Thermal regime and stability of a tropical shallow reservoir : Lake Monte Alegre, Brazil

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ABSTRACT

Lake Monte Alegre (21°11′ S, 47°43′ W) is a small and shallow eutrophic reservoir (area 7 ha, max. depth 5 m, mean 2.9 m), situated in southeastern Brazil. Temperature, dissolved oxygen, pH and electrical conductivity were measured weekly in the water column, during 14 months. The reservoir is warm discontinuous polymictic in its deeper region, with more stable stratification in spring and summer, when oxygen depletion at the bottom was common. The values of heat budget, maximum stability, tropicality index and nondimensional storage flux are 3030-3427 cal.cm^{-2}.year^{-1}, 15g-cm.cm^{-2}, 1756-1796 cal.cm^{-2}.m^{-1}, and 1.17-2.46, respectively. The influence of seasonal and unpredictable climatic events on the thermal regime is discussed.

KEY WORDS : Stratification — Thermal Structure — Reservoirs — Tropical region — South America — Brazil.

RÉSUMÉ

LE RÉGIME THERMIQUE ET LA STABILITÉ D'UN RÉSERVOIR TROPICAL PEU PROFOND : LE LAC MONTE ALEGRE, BRÉSIL

Le lac Monte Alegre (21°11′ S, 47°43′ O) est un petit réservoir, peu profond, eutrophe (surface 7 ha, prof. max. 5 m, prof. moyenne 2,9 m), situé au sud-est du Brésil. La distribution verticale de la température, de l'oxygène dissous, du pH et de la conductivité, a été mesurée toutes les semaines, pendant 14 mois. Le réservoir est, dans sa région la plus profonde, du type polymictique discontinu chaud, avec une stratification plus stable pendant le printemps et l'été; durant cette stratification, l'anoxie du fond est fréquente. Le bilan thermique, la stabilité maximale, l'index de tropicalité et du « storage flux » (sans-dimension) sont de 3030-3427 cal.cm^{-2}.an^{-1}, 15 g-cm.cm^{-2}, 1756-1796 cal.cm^{-2}.m^{-1} et 1,17-2,46, respectivement. On discute l'influence des facteurs climatiques saisonniers ou imprévisibles sur le régime thermique du réservoir.

MOTS-CLÉS : Stratification — Structure thermique — Lac de retenue — Région tropicale — Amérique du Sud — Brésil.

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RESUMEN

EL REGIMEN TÉRMICO Y LA ESTABILIDAD DE UN EMBALSE TROPICAL RASO : EL LAGO MONTE ALEGRE, BRASIL

El Lago Monte Alegre (21°11′ S, 47°43′ W) es un embalse eutrófico pequeño y raso (área 7 ha, prof. máx. 5 m, media 2,9 m), situado en el sudeste del Brasil. La temperatura, el oxígeno dissuelto, el pH y la conductividad eléctrica fueron medidos semanalmente en la columna de água, durante 14 meses. El embalse es de tipo polimíctico discontinuo caliente en su región más profunda, con una estratificación más estable en la primavera y en el verano, cuando fué común el agotamiento de oxígeno en el fondo. Los valores de «heat-budget», estabilidad máxima, índice de tropicalidad y del flujo de almacenamiento no-dimensional son 3030-3427 cal.cm^{-2} .año^{-1}, 15 g-cm.cm^{-2}, 1756-1796 cal.cm^{-2}.m^{-1} y 1,17-2,46, respectivamente. Es discutida la influencia de eventos climáticos estacionales y eventos climáticos imprevisibles sobre el regimen térmico del embalse.

PALABRAS CLAVES : Estratificación — Estructura térmica — Embalses — Région tropical — America del Sur — Brasil.

INTRODUCTION

Since the pioneer investigations on tropical lakes until nowadays, initial ideas concerning seasonality and predictability of events as, for instance, circulation and stratification periods have been modified. The increasing number of limnological researches in the tropics, involving studies of short and long-term variations, as those by TALLING (1969), LEWIS (1973, 1983a and 1984), and WOOD *et al.* (1976), showed that even lakes located close to the Equator can present predictable seasonal variations. On the other hand, the investigations also indicate the existence of non-seasonal variations in tropical lakes, which assume a more important role than in temperate ones. In a revision of limnological concepts, LEWIS (1983b) proposed a new classification of lakes concerning stratification, based on that of HUTCHINSON and LÖFFLER (1956).

Due to the importance given to large water bodies, studies of small lakes or reservoirs contribute with a smaller portion of the total of limnological research in the tropical zone. Detailed studies of such water bodies, however, can reveal not only unexpected characteristics but may also contribute to a better comprehension of the functioning of tropical aquatic ecosystems. An expected feature of a small and shallow water body is to present a very low stability of the stratification and nocturnal circulation. However, depending on morphometric, hydrological, and climatic characteristics, a shallow water body can show a different picture. The most important factors influencing the pattern of circulation deserves attention for the prediction of the circulation and stratification periods and for the understanding of physical, chemical and biological features.

In this paper, an analysis of stratification, heat content and stability of Lake Monte Alegre is presented. In a detailed investigation we evaluated the influence of static and dynamic climatic factors on the thermal regime of a shallow reservoir.

STUDY AREA AND DYNAMIC CLIMATIC FACTORS

Lake Monte Alegre (21°11′ S 47°43′ W) is located in Ribeirão Preto, São Paulo State, Brazil, at 500 m of altitude. It resulted from the damming of Laureano Stream, which above the lake is surrounded by sugar cane plantations, a predominant culture in the region. The reservoir is surrounded by grass and few trees. The geographic location and morphometric data are presented in Figure 1. The annual water level fluctuation is not much pronounced (~ 40 cm), even in very dry years (M. S. ARCIFA, unp. data), and the retention time is about 45 days.

The region is characterized by a tropical climate of transition between warm and sub-warm, with marked dry and wet seasons (NIMER, 1979).

The air-masses which, together with static factors, are important in the determination of the southeastern Brazilian climate are the Tropical Atlantic (TA), Equatorial Continental (EC), and the Polar Atlantic (PA) (NIMER, *op. cit.*). The TA air-mass, originating from the Atlantic Ocean, is characterized by high temperatures and moisture acquired over the sea. Through typical movements of this air-mass, the oceanic humidity is carried to high altitudes (above 1 500 m) and the air becomes limpid over the continent. The EC air-mass originates from the Northwestern Amazonian basin and is characterized by warm and misty air. The PA air-mass, originating from the Antarctic Continent, with cold air, is responsible for disturbances of the zonal circulation promoted by the former two air-masses. The discontinuity zone formed between TA and PA constitutes the Atlantic Polar Front.

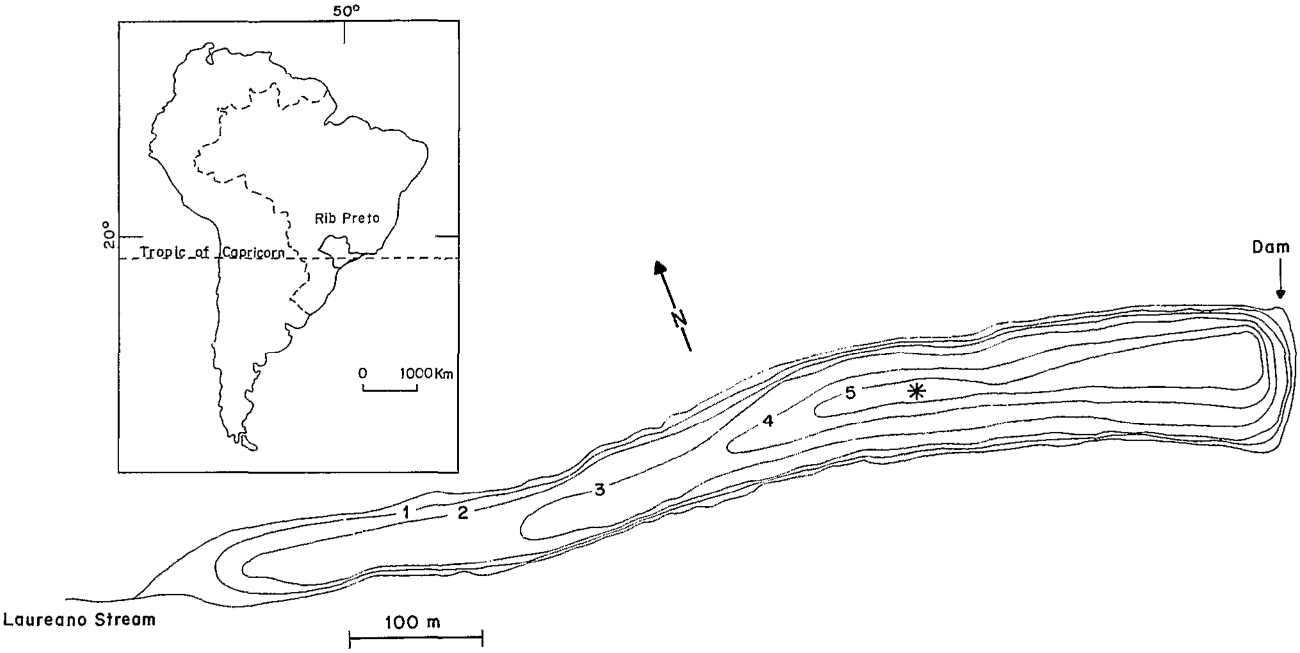

FIG. 1. — Upper : Ribeirão Preto location in South America. Lower : morphometric map of Lake Monte Alegre, showing location of sampling station.
Situation de Ribeirão. Preto en Amérique du Sud, morphométrie du lac Monte Alegre et station de mesure.

The TA predominance in the autumn-winter months gives to this period the features of low rainfall and limpid air. In summer, the TA gives way to the EC, which pushes the former to the coast, at São Paulo State latitudes.

In South America, the Polar Front (PF) follows trajectories directed by the relief, chiefly by the Andes. Two of them are of interest to our climate: the maritime atlantic and the continental trajectories. The former is more frequent, mainly in the warmer months; the latter, rarer, affects more sharply the interior of São Paulo, reaching sometimes the Amazonian region. The cold and dry air of the Polar Front warms up and gains moisture in its way to lower latitudes, promoting frontal and post-frontal rains. The initial heavy showers are followed by intermittent rains for several days. After the rains, the weather becomes clear and colder than that at the arrival of the PF. The Tropical Line Squall, apparently originated in the PF ondulations, propagates with clouds and pre-frontal rains, announcing the arrival of a cold front, 24 hours in advance. The PF action is weakened in summer, but even so can be felt through persistent rains, which differ from summer showers, of short duration.

The weather can also present instabilities caused by local disturbances which are, in general, of short duration.

MATERIAL AND METHODS

Weekly samplings were carried on in one station (Fig. 1) from April 1985 to June 1986. Two diurnal cycles were also studied, one in summer and another in winter.

Climatic data were supplied by the Agronomic Institute, located approximately 5 km from the reservoir. The evaporation was measured with an standard evaporimeter class A.

The annual heat budget, heat content, and stability were estimated according to HUTCHINSON (1975) and COLE (1979). The annual heat budget was also evaluated for 1988-89.

The tropicality index (COCHE, 1974) is defined as $TI = RH.\bar{z}^{-1}$, where RH = residual heat; $\bar{z}$ = mean depth. It was calculated for 1985-86 and 1988-89. The non-dimensional storage flux (TAYLOR and AQUISE, 1984) is defined as $S^* = \frac{\sigma_\varsigma}{(B/T)}$, where σ_ς = standard deviation of monthly or weekly storage flux in relation to the annual mean; B = annual heat budget; T = time interval between the minimum and maximum heat storage.

A Ruttner bottle with a coupled thermometer was used for temperature measurements and for collecting samples for the analyses of : dissolved oxygen

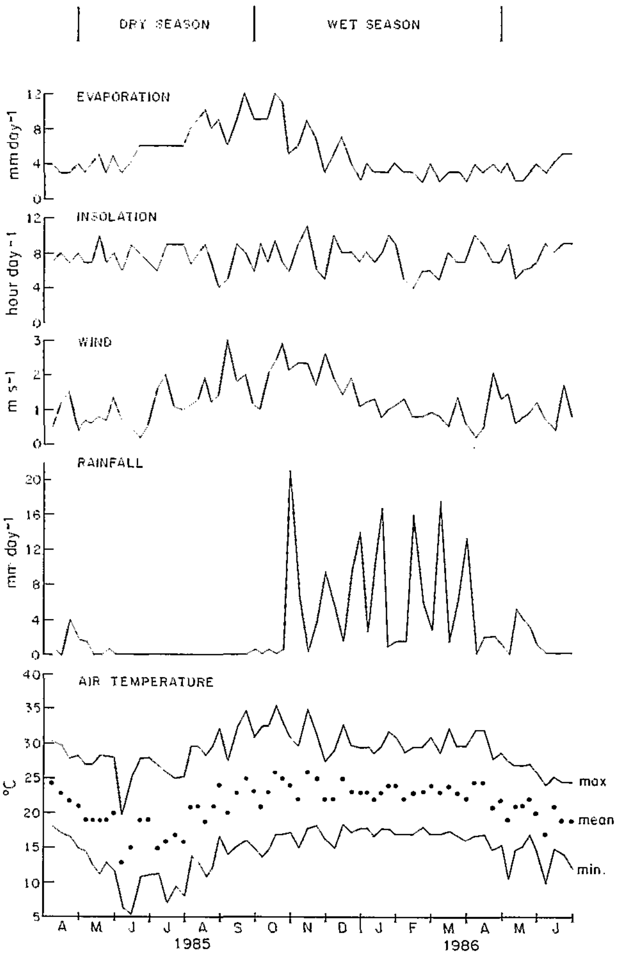

FIG. 2. — Weekly means of meteorological data, from March 1985 to June 1986. Air temperature and wind values refer to weekly means based on daily means.
Moyennes hebdomadaires des données météorologiques, de mars 1985 à juin 1986. La température de l'air et le vent ont été calculés à partir de données journalières.

(DO) through WINKLER's method, azide modification (GOLTERMAN, 1969); pH with an Orion Research pHmeter, model 301; electrical conductivity, at 25 °C, with a Metrohm E 382 conductivimeter. Water transparency was measured with a 30 cm white Secchi disc.

RESULTS

Climate

The dry season comprises an approximate period of 5 months (May to September) and the wet season 7 months (October to April) (Fig. 2). The dry season can be divided in a cold period (May to July), and a warm and more windy period (August-September). The wet season is warm and more windy at the beginning. The dry season coincides roughly with the autumn-winter period and the wet season with the spring-summer period. Total rainfall was very low in 1985, a particularly dry year.

The other climatic variables presented fluctuations not exactly coincident with dry and wet seasons. The mean air temperatures increased from midwinter, attaining the highest values in early spring (end of dry season-start of wet season Fig. 2); during summer, temperatures were lower and more stable, due to the cooling effect of atmospheric precipitation. Temperature values declined when autumn started (beginning of dry season). The minimum and maximum air temperatures clearly indicate June and July as the coldest months (Fig. 2). At the end of the dry season-beginning of the wet season, the maximum temperatures were higher, but the minima attained the highest values only in summer.

Wind velocities were relatively low, with no predominant direction. The mean values increased at the start of winter, decreasing at the start of summer. Mean evaporation values increased in the period of higher wind velocities.

The mean insolation hours, during the studied period, showed fluctuations which were not directly related to dry and wet seasons. The wet season of the 1985-86 period presented few cloudy days, which is usually not a common feature of this season.

Heat content

There is clearly a seasonal component in the evolution of heat content, as expected, reaching maximum values in summer (Fig. 3). The water heating in summer showed direct relation with the minimum air temperatures, which reflect the atmosphere heating (Fig. 2). Low scale variations occurred related to disturbances caused by unpredictable events like cold fronts, summer showers, and cloudy weather due to movement of local air masses. The heat content drop at the end of November 1985, for instance, was due to the influence of a Polar Front, which brought about a dense cloud cover, rains and slight atmospheric cooling for a week, interfering on the insolation and other heat budget components.

The water heating rate was initially (August, October 1985) 23.8 $cal.cm^{-2}.day^{-1}$, decreasing to 7.5 in November to January. A period of stability (February, March 1986) was followed by one of heat loss at a rate of 35.8 $cal.cm^{-2}.day^{-1}$ (April to June). In

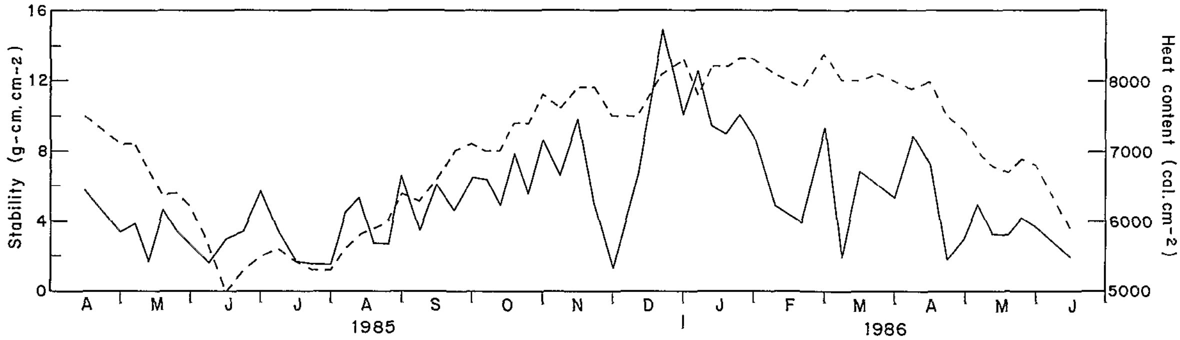

FIG. 3. — Heat content (---) and stability (——) of the reservoir, from April 1985 to June 1986.
Contenu calorique (---) et stabilité (——) du lac, d'avril 1985 à juin 1986.

1985, the heat loss rate, in an equivalent period from April to June, was 44.6 $cal.cm^{-2}.day^{-1}$. There is, however, intense and dynamic diel heat exchanges between air and water (Tabl. I). In summer as well as in winter, there is a positive heat balance in the morning (6-12 h). In winter, the heat loss rate was slightly higher in the 18-24 h period and in summer in the 24-6 h period.

Following the establishment of marked temperature-density gradients, there was a gradual increase in stability beginning in spring (Fig. 3). As occurred with heat content there is a decrease in November 1985, when the stability approched zero.

TABLE I

Heat flux ($cal.cm^{-2}.period^{-1}$), during 24 hours in winte r (July 17-18, 1985) and summer (Feb. 28-March 1, 1986)
Flux de chaleur ($cal.cm^{-2}.period^{-1}$) au cours d'un cycle nycthéméral en hiver (17-18 juillet 1985) et en été (28 février-1er mars 1986)

Period (h)	Flux
Winter	
12 - 18	- 31.8
18 - 24	- 119.6
24 - 6	- 104.4
6 - 12	+ 103.6
Summer	
6 - 12	+ 148.3
12 - 19	- 22.2
19 - 24	- 94.2
24 - 6	- 132.7

The transparency values ranged from 0.90 to 1.90 m, with a mean of 1.38 ± 0.29 m. Weekly fluctuations in light penetration were characteristic, and close relationships with dry and wet seasons were not observed in the studied period. In other occasions, however, as the wet seasons of 1983-84 and 1986-87, the influence of large amounts of suspended solids on transparencies was evident, reducing them to few centimeters (M. S. ARCIFA, unp. data). Only in years with exceptional rainy seasons is the influence of suspended solids remarkable, although for short periods of approximately one month.

The water column structure

The lowest temperatures in the water column were observed in the first half of the winter after which an increase took place until the maximum values were reached in summer (Fig. 4). Marked and durable stratification periods occurred in spring and summer. Even in winter, brief stratification periods can occur, characterized, however, by gentle gradients. Homothermy or conditions near homothermy occurred in some occasions in autumn-winter. Surface heating is a very important event in the water column, occurring in cold and warm periods, but with higher frequency and intensity in the latter, as expected.

Dissolved oxygen supersaturations in surface layers, reaching 140 %, were very frequent (Fig. 5). The establishment of differential layers is evidentiated most of the year through DO stratification. Following the more stable thermal stratification of the spring-summer period, sharp DO stratifications occurred, with anoxia in the deeper layers. The periods of total circulation were characterized by relatively high DO values near the bottom.

The duration of the stratification and the depth

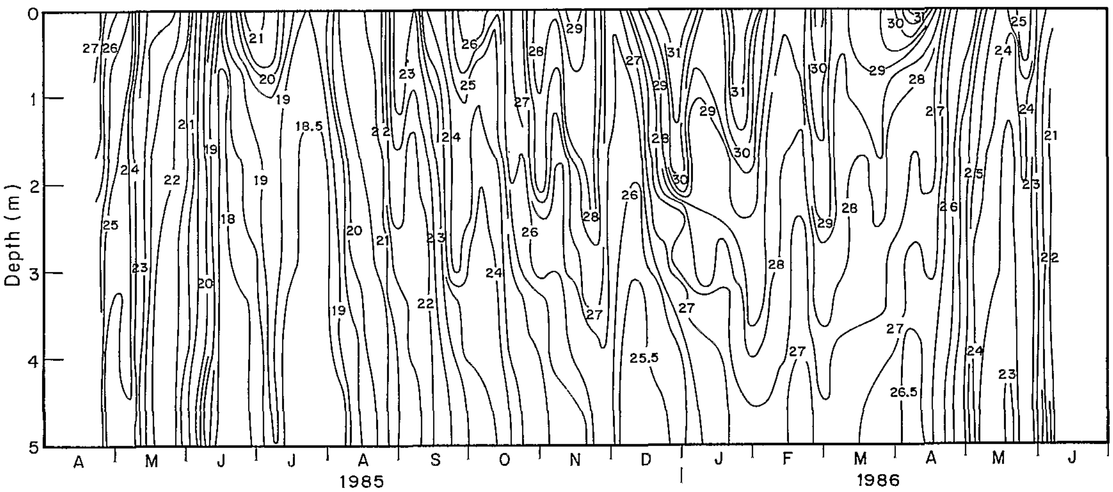

FIG. 4. — Isothermal variations, at intervals of 0.5 °C, from April 1985 to June 1986.
Diagramme profondeur-temps des températures (intervalle des isolignes : 0,5 °C).

influenced by surface heating can be observed in the 24 h samplings (Fig. 6). In winter, the thermal gradient caused by surface heating during the day was destroyed at night. Dissolved oxygen was, however, not homogeneously distributed in the water column. In summer, the thermocline and oxycline were very evident, the stratification being maintained during the night, when DO was depleted in the deeper layers. Surface heating, stronger in summer, affected to 2 m depth and notwithstanding a strong gradient (1.8 °C), disappeared at night. The 24 h samplings, in summer, were carried on after a short circulation period, which brought DO to the previously anoxic bottom (February 1986, Fig. 5). The anoxia recovery occurred in a brief period of approximately one week; the low DO amount of the deeper layers was totally exhausted during the 24 h period. The one week interval for the re-establish-

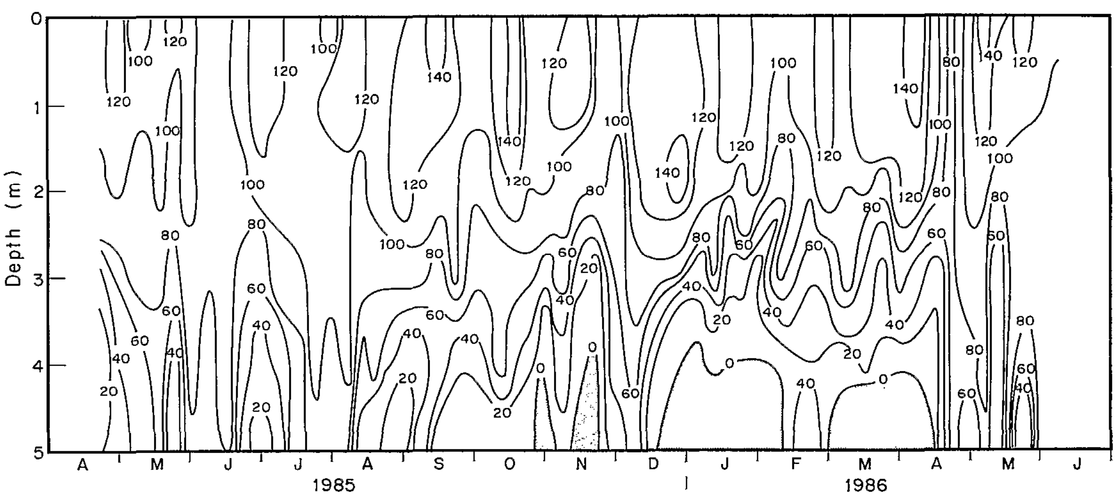

FIG. 5. — Depth-time diagram of dissolved oxygen isopleths, in per cent saturation, from April 1985 to June 1986. Isopleths at intervals of 20 %.
Diagramme profondeur-temps du pourcentage de saturation en oxygène (intervalle des isolignes : 20%).

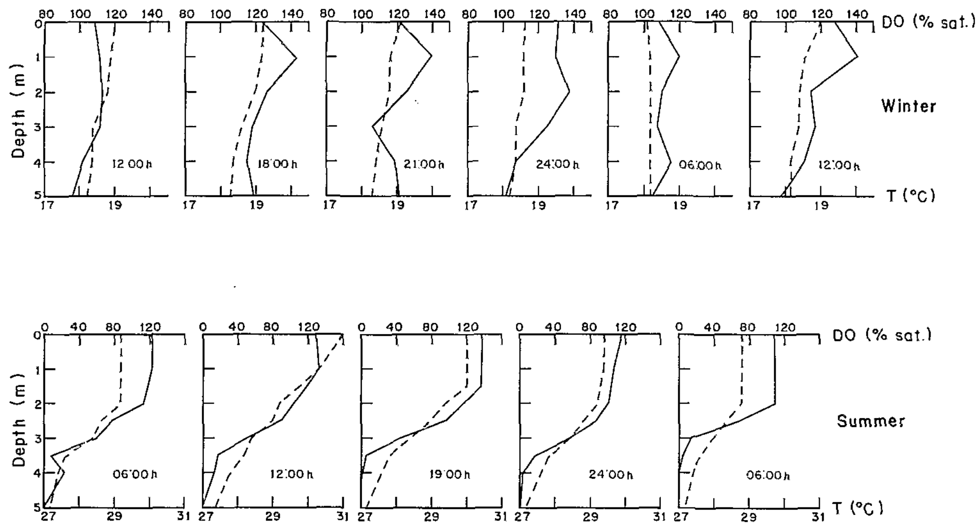

FIG. 6. — Depth profiles of temperature (----) and dissolved oxygen (———) in 24 hours. Winter : July 17-18, 1985; summer : February 28 - March 1, 1986.
Température (---) et profils d'oxygène (——) au cours de cycles de 24 h en hiver : 17-18 juillet 1985 et en été : 20 février-1er mars 1986.

ment of a clear stratification, with oxygen depletion at the bottom, can also be observed in December 1985, after a circulation period (Fig. 4, 5).

The influence of weather disturbances, as those brought about by a Polar Front, on the reservoir stratification, can be seen in Figure 7. On 22.XI.85, the arrival of a Polar Front was responsible for rains and relatively strong winds, but the thermocline was not yet broken. On 29.XI, after a week of rainy weather and slight air temperature decrease, the water column was practically homothermal, and between 6 and 12.XII the stratification was recovered.

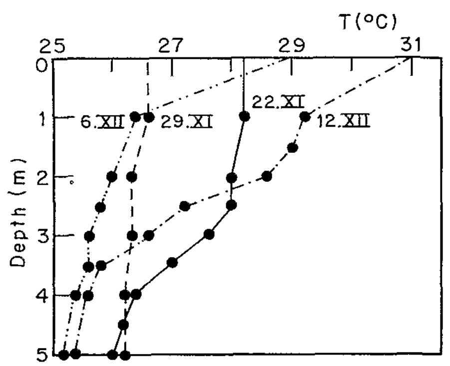

FIG. 7. — The arrival of a Polar Front on 22.XI.85, and the influence of its disturbances on the reservoir thermal stratification.
L'arrivée d'un front polaire le 22-XI-85 et son influence sur la structure thermique.

The distribution of pH values follows the stable thermal stratification periods in spring and summer, with clear stratification in the water column (Fig. 8). The values were lower and homogeneously distributed in the column during circulation periods. Relatively high values in surface layers are related to higher primary productivity rates (ARCIFA *et al.*, *in prep.*).

The vertical and temporal distribution of conductivity, as the pH, showed marked stratifications in the spring-summer period (Fig. 9). The surface values of 50-60 $\mu S.cm^{-1}$, in the dry season, increased to 80-90 $\mu S.cm^{-1}$, in the wet season.

DISCUSSION

The thermal dynamic is complex in Lake Monte Alegre, as it seems to be in tropical lakes in general (LEWIS, 1973). The complexity is increased by the shallowness of the reservoir. The relative pronounced daily variations of the atmospheric heat content, evaluated through the range of air temperature values, promote nocturnal heat loss of the water, so that the instantaneous heat content do not reflect the reality of heat exchanges. But the evolution of the heat content throughout the year, even without

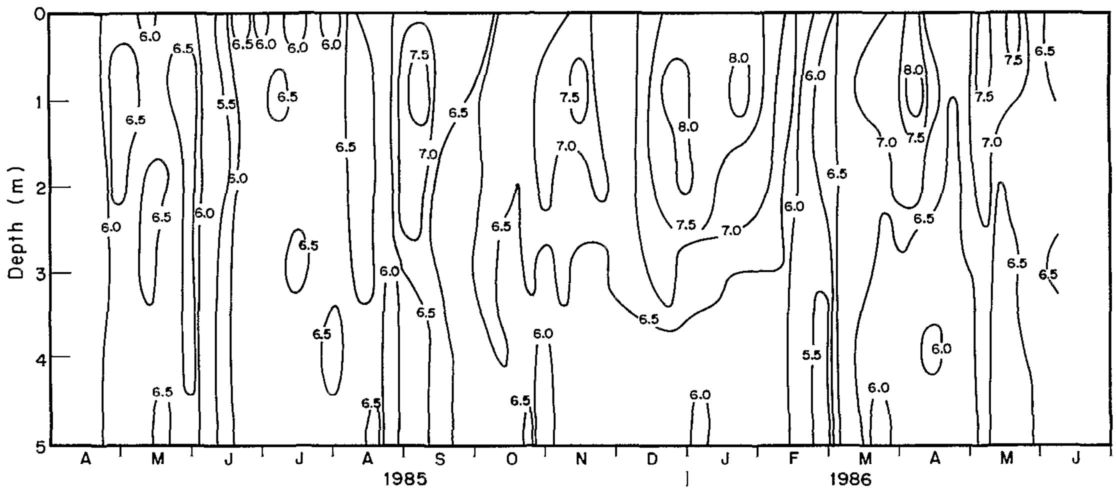

FIG. 8. — Depth-time diagram of pH isopleths, at intervals of 0.5, from April 1985 to June 1986.
Diagramme profondeur-temps du pH (intervalle des isolignes 0,5 unités) d'avril 1985 à juin 1986.

showing the short-term relationships between air and water, evidences the influence of clearly seasonal and of unpredictable events.

Under the influence of seasonal events, as the amount of available solar radiation, there is an increase of the heat content in the reservoir, from August, and the establishment of progressively more conspicuous temperature-density gradients, which culminate in summer. Related to the establishment of sharper gradients, there is an increase in the stability of the water column.

The unpredictable events are connected to seasons, but their frequency and intensity are not predictable. Polar Fronts are an example of this type of event and, under their influence, heat loss and stability decrease were verified in several occasions, as for instance, in November 1985 (Fig. 3). So, the development of the heat content and stability curves show tendencies related to marked seasonal events and fluctuations caused by unpredictable events. The stability of this small reservoir is very sensitive to heat losses under the influence of weather

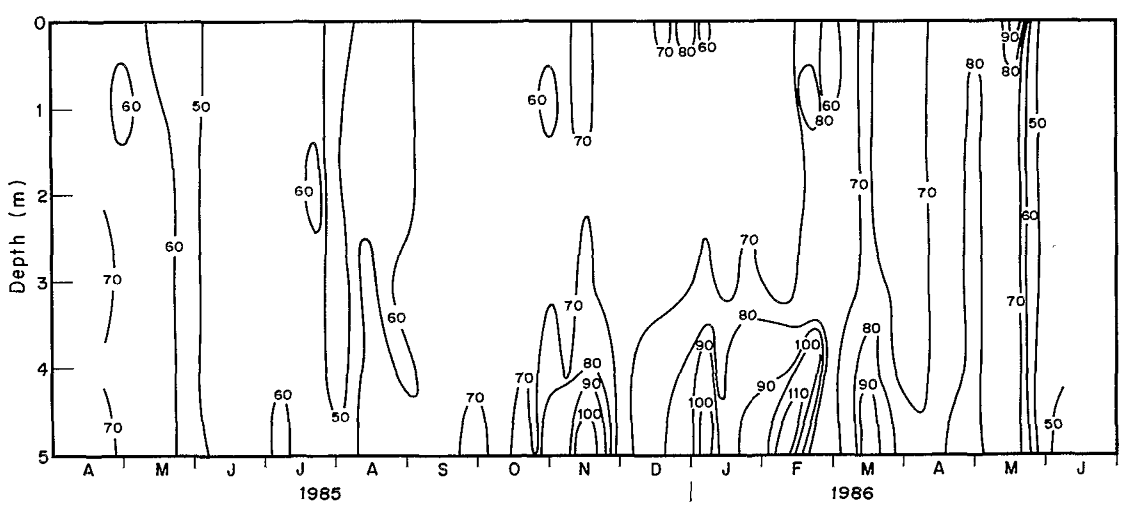

FIG. 9. — Depth-time diagram of conductivity isopleths, at intervals of 10 $\mu S.cm^{-1}$, from April 1985 to June 1986.
Diagramme profondeur-temps de la conductivité (intervalle des isolignes 10 $\mu S\ cm^{-1}$) d'avril 1985 à juin 1986.

TABLE II
Annual heat budget, tropicality index, storage flux, and stability values for several tropical water bodies
Bilan de chaleur annuel, indice de tropicalité, flux de réchauffement et stabilité de divers plans d'eau tropicaux

Lake	Heat budget ($cal.cm^{-2}.yr^{-1}$)	Tropicality Index ($cal.cm^{-2}.m^{-1}$)	Non-dimensional storage flux	Stability ($g\text{-}cm.cm^{-2}$)
Monte Alegre, Brazil	3030-3427[a]	1756-1796[a]	1.17-2.46	15
Carioca, Brazl[1]	3163	2159	2.08	92
D.Helvécio, Brazil[1]	5732	2010	1.32	335
Rio Pardo, Brazil[2]	3036	1302	1.06-2.13	1.36
Lobo, Brazil[2]	2815	1436-1767	1.75	26
Valência, Venezuela[3,4]	3045-6059	2631-2789*	1.99	345-410
Titicaca, Peru-Bolívia[4,5,6]	12183-19300		1.51	
Brokopondo, Suriname[7]	3326-7012	2214-2354		21-391
Atitlãn, Guatemala[8]	22110			21500
Amatitlãn, Guatemala[8]	8510			415
Guiga, Guatemala[8]	5410			175
Lanao, Philipines[7,9]	4500-7250	2012		
Ranu Lamongan, Java[10]				70
Ranu Kindungan, Java[7,8]	ca. 3410	2100		
Victoria Uganda,Kenya Tanzania[7,11]	9000-11000	1900		
Kariba, Zambia[12]	14000-20000	1390-1846		2577
Pawlo, Ethiopia[13]	5700			
Bishoftu, Ethiopia[13]	4950			
Araguandi, Ethiopia[13]	3100			
Kilotes, Ethiopia[13]	ca.1300			

1. HENRY and BARBOSA, 1989; 2. HENRY and TUNDISI, 1988; 3. LEWIS, 1984; 4. TAYLOR and AQUISE, 1984; 5. CARMOUZE *et al.* 1983; 6. KITTEL and RICHERSON, 1978; 7. HEIDE, 1982; 8. HUTCHINSON, 1975; 9. LEWIS, 1973; 10. GREEN *et al.*, 1976; 11. TALLING, 1966; 12. COCHE, 1974; 13. WOOD *et al.*, 1976.
*Calculations based on LEWIS, 1984. a : Values for 1985-86 and 1988-89.

changes. This sensitivity is much more pronounced in tropical than in temperate lakes (LEWIS, 1987).

Short-term fluctuations of some isopleths, chiefly temperature and dissolved oxygen, show intense dynamism among layers, evidentiating partial mixtures in the water column, consequences of the sensitivity of Lake Monte Alegre to weather changes. Deeper stratified tropical lakes can present partial mixtures with some frequency (TALLING, 1969; LEWIS, 1973), and consequently a thickening of the mixed layer in a characteristic way for tropical lakes (LEWIS, 1987).

Considering the dimensions of Lake Monte Alegre, its stratification is stable enough, at least during the summer, to prevent a daily circulation. This can be explained by its geographic location and low altitude, the inexistence of strong winds with constant direction, the superficial location of the outlet, and the low water volume brought in by the dammed stream ($0.0095\ m^3.s^{-1}$) with consequent low influence on the water mass, whose residence time is relatively long in relation to the reservoir dimensions. Once the stratification is broken, its recovery is a fast event, a fact observed in this reservoir as well as in other tropical water bodies (GREEN *et al.*, 1976; FROEHLICH *et al.*, 1978).

The annual heat budget, tropicality index, non-dimensional storage flux and stability values of some tropical water bodies, including Monte Alegre, are found in Table II. Unfortunately, the heat content of the sediment was not included in the heat budget calculations since it was not evaluated. Its influence, however, might be considerable taking into account the depth of the water body. Both indices, tropicality and storage flux, are used to compare the calorific characteristics of different water bodies.

The tropicality index, which is a way to make comparable the minimum heat content of the water bodies, shows that Monte Alegre value is close to the indices of Lake Kariba, Victoria and Lobo Reservoir. The comparison of the annual heat budgets is made difficult by the variable morphometric characteristics of the water bodies, but calls the attention to the fact that the reservoir value is situated in the range of several of them. As expected, considering its dimensions, the maximum stability of Lake Monte Alegre is much lower than those of most tropical water bodies excepting Rio Pardo Reservoir.

The non-dimensional storage flux, introduced by TAYLOR and AQUISE (1984), seems to be at first sight, suitable for comparing different water bodies in relation to their calorific characteristics. However, the use of just one heat content value of each month in the index calculation in comparison with the use of weekly data lead to very different results for Lake Monte Alegre. The value 1.17 (see Tabl. II) was obtained using monthly data, and 2.46 using weekly data, resulting in the classification of the reservoir as temperate or tropical type, respectively. This indicates that for a water body with high short-term variations of heat flux, the index is not suitable. Short-term fluctuations of heat content can be frequent in small and medium sized tropical water bodies, as e.g. Lake Monte Alegre, Rio Pardo and Lobo Reservoirs (HENRY and TUNDISI, 1988). On the other hand, the tropicality index introduced by COCHE (1974) is based on the minimum heat content which seems to be more characteristic for water bodies, suggesting that this index could be more adequate for comparing tropical water bodies, mainly the smaller ones, excepting the lakes with high water level fluctuations. Both tropicality index values for Monte Alegre, calculated for 1985-86 and 1988-89, are close, the minimum heat being 5093 $cal.cm^{-2}$ for 1985-86 and 5208 $cal.cm^{-2}$ for 1988-89.

According to LEWIS' model (1983b), although it does not include reservoirs, Lake Monte Alegre, with its geographic location and low depth could be continuous warm polymictic. Actually, the detailed analysis showed that in summer the thermal stratification can last more than 24 hours. So it would belong to the discontinuous warm polymictic type. Useless to say that only the deeper region could be classified as discontinuous. As the area occupied by shallow waters is relatively large, the reservoir could be a continuous and discontinuous mixed type.

Although there are shallow equatorial lakes of the continuous warm polymictic type, as Lakes George and Chad (BEADLE, 1974; GANF and HORNE, 1975), other shallow water bodies situated near the Equator or the Tropic of Capricorn can be classified as discontinuous instead of continuous type (BEADLE, *op. cit.*; FROEHLICH *et al.*, 1978; HARE and CARTER, 1984; TUNDISI *et al.*, 1984), as would be expected according to LEWIS' model. Therefore, there are several exceptions indicating that regional dynamic climatic factors are very important, besides the static climatic factors and the hydrological features of the water bodies.

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