better comprehension of physical processes than bi and tri-dimensional models, which are more complexes.

DATA AND REGION OF STUDY

The *in situ* meteorological data, from a PIRATA buoy (*Pilot Research Moored Array in the Tropical Atlantic*) have being used to estimate the surface fluxes and set as boundary conditions, while the PIRATA oceanographic *in situ* data are set as initial conditions in the model. The PIRATA buoy is located at (0^oN 23^oW). The observed variables used in this work are shown in table 1.

The PIRATA dataset does not provide a long series of observed sea surface pressure and therefore the sea surface pressure data from NCEP2 reanalysis has been used in this work (Kanamitsu et al., 2000; Kalnay et al., 1996). For bottom boundary conditions, no slip and no fluxes conditions are used.

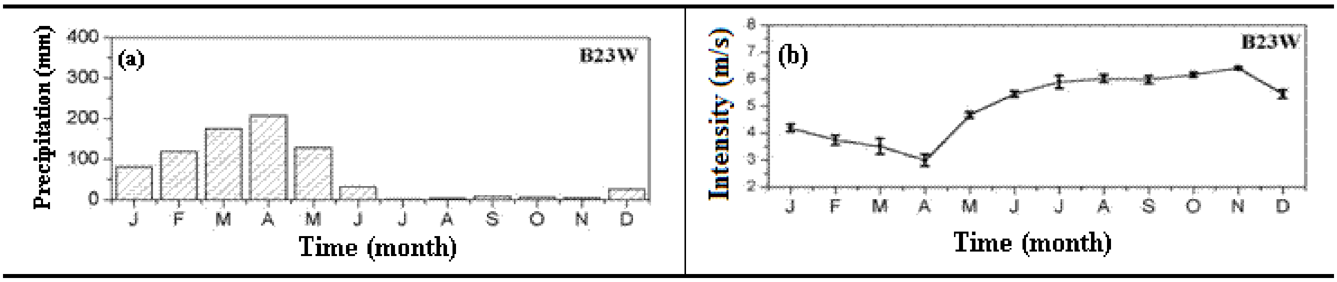

Figure 1: Six year monthly averaged PIRATA data from buoy at (0^o, 23^oW). (a) Accumulated precipitation and (b) wind intensity.

Figure 1a shows the ITCZ presence over the region, between February and May, when occurs the maximum of precipitation. The trade winds are weaker during the first semester of the year (figure 1b).

NUMERICAL MODEL – GOTM

In GOTM, the statistical treatment of turbulence is based on the Reynolds averaged primitive equations, separating the flow in two fields, mean and turbulent. The model calculates the turbulent quantities in the Reynolds equations (Reynolds tensors and the heat and salt turbulent fluxes) using a second order closure model and the k-ε equations (Burchard, 2002).

The model equations were discretized by an implicit numerical scheme, centered in space and advanced in time, using Canuto et al. (2001) second order turbulent closure. The time step was of 60 seconds and the grid cell size of 1 meter. The model was run for 5 month long, from January to May and used a total depth of 200 meters.

RESULTS

The results shown here are the preliminary ones obtained from the basic implementation of the GOTM in the Laboratory of Air–Sea Interaction of IAG-USP. The simulation was from March to May, when the ITCZ is over the region.

	In situ data **$0^{o}23^{o}W$**	**Specification on the model**
Meteorological	Air temperature; Sea surface temperature; Relative humidity; Wind components (u and v); Downward short-wave.	Upper boundary conditions: • Moment and heat turbulent fluxes (Fairall et al. 1996); • Long-wave surface balance (Hansterath e Lamb 1987).
Oceanographic	Temperature, salinity and current vertical profiles (ADCP).	Initial conditions.

Table 1: PIRATA *in situ* data used in the simulation and theirs specifications.

Figure 2 shows the simulated and observed SST. Despite the model underestimation of the SST, its variability has a good agreement with the observations during the period. This underestimation seems to be related to the estimation of the surface heat balance and needs to be better investigated.

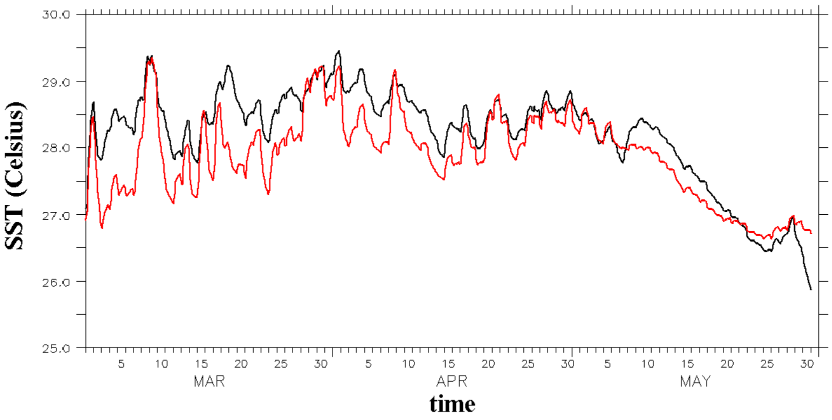

Figure 2: Sea surface temperature. Black line for the observation and red line for the simulation results.

Figure 3 shows the surface wind stress intensity for the first two weeks of April. One can observes that, at the final of this period, beginning around day 12, there is an intensification of the wind persisting until the end of the period.

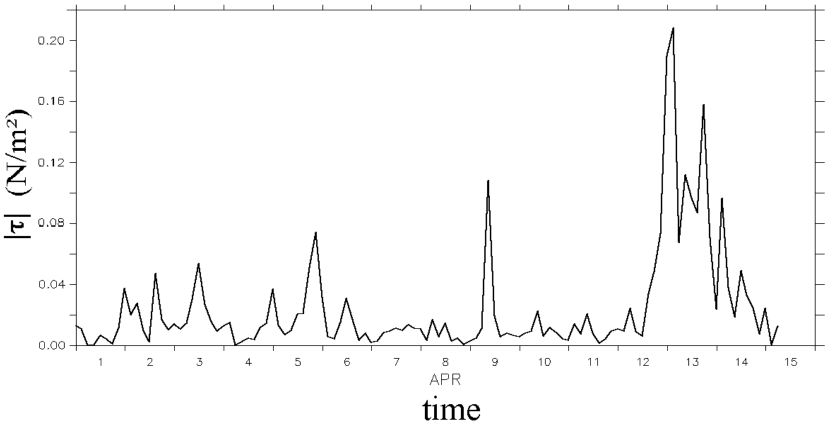

Figure 3: Surface wind stress intensity during the first days of April.

Figure 4 shows the extension of the OML, which can be inferred considering the depth that the temperature gradient is almost null.

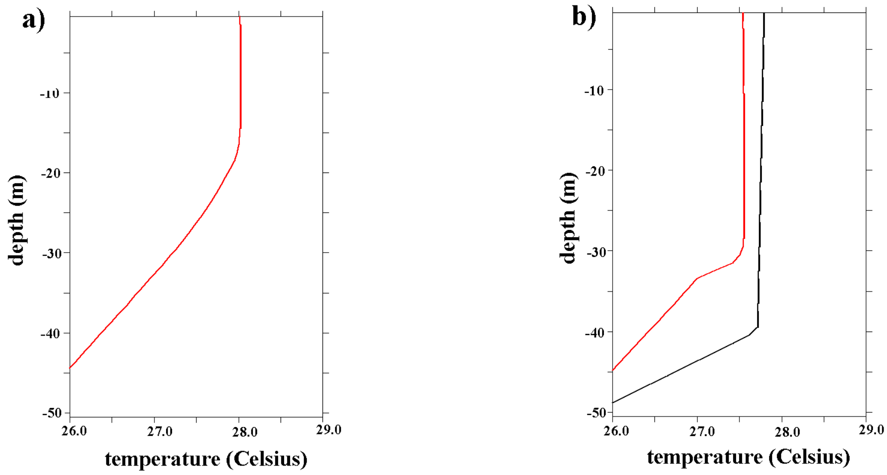

Figure 4: Vertical temperature profiles. (a) April 11, day before the strong wind event and (b) April14, day after. Black line for the observation and red line for the simulation results.

The OML simulated (Figure 4a) is shallower before the strong wind event shown in Figure 3 (April, 12-13) when compare to the day after of the event (Figure 4b). It should be expected once that higher wind stress on the ocean surface, higher the mechanical mixed and therefore, deeper the OML. The OML observed (black line in Figure 4b) during day 14 of April is a little deeper than the numerical one (red line in Figure 4b).

CONCLUSION

The SST is the oceanic variable which most affects the atmosphere circulation. Over the equatorial Atlantic Ocean, the variability of the SST is driven mainly by the zonal surface stress and the latent heat flux (Carton and Zhou, 1997). Both processes are related to the mixing in the ocean, caused by the generation of mechanical turbulence and the static instability. However, how the OML and its depth variation influence the dynamics in this region still need to be further explored. Chang et al. (2000) pointed out the necessity to better understand the process occurring in the ocean that may influence the ocean-atmosphere feedbacks in this region. So, more detailed studies of the variability of the OML to the air-sea interactions in this region are necessary.

Here is shown preliminary results of a study of the OML variability over the equatorial Atlantic Ocean applying a one-dimensional turbulence closure model, the *General Ocean Turbulence Model (GOTM)*, using *in situ* data from the PIRATA buoy and NCEP2 reanalysis. The model was capable to simulate the SST variability despite of its underestimation, which revealed the necessity of some corrections for the surface heat balance. It was verified the need to include the freshwater surface flux during the ITCZ period for a right density simulation. The freshwater surface flux has influence on the simulated water salinity and therefore on the oceanic density which is computed from temperature and salinity data using the UNESCO algorithm (Fofonoff and Millard, 1983).

The model has shown capability to simulate the OML entrainment due to mechanical production of turbulence and, therefore, vertical mixing in the ocean.

ACKNOWLEDGEMENT: The authors thank the support of CNPq and Fapesp.

REFERENCES

BURCHARD, H. Applied Turbulence Modelling in Marine Waters, Lecture Notes in Earth Sciences, 100, Springer, 2002.

CARTON, J.A.; CAO,X., GIESE, B.S.; DA SILVA A. M. Decadal and interannual SST variability in the tropical Atlantic. J. Phys. Oceanogr., 26, 1165-1175, 1996.

CARTON, J. A.; ZHOU, Z. Annual cycle of sea surface temperature in the tropical Atlantic Ocean. J. Geophys. Res., 102, 27813 -27824, 1997.
CHANG, P.; SARAVANAN R.; JI L.; HEGERL G.C. The effect of local sea surface temperatures on atmospheric circulation over the tropical Atlantic sector. J. Climate, 13, 2195-2216, 2000.

HASTENRATH, S. Climate Dynamics of the Tropics. Kluwer Academic, 488 pp, 1991.

HASTENRATH, S.; LAMB P. J. Heat budget atlas of the tropical Atlantic and Eastern Pacific Oceans, Tech. rep., University of Wisconsin, Madison, 1978.

FAIRALL, C. W.; BRADLEY, E. F.; ROGERS D. P.; EDSON, J.B.; YOUNG G.S. Bulk parameterizantion of air-sea fluxes for tropical Ocean-Global Atmosphere Coupled-Ocean Atmosphere response experiment. J. Geophys. Res., 101, 3747-3764, 1996

FOFONOFF, N. P.; MILLARD, R. C. Algorithms for the computation of fundamental properties of seawater. *Unesco technical papers in marine sciences*, **44**, 1-53, 1983.

KALNAY, E.; AND COAUTHORS. The NCEP/NCAR 40-Year Reanalisys Project. Bull. Amer. Soc., 77, 437-431, 1996.

KANAMITSU, M.; EBISUZAKI, W.; WOOLEN, J.; POTTER, J.; FIORIN, M. An overview of NCEP/DOE Reanalysis-2. *Proc. 2nd Int. Conf. on Reanalysis*, Reading, United Kingdom, WMO, 1-4, 2000.

WANG, J.; CARTON, J. A. Modeling climate variability in the tropical Atlantic atmosphere. *J. Climate*, **16**, 3858-3876, 2003.