

INTERANNUAL ANALYSIS OF THE OCEAN-ATMOSPHERE *IN SITU* OBSERVATIONS AT THE BRAZIL-MALVINAS CONFLUENCE REGION

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1. INTRODUCTION

The western region of the South Atlantic Ocean is highly complex in terms of ocean circulation, water masses formation and mixing both at the open ocean and at the coast. The open ocean is modulated by strong mesoscale variability, mainly dominated by the Brazil Current (BC) and the Malvinas/Falkland Current (MC) at their meeting region known as the Brazil-Malvinas Confluence (BMC). These currents are characterized by high temporal and spatial variability of the transport, sea surface temperature (SST), chlorophyll concentration and sea surface height.

As part of the Brazilian Antarctic Program (PROANTAR), simultaneous *in situ* measurements of the Atmospheric and Oceanic Boundary Layers (MABL and OBL) are continuously performed at the Brazil-Malvinas Confluence region (BMC) since 2004. The BMC region is known as one of the most energetic regions of the World Ocean presenting very strong thermal gradients between the meeting waters of the warm Brazil Current (BC) and the cold Malvinas Current (MC). The *in situ* experiments were inspired by previous works where the air-sea coupling was investigated in the Equatorial Pacific (Hashizume *et al.*, 2002), Agulhas Current return flow regions (Rouault *et al.*, 2000) and in the BMC region itself (Pezzi *et al.* 2005; Tokinaga *et al.* 2005). All these regions are subject to high thermal and/or sea level contrasts owing to the presence of Tropical Instability Waves (TIW), oceanographic fronts and mesoscale features such as meanders or eddies.

Four experiments were conducted onboard OSS *Ary Rongel*. While crossing the BMC front, profiles of water temperature and atmospheric parameters were made. Using data from 2004, Pezzi *et al.* (2005) demonstrated that the MABL was directly modulated by the very strong surface thermal gradients between the warm waters of the BC and cold waters of the MC. To our knowledge, simultaneous descriptions of the MABL-OBL synoptic conditions at BMC are very rare. This work presents an original description of the MABL and OBL structure as well as the air-sea coupling at the BMC region based on *in situ* data collected during four INTERCONF cruises that took place during specific dates in the Austral spring from 2004 to 2007.

2. DATA AND METHODS

The study area for the experiments described here is located between 30°S to 50°S, 50°W to 60°W. This area was covered during specific dates in 2004 to 2007. While crossing the BMC front, Expendable Bathy-Thermographs (XBTs) were launched from the OSS *Ary Rongel* in order to measure the water temperature as a function of depth along the ship's route. When at the close vicinity of the BMC front, a sequence of radiosondes was also launched from the rear deck of the ship. The radiosondes measured pressure, temperature and relative humidity (RH) in the atmosphere. Wind speed and direction were also estimated from the relative movement of the radiosonde balloon in the atmosphere. The measurements were made at regular intervals of 2 seconds, which guaranteed a fair number of observations within the MABL. Additional calculations were made to help on the analysis of the vertical MABL structure.

In order to describe the mean MABL, vertical structure composites (average) of the radiosondes data were calculated using a similar strategy as in Pyat *et al.* (2005). The composite method was applied for each transect accomplished during the four experiments. The radiosondes data were grouped as function of their location relative to the SST gradient at the BMC region. The warm (cold) side was always located northwards (southwards) of the BC/MC frontal gradient. For example, during the first experiment (OP23) which took place during spring 2004 there were five radiosonde ascents. Three of them were located over the warm BMC side and were used to calculate the warm vertical structure composite. The other two ascents over the cold BMC side were used to compose the cold composite of the OP23. Warm and cold composites were obtained for all four experiments.

3. RESULTS

Figures 1 and 2 display the composite calculations based on radiosonde vertical profiles of θ , q , RH, u and v wind components, θ_e and θ_v . The profiles were biased in order to plot temperature values in the same figure as humidity values. Profiles of θ are biased by subtracting 283 K from its original value, θ_e by 280 K, θ_v by 275 K and RH is divided by 10-1. The analyses presented here are restricted to the first 1200 m height from the sea surface. These results help to understand the atmosphere characteristics as function of the lower boundary surface.

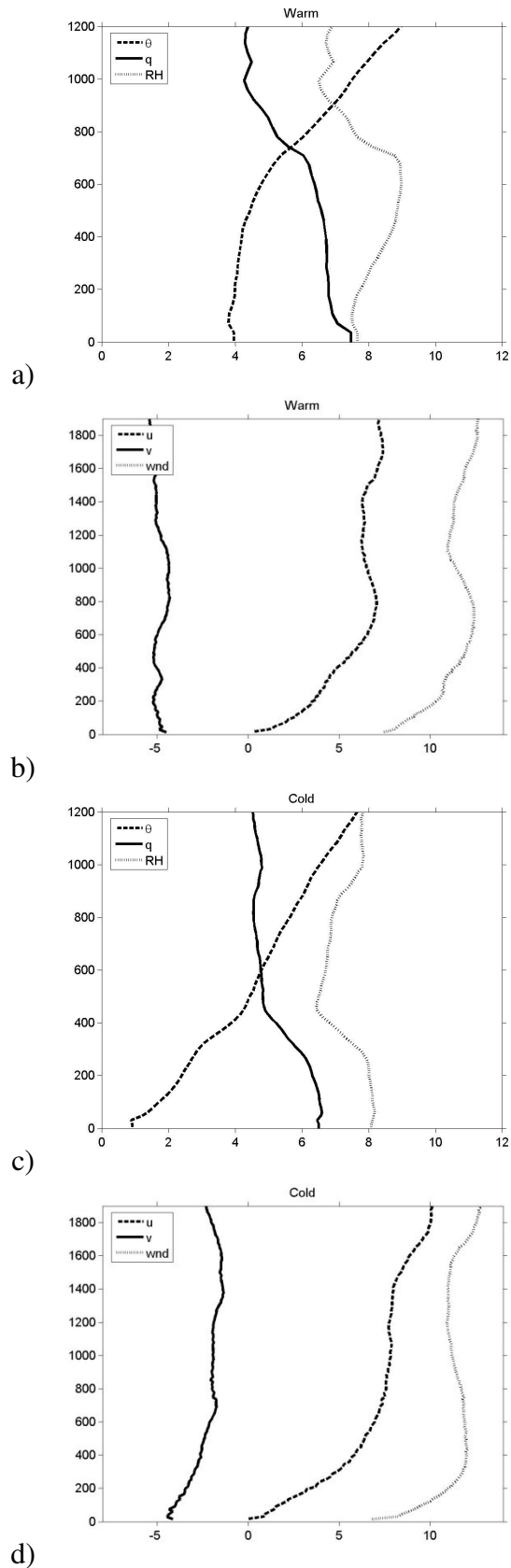


Figure 1 Vertical composite profiles of potential temperature (θ), specific humidity (q) and relative humidity (RH). (a) for warm cases and (b) for the cold cases. Vertical composite profiles of Wind magnitude (wnd), zonal (u) and meridional (v) wind components. (c) for warm cases and (d) for the cold cases.

The composites of the atmosphere over warm waters (Figures 1a and 1b) show a well defined convective MABL structure, including the top height (h_0). The observed changes seen in the composites displayed in Figure 1a and 1c are consistent with the SST changes observed from the warm side to the cold side of the front. Figure 4a shows the MABL top at 600 m approximately. This feature is diagnosed in both θ and q parameters. The humidity is well mixed at the warm region and does not show a strong vertical gradient. A strong thermal (θ) inversion occurs between 600 m and 800 m after which a softer gradient is observed up to about 1600 m. At the lower levels inside the MABL, q remains almost constant with h due to the vertical turbulent mixing showing a well developed mixed layer. The specific humidity diminishes above h_0 (~ 600 m) with height. This decline is less intense than the one observed for θ . The θ_v data in Figure 2a confirms this information.

Figures 1c and 1d show interesting features of the vertical composite profiles calculated over the colder waters of the BMC region. These profiles display a lower MABL top with capping inversion at 300 m of height, approximately, where the atmosphere is becoming dryer ($\sim 60\%$ of RH) compared to the lower levels where RH reaches values between 70% and 80%. Above the inversion level q remains almost constant up to a secondary inversion level, which is detected at 700 m of height. The vertical structure of the inversions is observed in the RH and θ_e profiles indicating a strong reduction of moisture, which comes from the sea surface to the boundary layer. This fact suggests that the upper MABL is decoupled from the mixed layer. Hashizume et al. (2002) observed a similar pattern over cold water at the eastern Equatorial Pacific. It should be noted that the θ profile itself does not clearly characterize the MABL top.

Figures 1b and 4d show the composites of the vertical distribution of u and v wind components and the associated wind magnitude for the warm and cold sides of the BMC respectively. These figures show that for both BMC sides the v component is negative indicating a wind flowing from the north throughout the whole atmospheric depth. The zonal component of the wind (u) for both cases is positive indicating that westerly winds prevail and showing a minimum at surface. Near the surface, the northerly component (v) is the prevailing, while above 400 m the westerly component dominates. The larger magnitude of the northerly wind component is showing that large scale synoptic circulations were prevailing during the time of the observations.

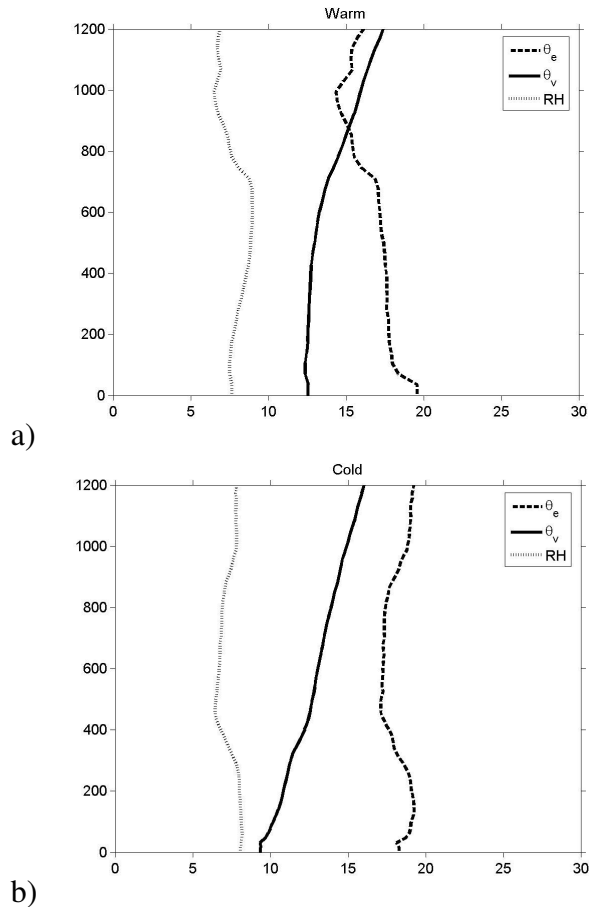


Figure 2 Vertical composite profiles of equivalent potential temperature (θ_e), virtual potential temperature (θ_v), relative humidity (RH). (a) for warm cases and (b) for the cold cases.

For instance, that surface northerly wind direction seen over the observation points are associated to the high pressure (anticyclone) circulation which is seen in OP23, OP25 e OP26. The meridional surface circulation showed larger magnitude at BMC region when compared to the zonal component. At the warm region the u component and wind magnitude are more intense at the surface when compared with the cold region (as seen in Figure 1b and 1d). Above 400 m this situation is reversed and the zonal component and wind magnitude at the warmer region are weaker compared with the cold case. This is not the same situation for the meridional component, where v is stronger throughout the whole MABL. The meridional component presents higher values at the warmer (colder) region from surface, -4.4 m.s^{-1} (-4.2 m.s^{-1}) up to 1200 m height with values of -5.0 m.s^{-1} (-1.6 m.s^{-1}) approximately. A stronger vertical wind shear near the surface is seen for the v component for the cold case composite. A less accentuated wind shear for both cases (warm and cold) is seen for the zonal component of the wind. However, the vertical wind shear is more accentuated for the zonal wind component when

compared to the meridional. These patterns show that the cool side of the BMC region has a larger static stability. As a consequence, there is a less mixed and more stratified MABL with stronger vertical shear at lower atmospheric levels compared to the warm part of the BMC region, where the wind shear is less accentuated indicating the presence of a MABL more turbulent and more mixed.

4. FINAL REMARKS

To our knowledge, this is a unique systematic observational ocean-atmosphere sampling effort conducted at this region. Despite the fact that the BMC region is acknowledged as one of the most energetic regions of the World Ocean, very few studies have addressed the importance of studying the air-sea coupling processes there. Analyzing the MABL-OBL coupling during four cruises between 2004 and 2007, this work shows that the MABL top is modulated by the strong SST gradients present at the sea surface of the study area. A possible explanation for this modulation lays on the fact that the MABL adjusts itself to the SST modifications characteristic from oceanic frontal regions. Over warm waters, the MABL static instability and turbulence are increased. This process causes the increase of the downward momentum transfer, consequently increasing the lower MABL winds. Over the cold side of the front, the MABL is more stable and less momentum is transferred downward, resulting on weaker surface winds. This process has been already proposed as an explanation for the air-sea coupling at other frontal regions of the world ocean such as Pacific Cold Tongue and the warmer waters around it. The mean MABL structure was thicker over the BC side than over the MC side. The warm side displayed systematically larger h_0 values compared to the cold side. The surface Q_S and Q_L fluxes always increased from the cold to the warm ocean front side owing to the increase of the wind and of the temperature (q) difference between the surface and the air.

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