# The impacts of the cold fronts on thermal stratification and water quality in a tropical reservoir (Brazil)

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## ABSTRACT
Cold fronts arising from Antarctic and reaching the southeast Brazil region modify the wind field basic and have important impact over physical, chemistry and biological processes that act in the hydroelectric reservoirs. During the winter time these cold fronts can reach southeast Brazilian coast each six days and summer each fourteen days in average. Most part of them reaches interior of São Paulo, Minas Gerais and Goias States. Thus, the objective of this work is to analyze the influence of cold fronts passage in the thermal stratification and water quality of the Itumbiara (Goias, Brazil) hydroelectric reservoir. To reach this objective a collection o meteorological (wind direction and intensity, short-wave radiation, air temperature, relative humidity, atmospheric pressure), water quality (pH, dissolved oxygen, conductivity, turbidity) and water temperature in four depths (5, 12, 20 and 40 m) data were used. These data were collected using an Integrated System for Environmental Monitoring called SIMA, in high frequency, 10 minutes. SIMA, developed in partnership between the Vale do Paraiba University and the National Institute of Space Research INPE), is a set of hardware and software designed for data acquisition and quasi real time monitoring of hydrological systems. SIMA utilizes Brazilian satellites to transmit the data. The stratification was assessed by non-dimensional parameter analysis. The Lake Number an indicator of the degree of stability and mixing in the reservoir was used in this analysis. It was possible to observe the developing of upwelling and downwelling in different shores of the reservoir during the cold fronts passage. These phenomena can modify the chemistry and biological processes in the water body.

## KEYWORDS
Thermal stratification, telemetric monitoring, Lake Number.

## INTRODUCTION
Some authors (Stech and Lorenzzetti, 1992) had identified that the cold fronts arising from Antarctic reach the southeast Brazil region modifying the basic wind, atmospheric pressure and also the air temperature. During the winter time these cold fronts can reach southeast Brazilian coast each six days and summer each fourteen days in average. Most part of them reaches interior of São Paulo, Minas Gerais and Goias States.

These modifications were identified as a key for change the physical, chemistry and biological processes in the hydroelectric reservoirs (Tundisi et al. 2004). The response of each water body to meteorological conditions is revealed firstly by the thermal structure present in the water column (Ambrosetti and Barbanti, 2001).

Based on this the objective of this paper is to show the influence of the passage of cold fronts on the thermal stratification of a tropical hydroelectric reservoir in Brazil.

# MATERIAL AND METHODS

## Study area

The Itumbiara hydroelectric reservoir (18°25'S, 49°06'W) is located in a region stretched between Minas Gerais and Goiás States (Central Brazil) that was originally covered by tropical grassland savanna. The basin's geomorphology resulted in a lake with a dendritic pattern covering an area of approximately 814 km² and a volume of 17.03 billion m³ (Figure 1).

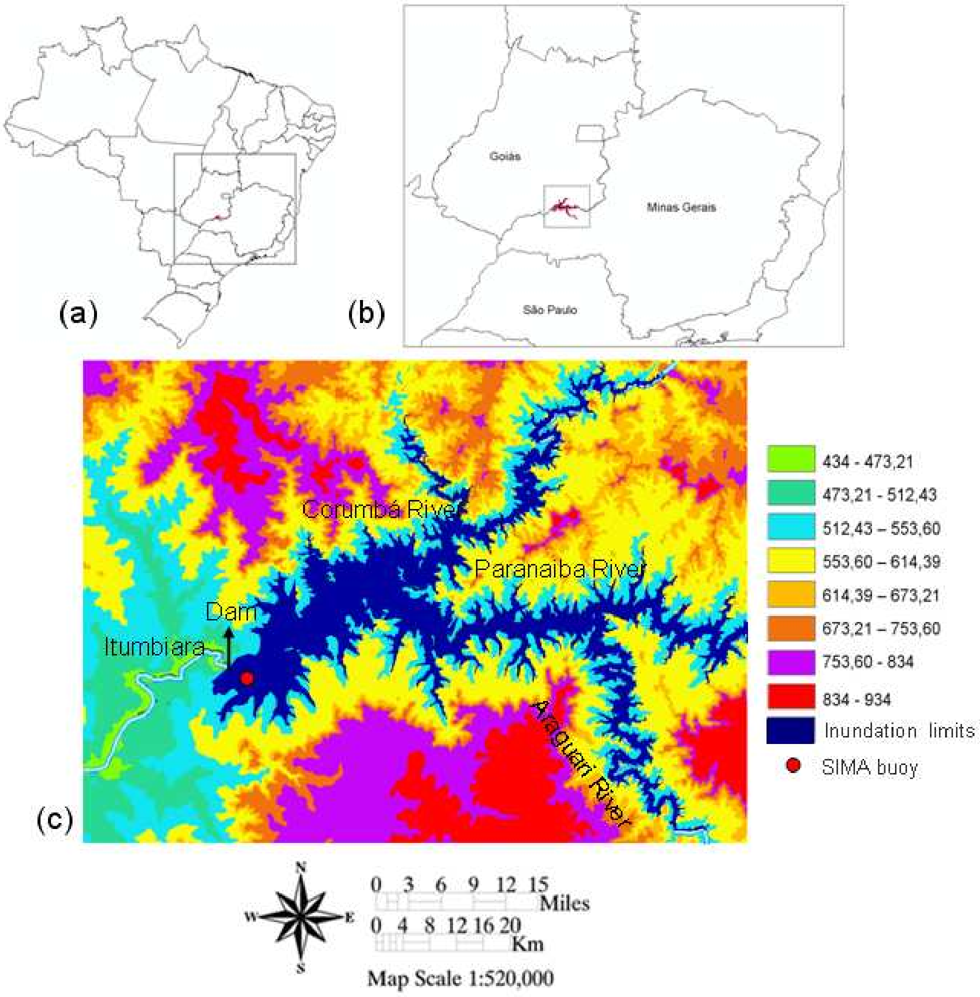


**Figure 1**: Itumbiara reservoir location in Brazil (a), between Minas Gerais and Goias States (b) and the topography near the reservoir and the location of the moored buoy (c).

## Satellite data

The data of GOES-10 (Geostationary Operational Environmental Satellite) from May 31$^{st}$ to June 06th 2009 was used to capture the track of cold front pass over the Itumbiara reservoir.

## Hydro-meteorological data

The meteorological (air temperature, humidity, air pressure and intensity wind) and limnological (water temperature in 5, 12, 20 and 40m depth) data from May 31$^{st}$ to June 06th 2009 was collected by a moored buoy called SIMA (Integrated System for Environmental Monitoring, see Stech et al., 2006) in each 1h.

**Surface Energy Budget**

A study of the energy exchange between the lake and atmosphere is essential for understanding the aquatic system behavior and its reaction to possible changes of environmental and climatic conditions (Bonnet, Poulin and Devaux, 2000). The exchange of heat across the water surface was computed using the methodology described by Henderson-Sellers (1986) as:

$$\phi_N = \phi_s(1-A) - (\phi_{ri} + \phi_{sf} + \phi_{lf}) \quad (1)$$

where $\phi_N$ is the surface heat flux balance, $\phi_s$ is the incident short-wave radiation, $A$ is the albedo of water (=0.07), $\phi_{ri}$ is the Longwave flux, $\phi_{sf}$ is the sensible heat flux and $\phi_{lf}$ is the latent heat flux. The units used for the terms in Eq. (1) are W $m^{-2}$.

**Lake Number - $L_N$**

To indicate the degree of stability and mixing in the reservoir, due to the passage of cold front, the $L_N$ was used (Imberger, 1998).

$$L_N = \frac{gS_t\left(1-\frac{Z_T}{Z_m}\right)}{\rho_0 u_* A_0^{3/2}\left(1-\frac{zg}{zm}\right)} \quad (7)$$

Where $z_T$ and $z_g$ are the height to the center of the metalimnion and the center of area, $\rho_0$ is the average density of the water column, $u_*$ is the water friction velocity, $A_0$ is the surface area of the reservoir and $S_t$ ($gcm^{-1}$) is an estimate of the stability of the reservoir calculated as (Hutchinson, 1957):

$$S_t = \frac{1}{\rho_0}\int_0^H g(h_v - z)\rho(z)A(z)dz \quad (8)$$

To calculate the stability of water column the reservoir bathymetry are needed.

**Bathymetric Data**

The bathymetry of the Itumbiara reservoir was made in two campaigns, the first from 11-15th May 2009 and second from 11-16 August 2009. The depth data was collected using an echo-sound LMS-525 from Lowrance, with a GPS (Global Positioning System) coupled. The depth data was treated in accordance to Merwade (2009).

## RESULTS

**Bathymetric Map**

The results of the depth surveys show that the reservoir presents the highest depths in the line of flooded river with depths higher than 78m during the high water level; with a littoral zone with depth less than 2m. Other higher deep region is near the Dam where the depth reach 70m (Figure 3).

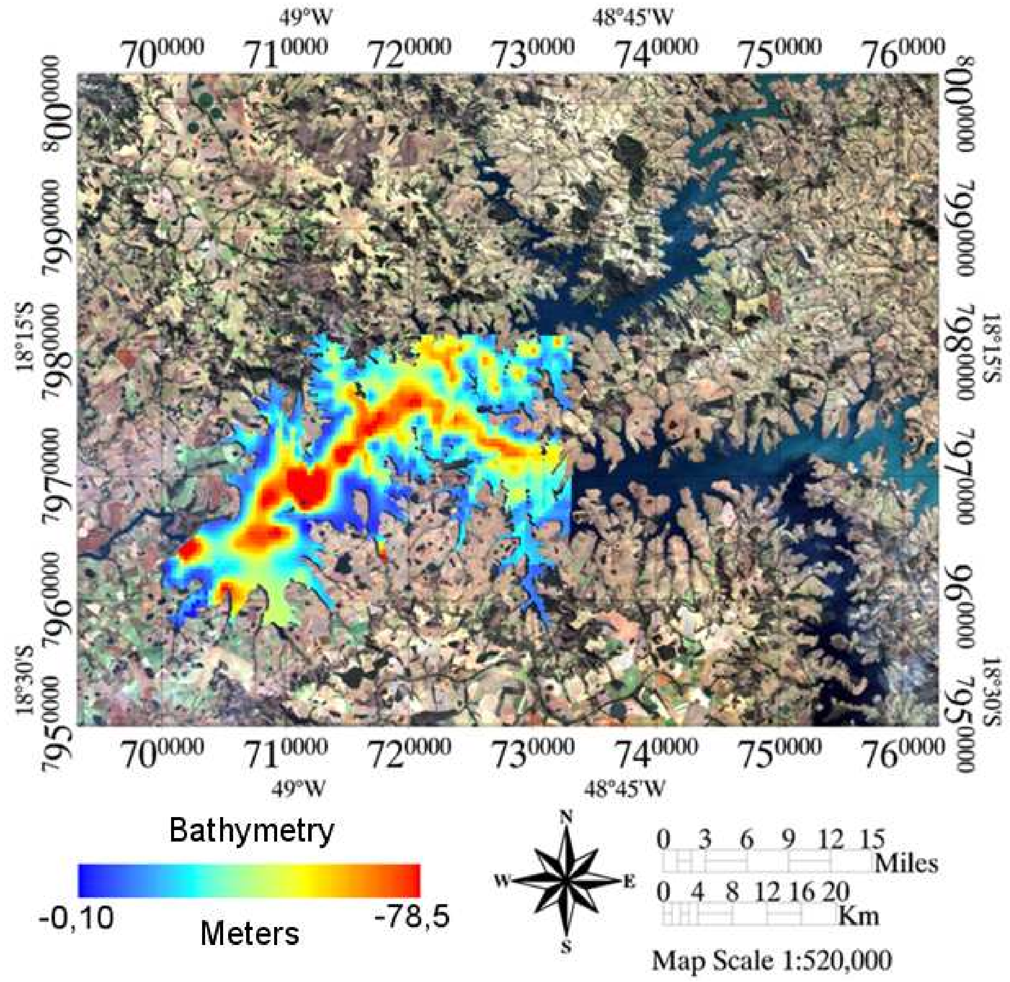


**Figure 5**: Bathymetric map of the Itumbiara reservoir.

### Satellite data

Using the satellite GOES data is possible to see the extension and the hour of the cold front passage over the reservoir. The Figure 3 shows the evolution of the cold front passage over the reservoir and identifies the maximum activity of the front (Figure 3-b).

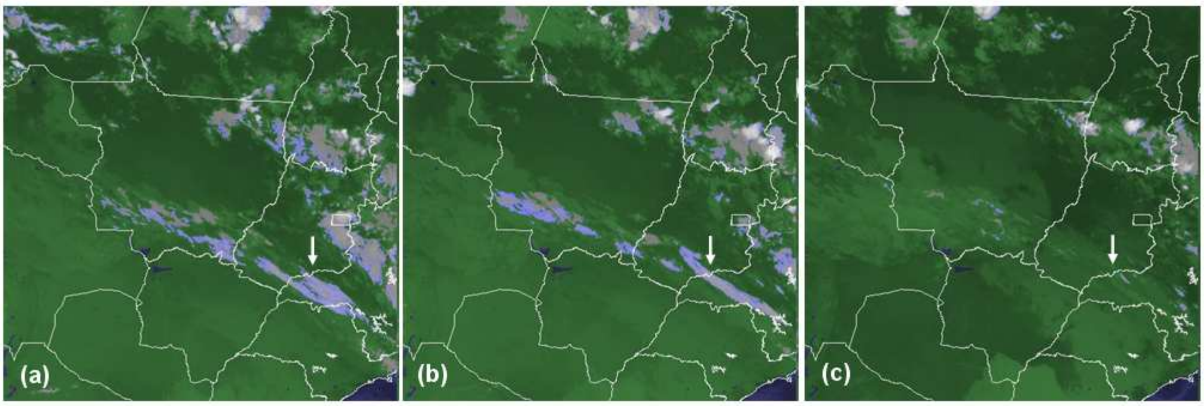


**Figure 3**: GOES-10 satellite data showed the evolution of the cold front passage over the reservoir: (a) 01st June 2009 at 08:00h, (b) 01st June 2009 at 09:45h (c) 01st June 2009 at 13:00h. The arrows indicate the location of the reservoir.

**Meteorological and Limnological Data**
The Figure 4 shows the meteorological and limnological parameters used in this study. It is clear that during the passage of cold front the atmospheric pressure and the air temperature decrease; in the other hand the wind shows a little increase and also the relative humidity. The water surface temperature decreases after the passage of the cold front as showed by Stech and Lorenzzetti (1992) for South Brazilian Bight..

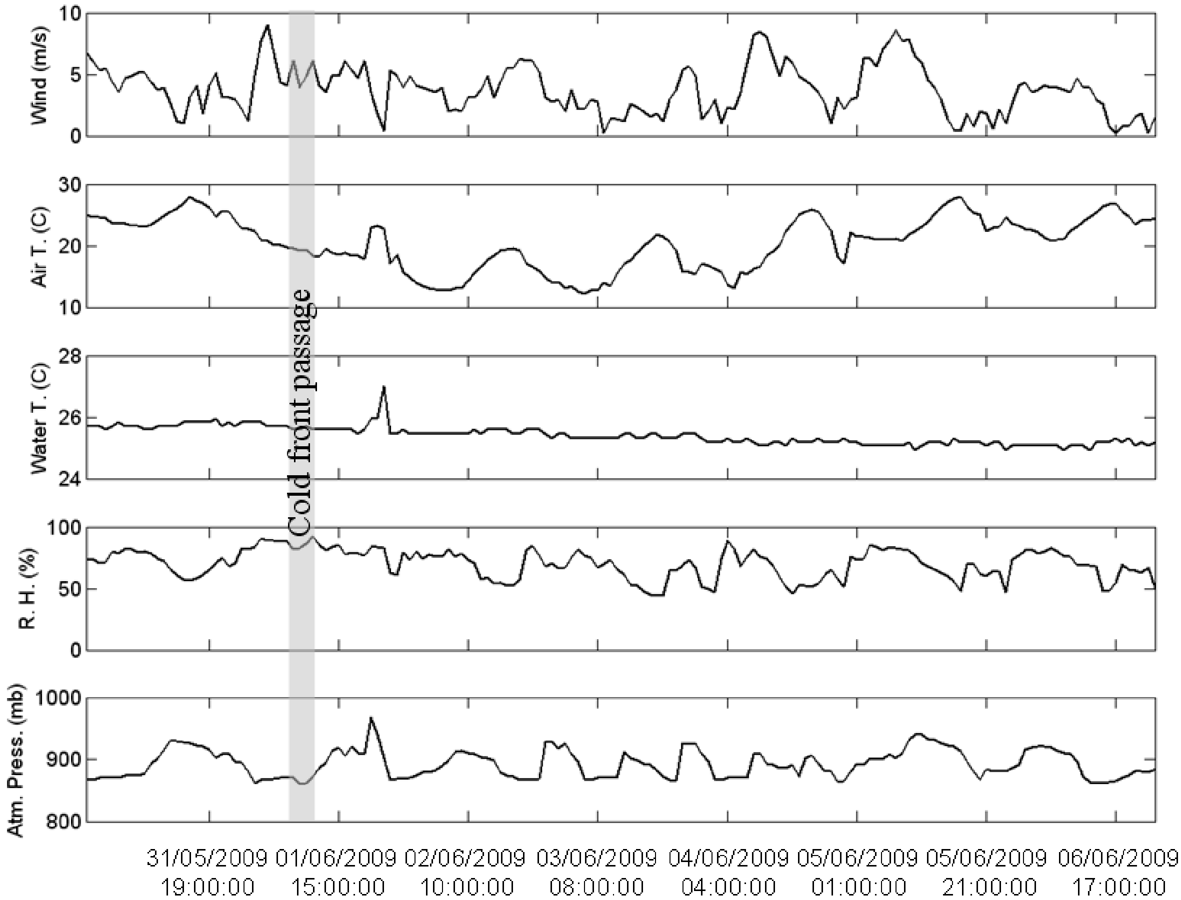


**Figure 4**: Meteorological (wind intensity, air temperature, relative humidity and atmospheric pressure) and limnological (water temperature) parameters collected by the SIMA buoy from May 31st to June 06th 2009.

This pattern observed before, during and after the passage of cold front is reflected in each component of the heat flux balance (Figure 5). During the passage of the cold front the intensity of the shortwave radiation decreases, with an increase of the longwave radiation. The sensible flux tends to be higher during and after the cold front passage if compared the period before the passage. The latent flux during the passage of the cold front tends to decrease, but after the passage the latent flux tents to increase again. The heat balance before the passage of cold front is positive when shortwave act in the systems; however during the passage the balance is negative and tends to normalize with the dissipation of the front.

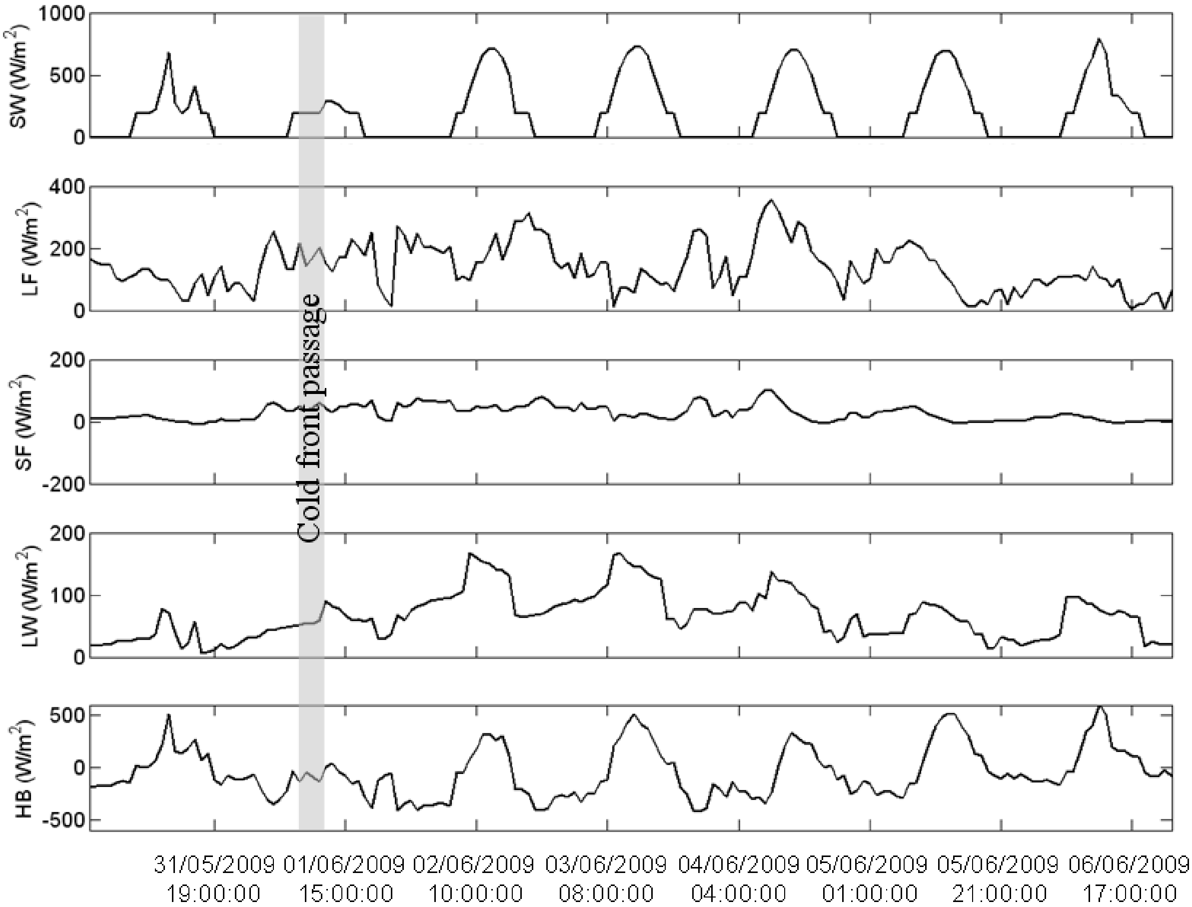


**Figure 5**: Heat flux components: SW – shortwave radiation, LF – latent flux, SF – sensible flux, LW – longwave radiation and HB – heat balance.

These pattern of meteorological and heat flux before, during the after the passage of the cold front will reflect in the water column temperature and stability (Figure 6). Before the passage of the front the water column presented a little temperature difference between the epilimnion and metalimnion; with the passage of the cold front the water temperature of the top-most layer decrease and the difference of temperature in the water column decreases also.

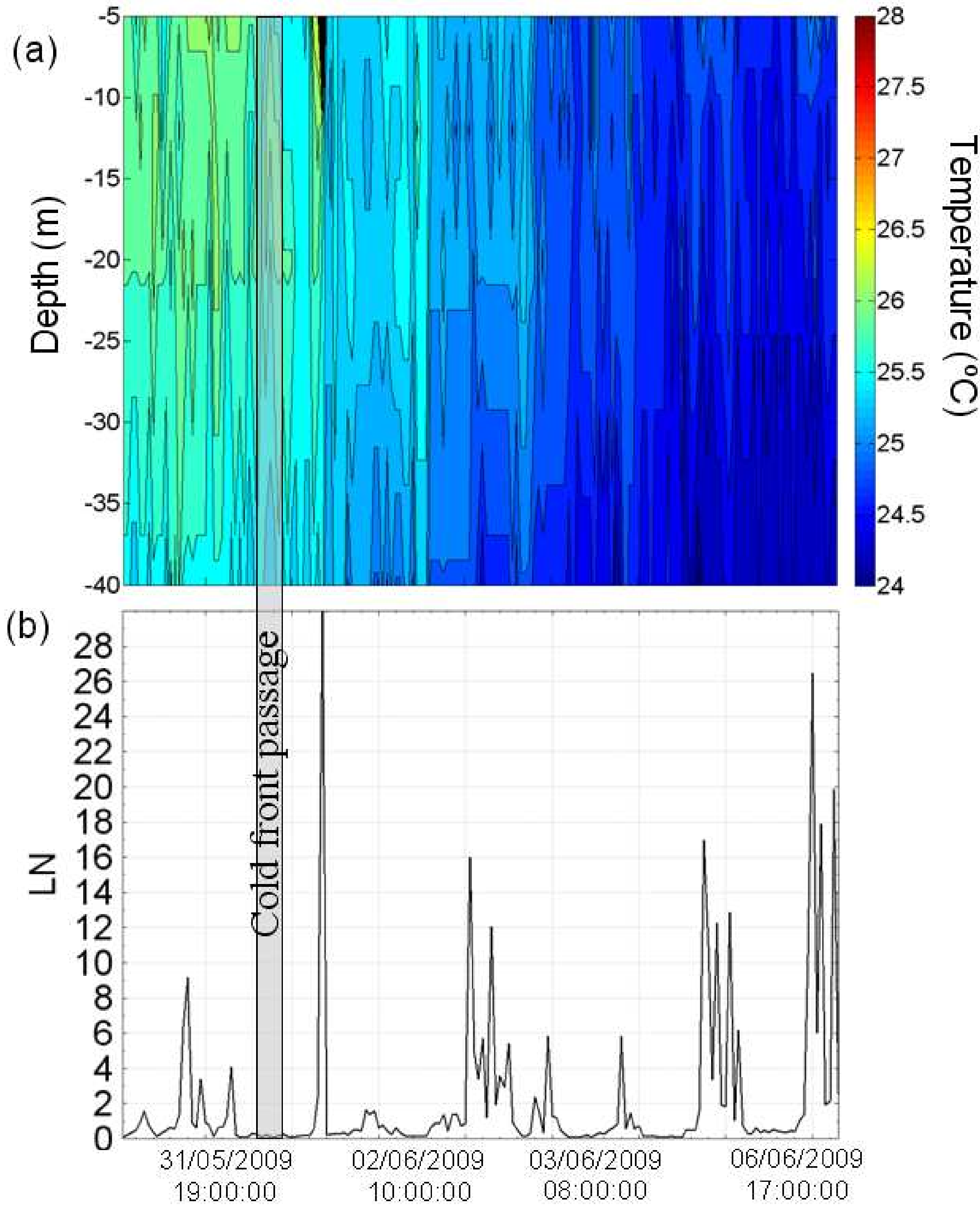


**Figure 6**: Thermal structure (a) and the Lake Number - $L_N$ (b) for the Itumbiara Reservoir.

In accordance to Antenucci and Imberger (2003) when $L_N > 1$ there is no deep upwelling and when $L_N < 1$ the cold deep, often nutrient rich, water from the hypolimnion will reach the surface layer during the wind episode. All $L_N > 1$ occurred during the daytime when the incident shortwave radiation is present, but after the passage of the cold front the values of $L_N$ increase during the heating phase. Often $L_N < 1$ occurred during the nighttimes, the unique exception is the day during the cold passage with $L_N$ less than 1.

After the passage of the front the water from hypoliminion progressively cooler and the mixed layer goes up to the top layer. The fact of the $L_N$ increases after the front passage during the daytime could be explained by the fact that during the cold front passage the water losses energy to the atmosphere and when the cold front dissipate the incident shortwave radiation heats the surface creating the condition enhancing the stability of the water column.
Tundisi et al. (2004) discuss that the most important finds of the cold front passage over a Brazilian hydroelectric reservoir is the release of iron and manganese; this is because this release could increase the costs of the drink water treatment.

## CONCLUSION

The passage of cold front over a region decreases the atmospheric pressure and air temperature, enhancing the relative humidity. In tropical hydroelectric reservoir these modifications in the thermal structure can induce a great modification in the biological and chemical processes. Also when the upwelling event occur a cold water rise at the surface bring a nutrient rich masses that enhance the biological productivity in combination with light penetration into the water column.

## ACKNOWLEDGMENTS

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