Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 1433-1436.

VELOCITY FIELD AT THE PIRATA SITES: MODEL OUTPUTS VS. OBSERVATIONS

Domingos F. Urbano* and Paulo Nobre
Centro de Previsão de Tempo e Estudos Climáticos – CPTEC/INPE, Cachoeira Paulista, SP, Brazil

1. INTRODUCTION

In the tropical Atlantic Ocean there is a complex surface current system related to the inter-hemispheric heat and salt budget. This current system affects the sea surface temperature (SST) by carrying North and South Atlantic waters and by generating convergence and divergence regions. The Intertropical Convergence Zone (ITCZ) seasonal displacement associated with the trade winds modulates the currents and the SST.

The SST in the tropical Atlantic is highly related to the climate in Brazil, where droughts and floods in the Nordeste region can be generated by SST anomalies of only 0.5°C (Nobre and Shukla, 1996). Seasonal rainfall forecast over the region is limited to the ability to predict the SST spatial distribution over the tropical Atlantic. Therefore, a better understanding about the mechanisms and processes that affect the SST anomalies is of greater relevance and have been subject of recent works (Foltz et al., 2003; Foltz et al., 2004; Foltz and McPhaden, 2004; Foltz and McPhaden, 2005).

A good methodology to investigate the ocean-atmosphere dynamics is the combination of direct velocity measurements and model outputs.

In this work, we briefly describe the novel velocity data at the western PIRATA sites. Also, a comparison of these observations to hi-resolution Ocean General Circulation Model (OGCM) outputs has been carried out as an evaluation of the model performance. Additionally, results from the CPTEC Coupled GCM are used for April 2001.

Besides the qualitative analysis, root mean square error (rms) differences between the velocity maps are estimated.

2. METHODOLOGY

Velocity and temperature observations in the tropical Atlantic have been successfully collected by the Pilot Research Moored Array in the Tropical Atlantic (PIRATA), since 1998 (Servain et al., 1998). Oceanographic and atmospheric data are collected in real time trough ATLAS moorings, in a similar way to the TAO Program in the Pacific (Fig. 1).

Once a year, oceanographic cruises are conducted for mooring maintenance, also collecting underway shipboard acoustic Doppler current profiler (ADCP) data and casting CTD profiles up to 500 m each degree of latitude along 38°W (Fig. 1). At the ATLAS sites, CTD profiles reaches 1000 m depth.

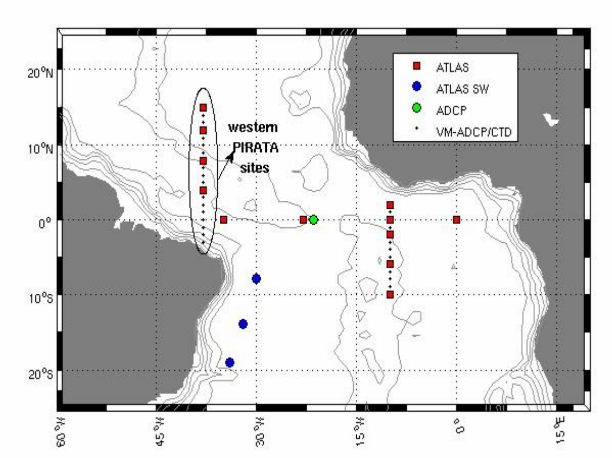


Figure 1. Map of tropical Atlantic. Red squares are ATLAS mooring locations. Blue circles show the southwest PIRATA extension (since August 2005). Small black squares are the CTD stations and the VM-ADCP tracks. Green bullet is the ADCP mooring. Contours are the bathymetry.

The velocity distribution in the upper ocean was measured with a 75-kHz vessel-mounted ADCP from RD Instruments. There are by now seven annual PIRATA ADCP sections, being two Transect and five VM-DAS data. The Transect data are still on pre-processing stage and one of the VM-DAS data presented calibration problems.

The data were collected using a vertical bin length of 8 m. The first reliable bin represents a velocity mean from 16 to 24 m depths. The depth range was about 400 m but it is dependent on sea state; the range was <250 m if the ship headed into heavier weather. ADCP absolute current was determined by using standard shipboard gyro heading and navigation from the global positioning system (GPS).

Here, four ADCP sections are used: two spring and two summer PIRATA cruises (Tab. 1). These ADCP velocity maps are novel direct observations in the western tropical Atlantic, reaching 15°N along 38°W. German and French observational programs have collected VM-ADCP

* Corresponding author address: Domingos F. Urbano, Centro de Previsão do Tempo e Estudos Climáticos, Instituto Nacional de Pesquisas Espaciais (CPTEC/INPE), Cachoeira Paulista, São Paulo, Brazil. e-mail: dfurbano@cptec.inpe.br.

data around the same longitude but no data were obtained north of 7.5°N.

Table 1. Summary of the VM-ADCP PIRATA cruises, with the respective dates and tracks.

Cruises	Dates	Sections
PBR04	09-14 April 2001	2°S to 15°N, 38°W
PBR05	05-16 April 2002	15°N to 2°S, 38°W
PBR07	26-31 July 2004	2°S,35°W-15°N,38°W
PBR08	13-18 July 2005	2°S to 15°N, 38°W

The OGCM is the Modular Ocean Model version 3 (MOM3). The model domain is from 40°N to 40°S and from 60°W to 12°E. The grid resolution is 0.25 degrees between 10°S and 10°N, changing linearly to 3 degrees out of this region. There are 20 levels in the vertical with 18 levels within the first 500-m depth and 7 in the first 100 m. The model used the NCEP wind stress as momentum forcing and Levitus climatology as initial condition. The solar radiation and heat flux were parameterized. The integration ran from January 1971 to December 2005, with 30 years of spin-up.

The CPTEC Atmospheric GCM has triangular truncation at wave number 62 in the horizontal, 28 sigma levels in the vertical, and RAS cumulus parameterization scheme. In the coupled experiment, the ocean GCM had the same configuration up to 1981. From 1982 to December 2001, the solar radiation, wind stress, and heat flux were supplied by the AGCM. As the coupled simulation reaches the year 2001, and the observations are from 2001 to 2005, CGCM-observations comparison will be presented only for April 2001.

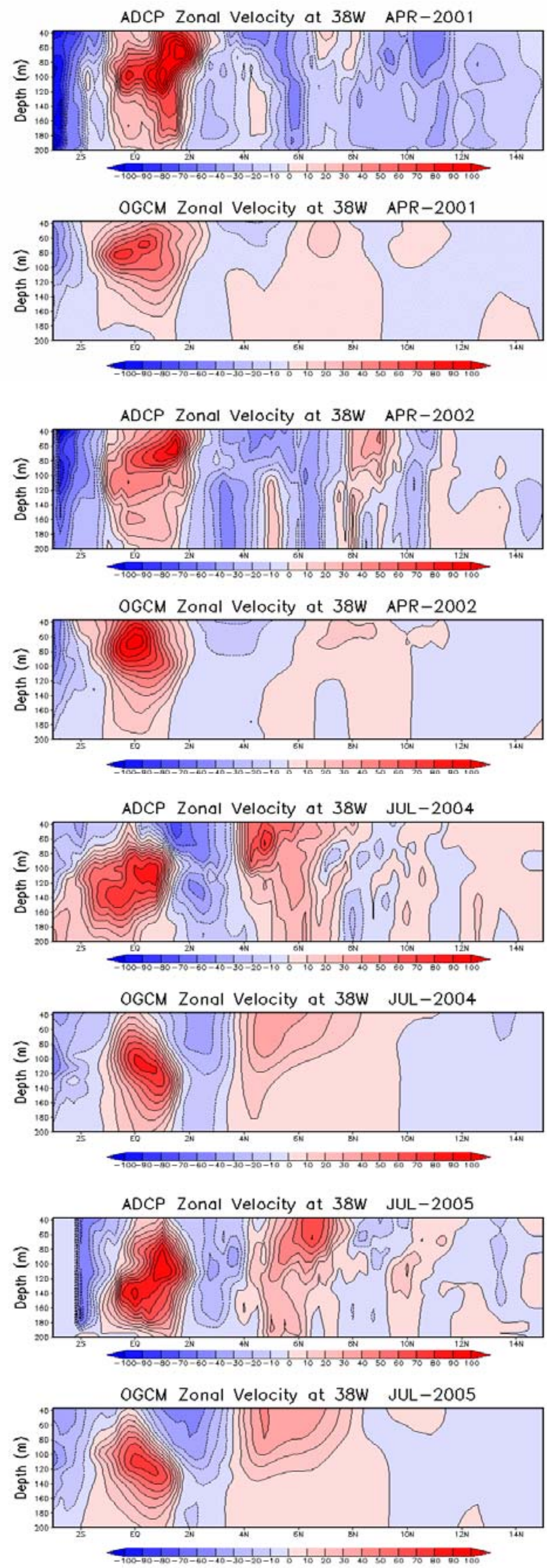
A qualitative analysis is conducted, describing the vertical velocity maps. Quantitative analysis consists of the computation of root mean square error (rms) differences between the maps. The rms were computed based on the (Pinardi and Robinson, 1987):

$$rms = \sqrt{\frac{\left\langle (Uadcp - Uogcm)^2 \right\rangle}{\left\langle (Uadcp)^2 \right\rangle}} \,. \qquad (1)$$

3. RESULTS

Figure 2 shows vertical velocity maps along 38°W, between 2.5°S and 15°N, in comparison to the OGCM velocities for 4 cruises, as summarized in Table 1. The ADCP sections were interpolated to the model grid for appropriated comparison.

Figure 2. Vertical velocity maps along 38°W. Blue



are westward (negative) velocities while red are eastward (positive), in cm s^{-1}. Contours interval is 10 cm s^{-1}.

Alternate eastward and westward fluxes characterize the surface current system over the region. The North Brazil Current – North Brazil Undercurrent system (NBC/NBUC) lies between the coast and the equator, flowing northwestward. Waters from the central branch of the South Equatorial Current (cSEC) feed the system.

Over the equator but slightly northward, and between the surface and 200 m, lies the strong eastward Equatorial Undercurrent (EUC). Its subsurface core can reach values over 100 cm s^{-1}.

Between the EUC and 15°N and above the thermocline (approximately 125 m) are the wind-driven northern branch of the Southern Equatorial Current (nSEC), flowing westward, and the Northern Equatorial Countercurrent (NECC), flowing eastward. These two currents are strongly dominated by the ITCZ seasonal cycle.

Below the thermocline between 4°N and 6°N at 200 m depth lies the North Equatorial Undercurrent (NEUC), which can stay connected to the NECC during most of the year (Urbano et al., 2006).

The NECC has a large meridional migration following the ITCZ displacement, staying northward in the first half of the year, and over the NEUC in the second half of the year; therefore lying between the range 3-13°N.

North of the NECC there is a second eastward band (nNECC) that reaches downward into deep layers (Urbano et al., 2006; Stramma et al., 2005). For July 2005, the nNECC was clearly captured by both model and ADCP measurement, at 11°N (Fig. 2). This northern branch was also measured during July 2004 and April 2002, but due to the superimposed eddy velocity component, this feature is not so evident. Even for April 2001, a second core is noted in the observations (Fig. 2), but the second core is added to the southern NECC core (sNECC), and was not reproduced by the model (Fig. 2). It would be necessary a higher model resolution to capture so small feature as the one registered during this cruise.

The rms analysis between the ADCP and OGCM velocity maps revealed that the best fits were for April 2002 and July 2004, with rms values of 95% and 90%, respectively (0.95 and 0.90 on Table 2). For April 2001 the model explained 87% of the observed velocities, while for July 2005 the rms was only 0.79 (79%).

Table 2. Root mean square error differences between OGCM and ADCP velocity maps.

Cruises	dates	RMS
PBR04	APR 2001	0.87
PBR05	APR 2002	0.95
PBR07	JUL 2004	0.90
PBR08	JUL 2005	0.79

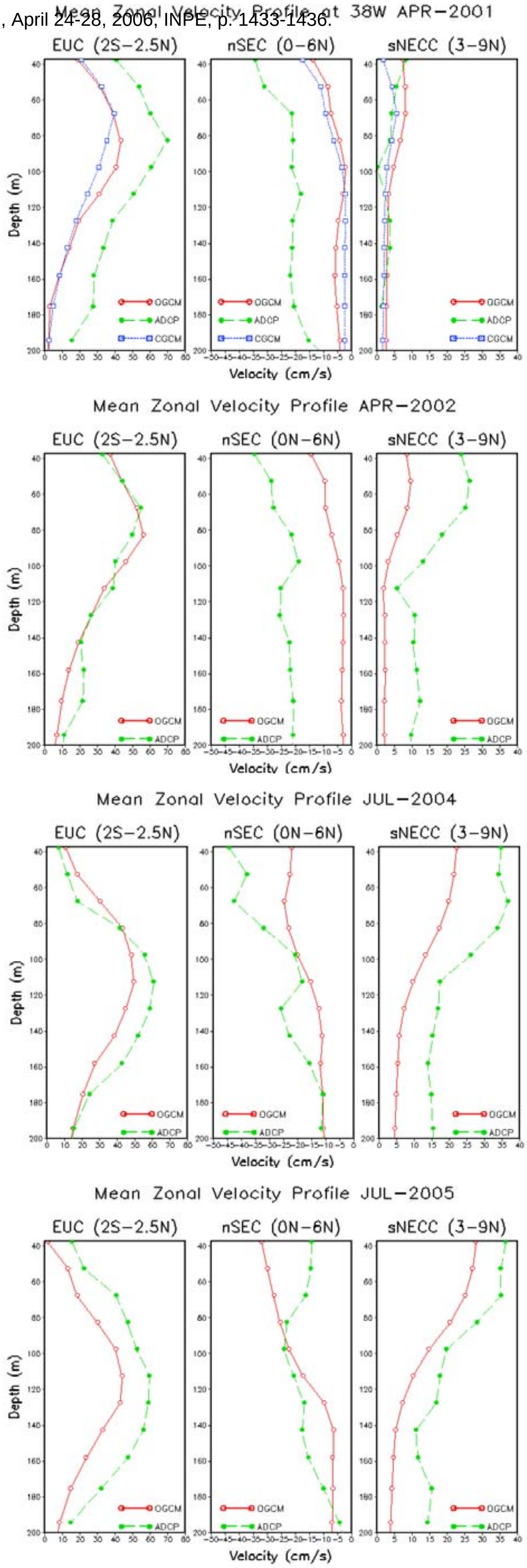


Figure 3. Mean velocity profiles for each latitudinal band that corresponds to the main current region.

These rms values are coherent to the comparison of the mean velocity profiles, presented in Figure 3. Note that the best rms values are due to the best fit between the EUC profiles. As the EUC is the strongest and largest current in the section, its signal probably affected the final mean rms value. Also, the region north of 10°N presents opposite flow during April 2001 and July 2005, leading to lower rms values.

Still from the profiles of April 2002 and July 2004, it is notable that both nSEC and sNECC are stronger than the OGCM velocities, while the EUC agree mostly. Since both nSEC and sNECC are direct wind-driven currents but the EUC is not, this velocity bias is probably due to the wind field that forced the model. Another reason to speculate that the wind is generating this difference is that the bias is bigger above the thermocline.

For April 2001, zonal velocities from the CGCM were added to the analyses. Note that the coupled results (Figure 3, blue curve) are similar to the OGCM (red curve). No conclusive results from this comparison could be found and more available coupled results are needed. This will be done in a future work.

4. SUMARY AND CONCLUSIONS

In this work, four ADCP PIRATA sections were presented, briefly described, and compared to model results.

In a qualitative way the OGCM was able to reproduce reasonably well the zonal current system over the tropical Atlantic, displaying the correct latitudinal position of the current cores. Quantitatively, the rms values were 95% for the best cruise and all cruises were over approximately 80%.

The ADCP data provided novel velocity maps, reaching 15°N. To the best of our knowledge, no other observational program have collected ADCP velocities northward 7.5°N at this longitude. This allowed us to describe the northern NECC branch, early presented in model results (Schott and Böning, 1991) and recently explained to be generated by the particular shape of the Atlantic ITCZ (Urbano et al., 2006). Here, the OGCM was able to simulate this feature as well.

The wind field appears also to play an important role on the model simulations. The comparison between the mean velocity profiles at the main current bands showed a negative bias in both OGCM and CGCM velocity profiles. Therefore, the models are underestimating the zonal fluxes.

An interesting result was that during two cruises (APR 2002 and JUL2004), the model EUC was very similar to the observed one, whereas the directly wind-driven SEC and NECC were stronger. Both negative SEC and positive NECC presented the bias. This result reinforces that the bias is not generated by data calibration, otherwise the negative SEC would be weaker than the simulated SEC from top to bottom.

Coupled experiments were restrictedly used in here due to the lack of longer CGCM simulation. For future analyses, the CGCM will be important to evaluate the influences of the solar radiation, heat flux, and wind stress supplied by the atmospheric GCM instead of the parameterized values used by the OGCM.

This preliminary work was only the first step on looking forward to better understand the mechanisms involved on the tropical Atlantic SST variability.

5. BIBLIOGRAPHY

Foltz, G. R., S. A. Grodsky, and J. A. Carton, 2004: Seasonal salt budget of the northwestern tropical Atlantic Ocean along 38W. *J. Geophys. Res.,* **109,**

Foltz, G. R., S. A. Grodsky, J. A. Carton, and M. J. McPhaden, 2003: Seasonal mixed layer heat budget of the tropical Atlantic Ocean. *J. Geophys. Res.,* **108,** 3146-3159.

Foltz, G. R., and M. J. McPhaden, 2004: The 30-70 day oscillations in the tropical Atlantic. *Geophys. Res. Lett.,* **31,** L15205/1-4.

Foltz, G. R., and M. J. McPhaden, 2005: Mixed Layer Heat Balance on Intraseasonal Time Scales in the Northern Tropical Atlantic Ocean. *J. Climate,* **18,** 4168-4184.

Nobre, P., and J. Shukla, 1996: Variations of sea surface temperature, wind stress, and rainfall over the tropical Atlantic and South America. *J. Climate,* **9,** 2464-2479.

Pinardi, N., and A. R. Robinson, 1987: Dynamics of deep thermocline jets in the POLYMODE region. *J. Phys. Oceanogr.,* **17,** 1163-1188.

Schott, F. A., and C. W. Böning, 1991: {The WOCE Model in the Western Equatorial Atlantic: Upper Layer Circulation}. *{J. Geophys. Res.},* **96,** 6993-7004.

Servain, J. M., A. J. Busalacchi, M. J. McPhaden, A. D. Moura, G. Reverdin, M. Vianna, and S. Zebiak, 1998: A Pilot Research Moored Array in the Tropical Atlantic. *Bull. Am. Meteor. Soc.,* **79,** 2019-2031.

Stramma, L., S. Hüttl, and J. Schafstall, 2005: Water masses and currents in the upper tropical northeast Atlantic off northwest Africa. *J. Geophys. Res.,* **110,** 1-18.

Urbano, D. F., M. Jochum, and I. C. A. d. Silveira, 2006: Rediscovering the second core of the Atlantic NECC. *Ocean Modelling,* **12,** 1-15.