Consequences of fluctuations in the ambient air temperature at Lake Tanganyika — A wavelet analysis

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Abstract

We study the fluctuations of the horizontal wind speed and of both the ambient air temperature and the water temperature according to the depth. Our study clearly shows how Lake Tanganyika is thermally stratified, showing four different water layers. The study shows how waters of upper layers tend to have the same temperature as the deepest water during the dry season. The water stratification tends then to disappear completely in the dry season. The study is based on the fact that water releases energy to heat the ambient air during the dry season and absorbs heat energy during the rainy season. We analyzed the behavior of the Richardson number in order to better understand the mode of transmission of the exchanged energy between water and ambient air. Fourier and wavelet analyses show that fluctuations in the ambient air temperature should play a major role in the behavior of water and of wind and probably of many other physical processes occurring in the site of Lake Tanganyika. This work shows the existence of a very large heat reservoir that consists of the great mass of waters of the hypolimnion and of another great heat source at variable temperature that consists of the large mass of atmospheric air surrounding the lake. The heat reservoir with variable temperature, namely the atmospheric ambient air, should ultimately determine the behavior of Lake Tanganyika.

1. Introduction

Climate change, global warming, melting glaciers, and rising frequency of natural disasters, these are unmistakable signs of the degradation of our environment. We understand that the survival of the human species is closely linked to the responsible use and the conservation of natural resources, and that development will be sustainable only when we are able to control the environment that continually provides us with basic needs.

Lake Tanganyika is not only an important economic area for the African Great Lakes countries and a source of food for many inhabitants in the region, but also an extensive library to scientists around the world [1]. Many papers have been published on Lake Tanganyika [1]-[6]. In this work, we focus on some observations reported in the literature concerning the water temperature and the wind speed distributions.

The water temperature varies from 24°C to 28°C in the surface layer, and is about 23.5°C at the bottom. Water is thermally stratified. This thermal stratification in the lake varies seasonally over the hypolimnion (which is the layer of bottom water isolated from the atmosphere and in contact with sediments). The lake is characterized by a permanent anoxic hypolimnion below 100 m in the North and below 200 m in the South. According to some authors [4], the upwelling of anoxic waters leads first to deaths of fishes and then causes the proliferation of phytoplankton due to the increase of deep waters rich in nutrients in the surface layers. This proliferation of phytoplankton is reflected by a subsequent increase in fish production.

Lake Tanganyika is a freshwater lake fed by a catchment area of 220,000 km^2 that consists of many small streams and two major tributaries, namely the Ruzizi and Malagarazi rivers. Only one outlet, the Lukuga River, drains Lake Tanganyika into the Congo River. The materials from land are transported by runoff and accumulate regularly in the lake. They are evacuated only very slowly by the Lukuga River. Thus Lake Tanganyika is very sensitive to pollution [1, 5].

Winds are supposed to be the cause of the upwelling of anoxic waters to the surface [3, 4]. The strong winds of the dry season would push warmer surface waters of the southern end of the lake to the northern end; there is an upwelling from the depth to replace the loss of water in the South. The waters of the epilimnion accumulated to the northern tip then tilt the thermocline downward by gravity (the epilimnion is the surface water layer in contact with the atmosphere, the thermocline is defined as the rapid thermal transition layer between the epilimnion and the hypolimnion [4]). Winds blowing from South-East intermittently during the dry season would also be responsible for the thermocline oscillations. A counter-current is established below the thermocline toward the South in the opposite direction to the winds and the cycle begins again in the South. Stratification and thermocline completely disappear at the South end and become very weak throughout the southern basin, whereas in the North thermocline and stratification persist throughout the dry season.

Naithani *et al.* [4] have concluded their analysis on the basis of observations made by scientists of the FAO/FINNIDA at Mpulungu, Zambia, at the southern end of the lake from 1 April 1993 to 31 March 1994. Bopili [6] studied the same data and has detected oscillation modes of the lake with periods of 6h, 8h, 12h and 24h. He also inferred that the oscillations of the lake should go in resonance with wind pulses when the wind speed reaches a certain value. This behavior of the lake has also been suggested by other scientists [4]. We then realized that data from FAO / FINNIDA can still reveal important aspects on Lake Tanganyika. Indeed, the previous studies on Lake Tanganyika [1, 6] indicate that the temperature of the hypolimnion waters remains constant throughout the year despite of variations in the temperature of surface waters. The role of the great mass of these deep waters has not been sufficiently discussed in the literature. Without wanting to revise the results already obtained, especially the role of winds in the mixing events, the present study aims to analyze the possible consequences of the existence of this large quantity of heat in the hypolimnion.

2. Data Analysis and results

2.1 Analysis of the amplitude of fluctuations in water temperature

We study the same data in order to better understand the consequences of fluctuations in the ambient air temperature during the year. These data consist in time series of values of several physical quantities measured every 3 hours, without interruption, for a whole year from 1 April 1993 to March 31, 1994. These quantities are the horizontal wind speed, the ambient air temperature and water temperatures at the depth of 1 m, 5 m, 30 m, 50 m, 70 m, 90 m, 110 m, 150 m, 200 m, 250 m and 300 m.

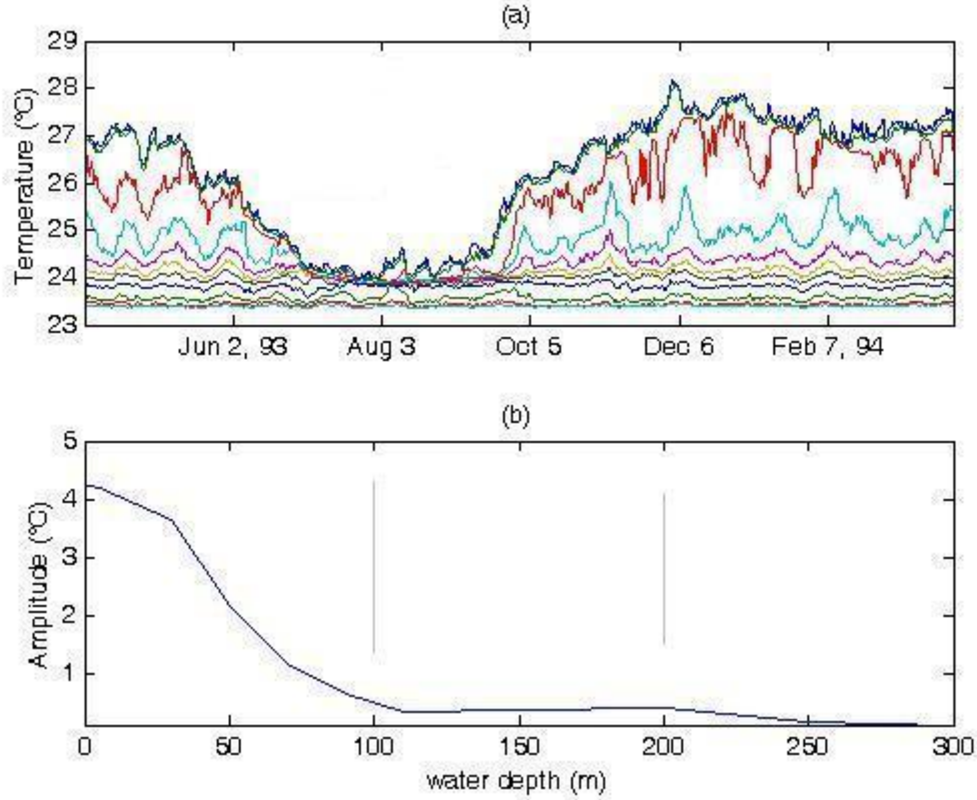

Figure 1: (a) Variation of temperature in Lake Tanganyika at the depth of 1m, 5m, 30 m, 50 m,70 m, 90 m, 110 m, 150 m, 200 m, 250 m and 300 m, from 1 April 1993 to March 31, 1994; (b) Variation of the amplitude of temperature fluctuations in Lake Tanganyika as a function of depth..

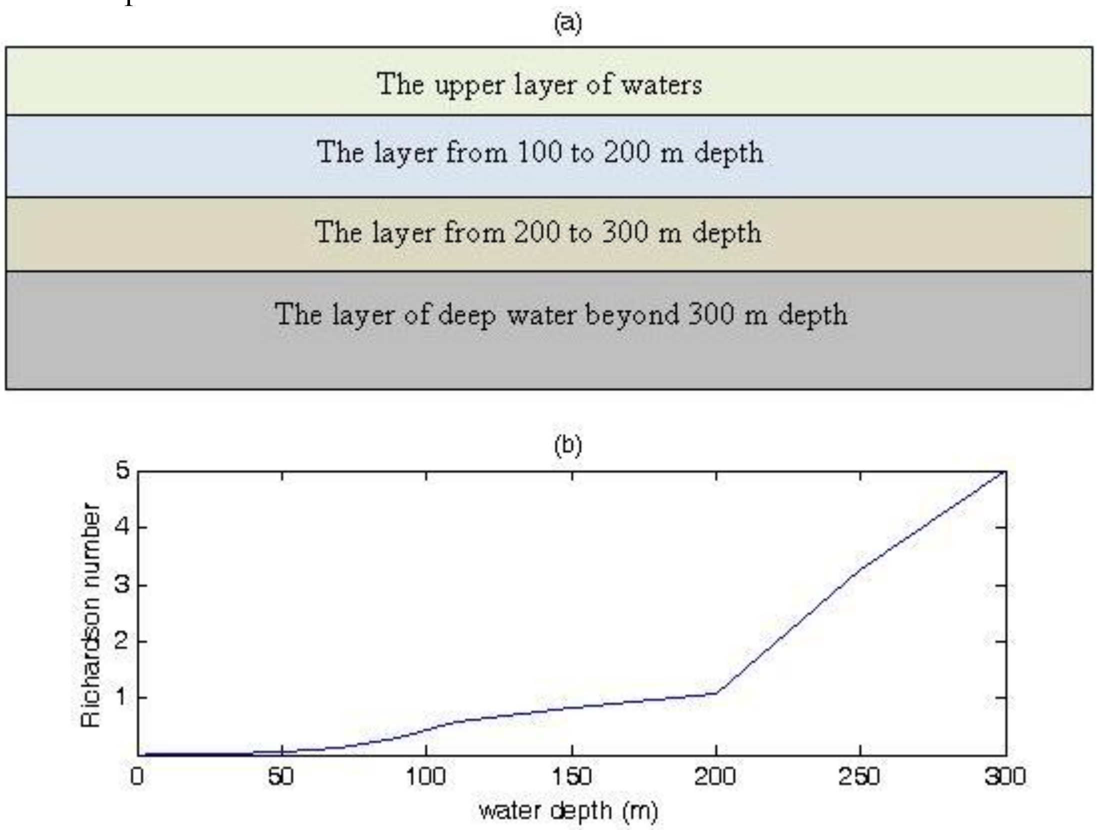

Figure 2: Thermal stratification of Lake Tanganyika.

All time series show that the lowest value of temperature is reached during the dry season between July 15 and August 16, while the highest temperature in all series is obtained during the rainy season. We call "amplitude of temperature fluctuations" at a given depth, the difference between the highest value in temperature and the lowest value obtained at this depth during the year 1993-1994. The amplitude of fluctuations in temperature should not be confused with the temperature dispersion around the average temperature at any time during the year. Figure 1(a) shows the variation of temperature in Lake Tanganyika at each depth from April 1, 1993 to March 31, 1994. Each point of this figure is an average of eight consecutive measurements of temperature. Each temperature measurement was performed every three hours. Figure 1(b) shows the variation of the amplitude of temperature fluctuations as a function of water depth. The behavior of the amplitude of temperature fluctuations (Figure 1(b)) suggests the existence of four layers in the waters of Lake Tanganyika, namely: (i) The layer of surface waters to a depth of 100 meters, characterized by a relatively high amplitude of temperature fluctuations which rapidly decreases with depth; (ii) An intermediate layer between 100 meters and 200 meters deep with an amplitude of temperature fluctuations of about 0.4°C that does not change with water depth; (iii) The layer of water from 200 meters to 300 meters deep, for which the amplitude of fluctuations decreases slowly with depth until zero; And finally (iv) the layer of deep waters below 300 meters, where the temperature does not change throughout the year (the amplitude of temperature fluctuations is almost zero). In Figure 1(b), vertical bars are used to separate the stratification layers in the lake. Figure 2(a) is an illustration of the thermal stratification of Lake Tanganyika. Figure 2(b) shows the behavior of the Richardson number as a function of water depth.

Because the thermal energy indirectly affects mixing very strongly through its influence on water density, stratification layers can be described in terms of thermal energy stored in the disordered motion of atoms and molecules. A specified column of water at a given depth possesses a thermal energy amplitude $\Delta Q = m\, c\, \Delta T$ defined as the difference between the maximum and minimum thermal energy stored at this depth during the year. ΔT is the amplitude of temperature fluctuations in the water column and c is its specific heat. The potential energy of a thermally stratified water column is defined as the potential energy of the water column in the situation where the temperature is on the one hand the same within the column water, and on the other hand equal to that of deep water. According to this definition, $\Delta U = m\, g\, h$ is the potential energy of a water column of mass m at the depth h. We define (thus not in absolute manner [7, 8]) the Richardson number (Ri) as the ratio between the potential energy of a water column and the total amount of kinetic energy dissipated by the same water column during its turbulent motion. We assume an ideal conversion of heat to mechanical energy, and propose that the amount of heat released from a water mass at a certain depth h is completely transferred to the ambient air through the water flow. This is obviously a violation of the second law of thermodynamics. The expression of the Richardson number is then greatly simplified and idealized as follows [9]:

$$Ri = \frac{g\, h}{c\, \Delta T} \qquad (1)$$

where g is the ordinary gravity. In agreement with observations, we assume that the lake stratification completely disappears during the dry season. Thus, the reduced gravity which is calculated between the ambient air and the water at any depth of the lake is approximately equal to the ordinary gravity.

2.2 Behavior of the ambient air temperature

Figure 3(a) presents the variation of the horizontal wind speed from April 1, 1993 to March 31, 1994, and Figure 3(b) shows how the temperature of the ambient air can remain for a long time lower than that of bottom waters during the cold season between June and September. One can observe in the temperature fluctuations of the ambient air from June through September, during the dry season, that the ambient air temperature is often lower than that of water at 300 m depth for fairly long periods, while from November to March, during the rainy season, the temperature of the ambient air is sometimes lower than that of water at 300 m depth for short periods.

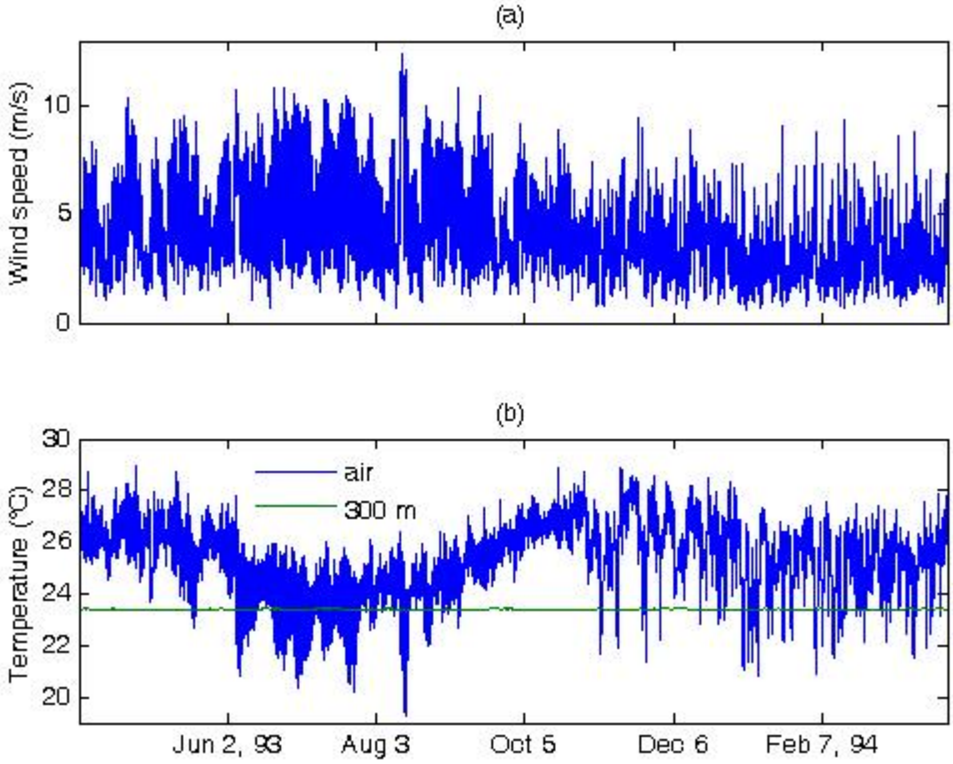

Figure 3: Fluctuations of (a) the horizontal wind speed, and (b) of the ambient air and the 300 m deep water temperature from 1 April 1993 to March 31, 1994.

2.3 Fourier analysis and wavelet analysis

The disappearance and reestablishment of thermal structures in Lake Tanganyika as well as the possible temporal and frequential correlations should be detectable both in the Fourier and the wavelet spectra of time series. In addition, these analyses should also reveal the behavior of the lake that occurs when the ambient air temperature rises above or when it falls below that of the hypolimnion.

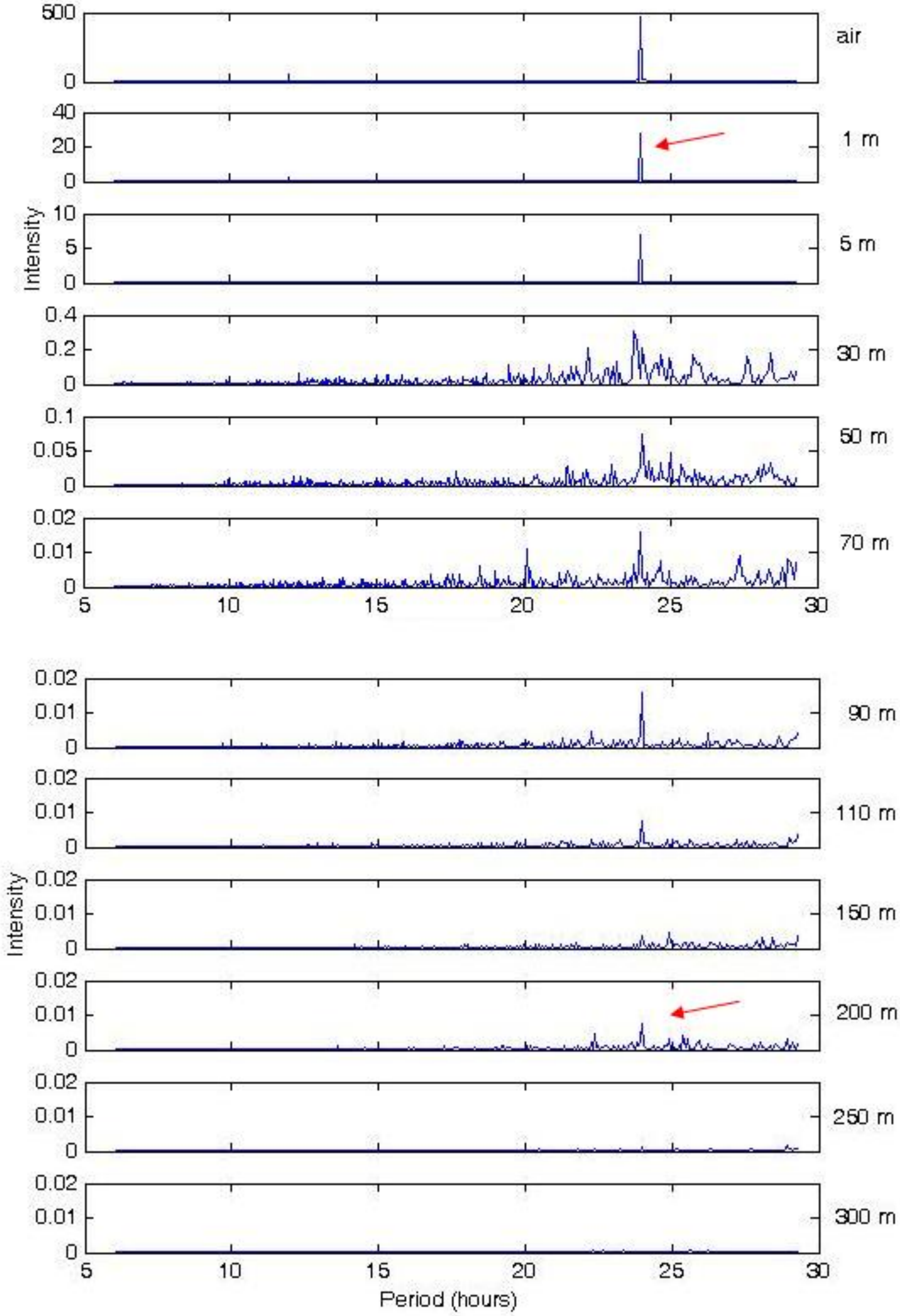

Figure 4: Fourier spectra of temperature fluctuations in Lake Tanganyika (Short-period components).

Fourier analysis allows a rapid analysis of relevant frequency ranges. The wavelet analysis should not only show the specific frequency components in the fluctuations at each depth, but should also demonstrate that phenomena related to these particular components actually occur either during the coldest period of the dry season or during the warmer season.

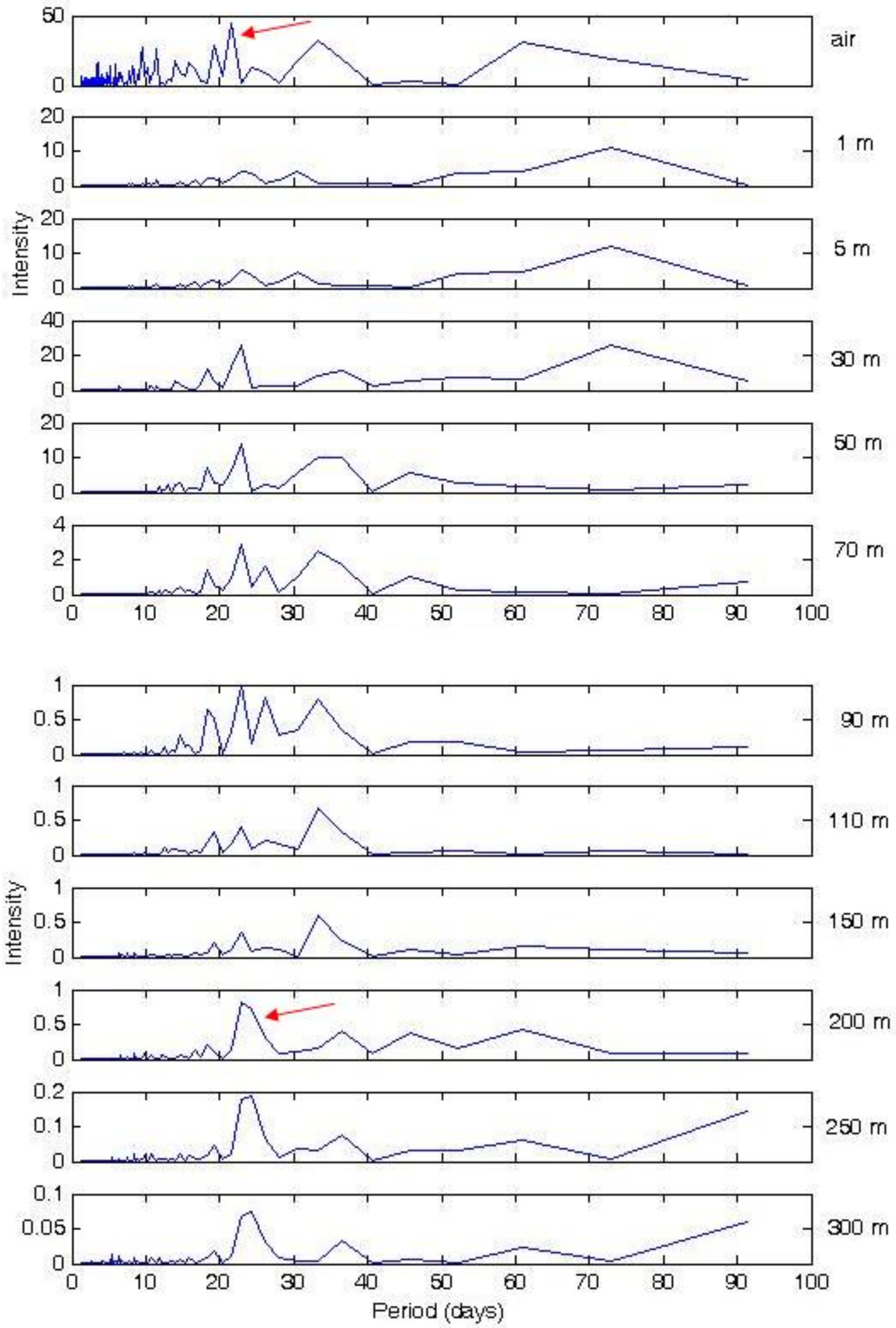

Figure 5: Fourier spectra of temperature fluctuations in Lake Tanganyika (Long-period components).

Indeed, the description of an event in the frequency domain complements the temporal description. The different phenomena present in the event having not necessarily the same rate of appearance, the introduction of the frequency concept will allow to distinguish them. The temperature fluctuations, described by a time function $s(t)$, may be the result of a superposition of several phenomena that differ from each other by their frequency of occurrence over time.

Two mathematical approaches have been considered for describing wind-generated surface waves. Some authors suggest describing the random stochastic behavior of these waves as a sum consisting of a full spectrum of simple harmonics of various frequencies. Others describe these waves as a succession of stochastic wave groups of varying heights [10]. The wave groups are transient events localized in time, while the wave spectrum is a mathematical representation in simple harmonics that integrates the whole extent of time. The first concept is the basis of Fourier analysis. The wavelet transform leads to localized time-frequency information and thus allows the analysis of wave groups. The advent of wavelet transforms has significantly increased the potential realm of data analysis [11, 12].

We present in Figures 4 and 5 the square of the Fourier transform of each time series of temperature fluctuations. Two period ranges are distinguished in the various spectra, namely the domain of short-period components or diurnal components, and the domain of long-period components (or intraseasonal components). Figure 4 presents short-period components. Diurnal components appear better resolved and more intense in the air and in surface waters; they become less intense and then turn into noise in deep waters. There are an 8h period, a 12h period and a 24h period components. The fluctuations of the ambient air temperature present a 24h period component (as indicated by the arrows in Figure 4) which is about 8 times more intense than the 12h period one, and a 12h period component which is about 12 times more intense than the component of 8h period. We will not insist on the behavior of the component of 8h that could be less accurate because it is too close to 2*dt, since the sampling period dt is 3h.

A Fourier analysis of long-period components reveals two distinct trends (as indicated by the arrows in Figure 5), namely the behavior at the upper waters above 100 m depth and that of deep waters between the depth of 200 m and 300 m. We particularly note (as indicated by an arrow in Figure 5) that the intensity of observable long-period components in surface waters rapidly decreases with depth. We also observe the appearance of Fourier components in the spectra of temperature fluctuations at a depth of 200 m, 250 m and 300 m, specifically the component with a period of 25 days. This is also indicated by an arrow in Figure 5. It remains to see whether we can relate these components to the disappearance and the reestablishment of the thermal structures in the Lake Tanganyika. This is why we analyze the modulus of the wavelet transform of each time series, especially in the frequency range suggested by the Fourier analysis. Thus, we limit the wavelet analyses in the domain of oscillations with periods between 10 days and 40 days. Clearly, this excludes from the present study certain interesting phenomena, which may be the subject of future studies, such as internal Kelvin waves, whose existence in Lake Tanganyika was suggested by some authors [13].

Figures 6 and 7 present the square of the wavelet transform of each time series of temperature fluctuations. We use a Morlet wavelet for the analysis. Figure 6 presents spectra of short-period components. The periods of 8h, 12h and 24h are prominent in this frequency range. These diurnal oscillations, especially that of the 24h period, persist during the whole year. The ambient air temperature fluctuations show diurnal components with a strong intensity during some moments in the dry season, and with a moderate intensity during the other periods of the year. The short-period components behave differently in the spectra of the water temperature. They persist during the whole year nearly with the same intensity at depth of 1 m and 5m. However they decrease in intensity as the water depth increases and completely vanish in deep waters below 30 m.

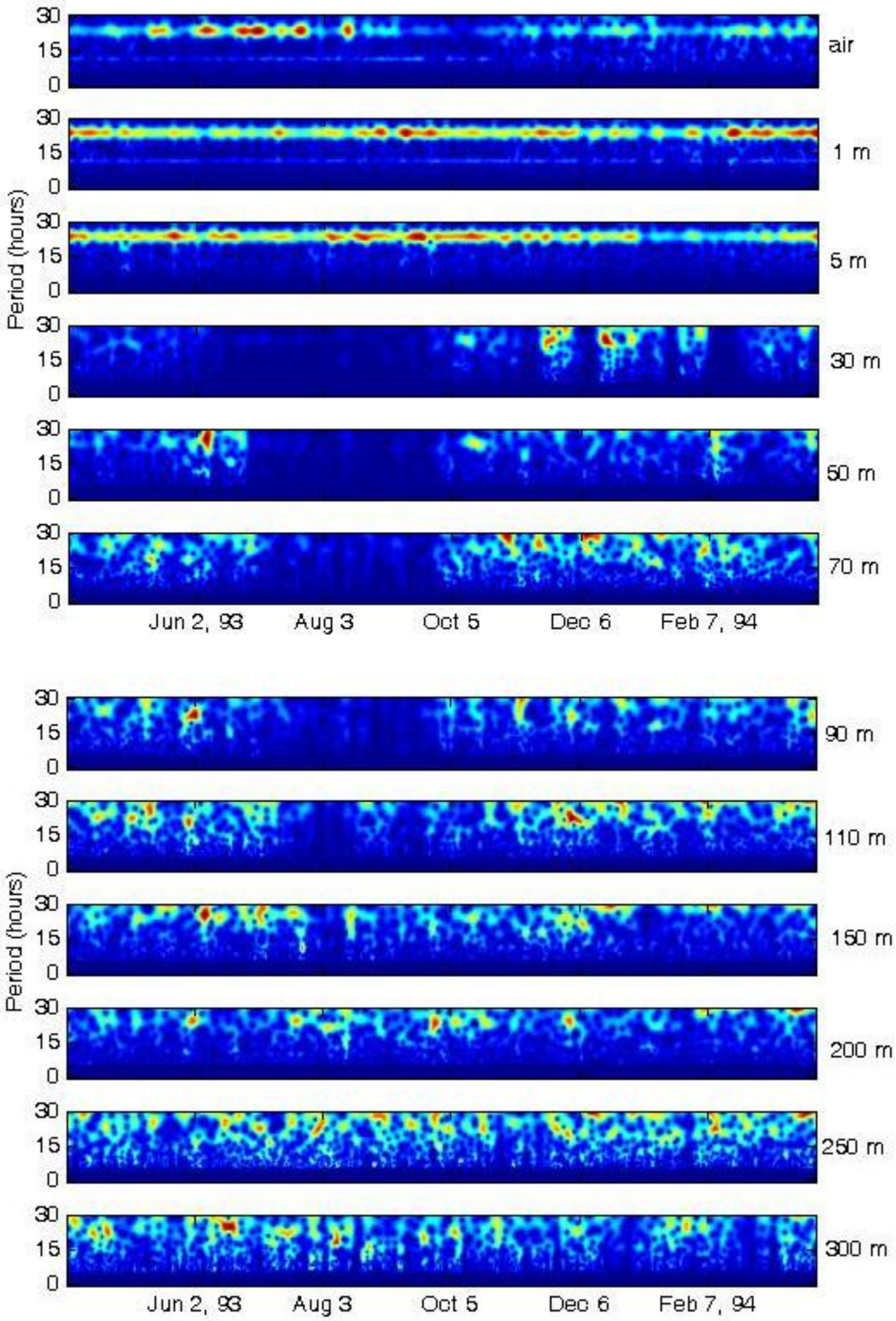

Figure 6: Wavelet spectra of temperature fluctuations in Lake Tanganyika (Diurnal components).

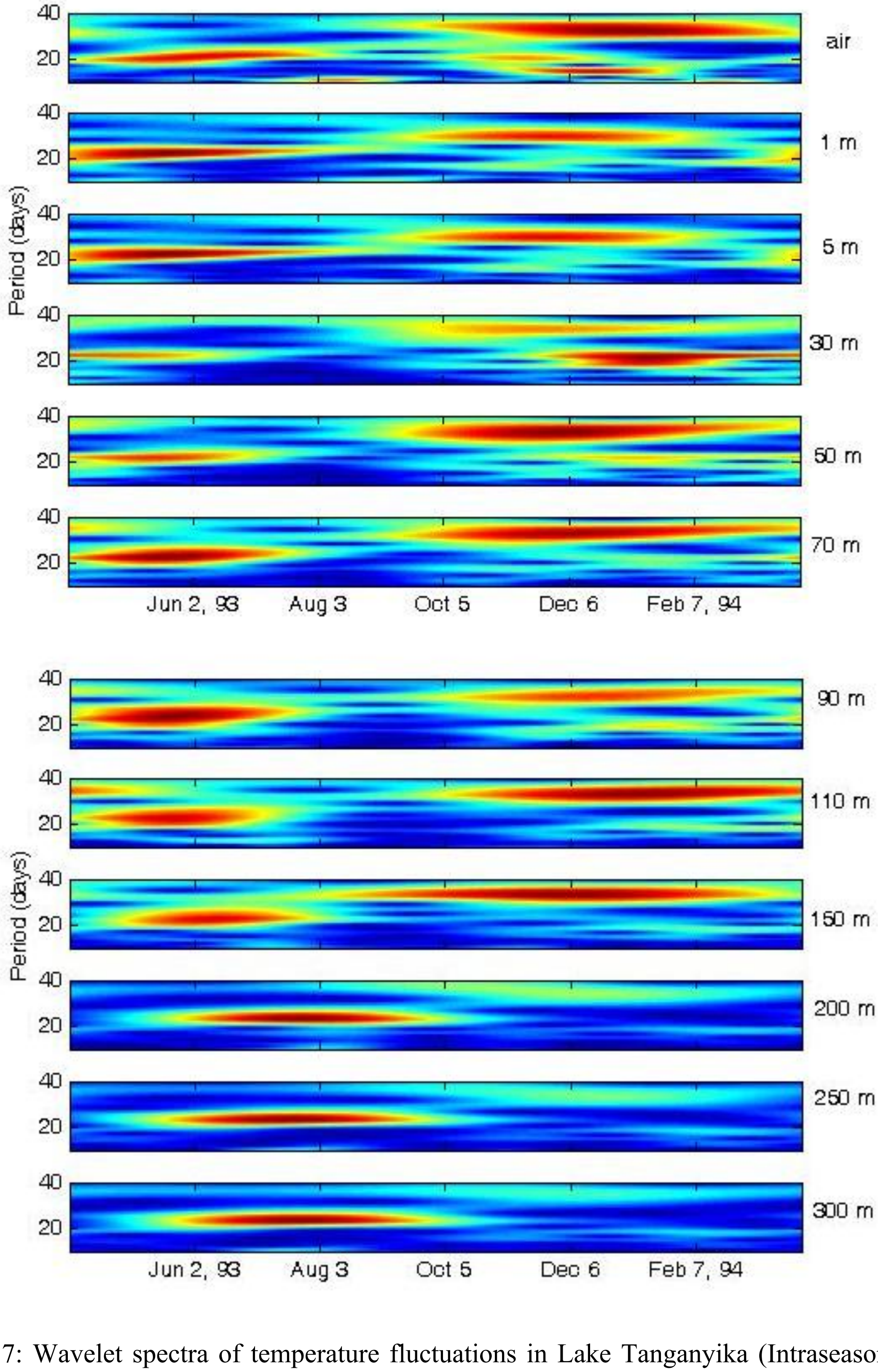

Figure 7: Wavelet spectra of temperature fluctuations in Lake Tanganyika (Intraseasonal period components).

Figure 7 presents intraseasonal components with periods comprised between 10 and 40 days. The wavelet spectra of the water temperature time series show two main wave groups that are localized differently in time depending of the water depth. In the spectra for water temperature above the depth of 100 m, one of the wave groups shows a period of about 25 days and extends from April to July, and the second wave group presents a period of about 35 days and extends from October to March. The spectra for the water temperature at the depth of 150 m shows that the wave group of the period about 25 days extends from the beginning of May until the end of July, while the second wave group of the period about 35 days extends from the beginning of August until the middle of March. The spectra for the water temperature at 200 m, 250 m and 300 m show that the first wave group of the period about 25 days runs from early June until late September (as indicated by an arrow in Figure 7), and the second wave group of the period about 35 days is less intense than the first one and extends from the beginning of August until the middle of March as in the spectra at the depth of 150 m.

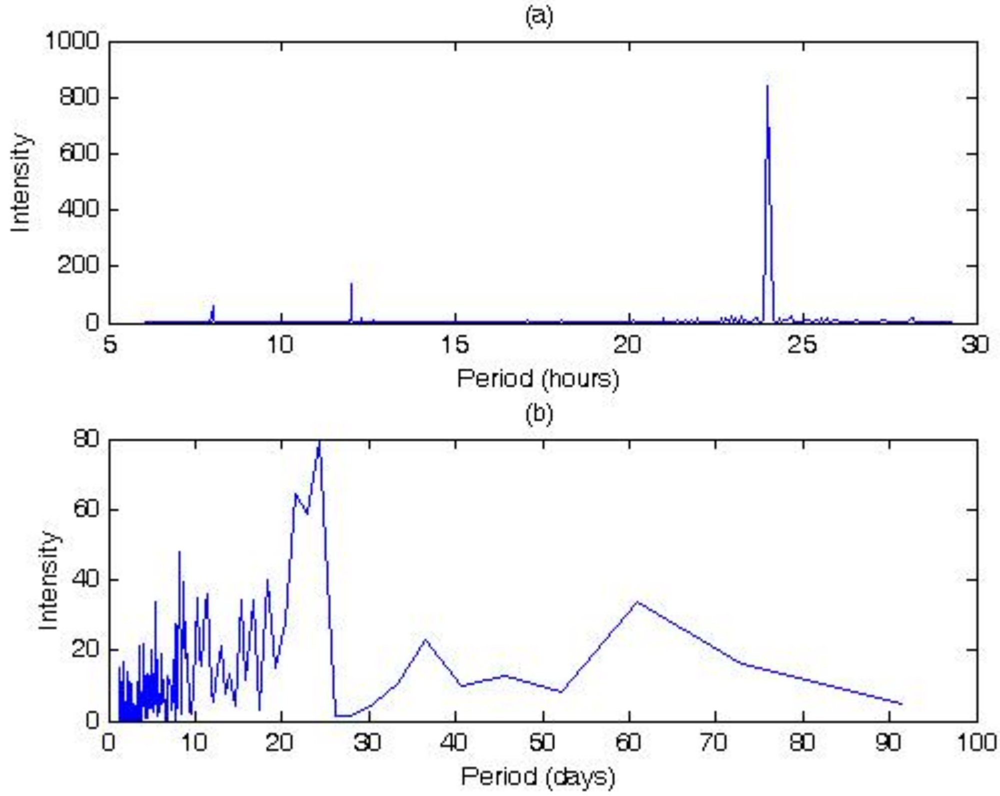

Figure 8: Fourier spectra of fluctuations of the horizontal wind speed: (a) diurnal and (b) intraseasonal components.

Figure 8 shows the Fourier spectrum of the time series corresponding to the fluctuations of the horizontal wind speed. Three components (8h, 12h and 24h) dominate the short-period domain (Figure 8(a)). The component of 24h is 4 times more intense than that of 12h, and the component of 12h is about 3 times more intense than that of 8h. The long-period domain shows components of about 25 days, 35 days and 60 days with a relatively low intensity compared to the short-period components (Figure 8(b)).

Figure 9 shows the wavelet transform of the time series corresponding to the fluctuations of the horizontal wind speed. The 24h period component dominates the short-period domain (Figure 9(a)). It is relatively more significant between May and October with two peaks of high intensity in July. The behavior of this component indicates that winds occur intermittently. The components of 8h and 12h are low and remain masked by that of 24h. The long-period domain is marked by a wave group of period between 20 days and 25 days. This wave group extends from April to August (Figure 9(b)). Another wave group of lower intensity and whose period varies between 30 days and 40 days occurs from October until February.

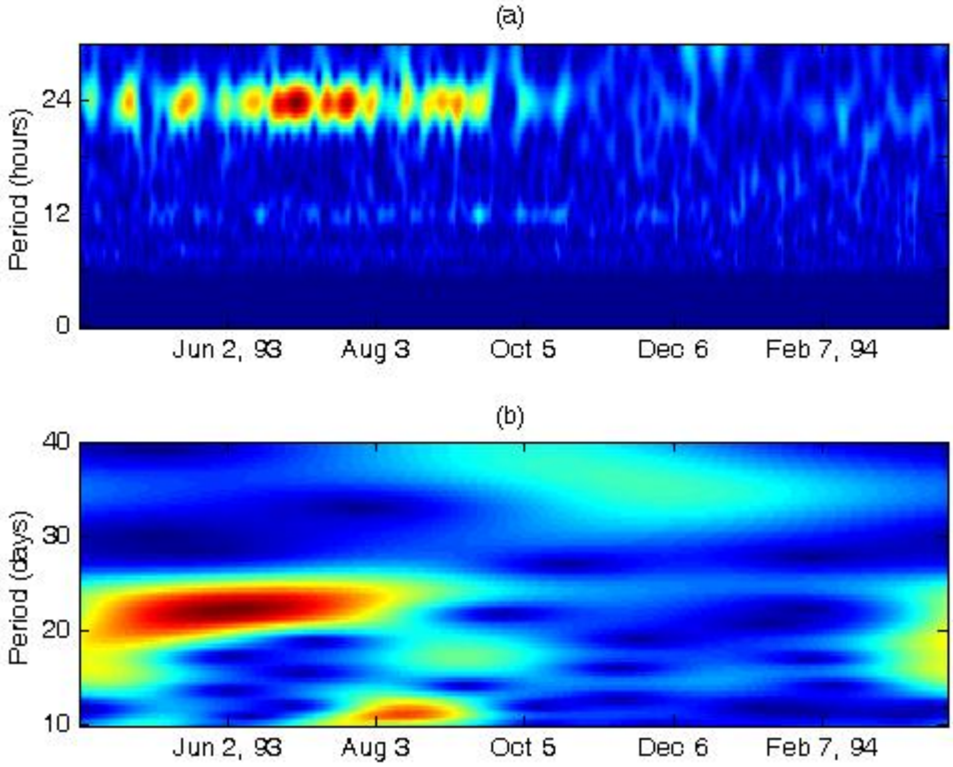

Figure 9: Wavelet spectra of fluctuations of the horizontal wind speed: (a) diurnal and (b) intraseasonal components.

3 Discussion

The behavior of short-period components in the wavelet transform of various time series shows free fluctuations of the temperature and of the wind speed at Lake Tanganyika. The short-period fluctuations can be considered as a superposition of simple harmonic oscillations of period of 8h, 12h and 24h. However we noted that these short-period components do not persist throughout the year in the spectra corresponding to the horizontal wind speed. They appear only during the dry season. We also noted that the temporal position of peaks in the spectra of short-period components for the wind speed do not necessarily match at the position of peaks in the spectra for temperature fluctuations (Figure 6 in air, at a depth of 1 m and 5 m, and Figure 9(a)). Our observations show that the short-period components of both fluctuations in the temperature and in the wind speed seem to be free and independent of each other.

The wavelet transform of the various time series reveals monthly fluctuations for the temperature and the wind speed. These fluctuations occur as groups of oscillations with a period of 20-25 days from the beginning of the dry season until September, and with a period of 30-40 days from the end of the dry season until the end of March. We also noted that the position of these groups of oscillations on the time axis (April 93 - March 94) varies from one time series to another. The wave groups with a period of 20 to 25 days extend from April until early August for both wind speed and temperature above the depth of 200 m. These wave groups are spread over time from early June until the late September for the temperature fluctuations between 200 m and 300 m. The groups of oscillations with a period of 30 to 40 days have a relatively low intensity in the time series of temperature between 200 m and 300 m. Naithani *et al.* [3] made the same observations for these groups of oscillations and had concluded that intraseasonal variability in the lake are independent of intraseasonal variability in the wind and that these oscillations can still be in the lake even if the wind had no imbedded oscillations.

In connection with the disappearance of the stratification, the oscillations with a period of 20-25 days from the beginning of the dry season until September could be related to the disappearance phenomenon of thermal layers in the lake (Figure 7). While the oscillations with a period of 30-40 days occurring from the end of the dry season until the end of March could be related to the phenomenon of reestablishment of thermal structures in the lake during the rainy season. According to the behavior of layers in Figure 1, we can suppose that the upper layer of water above the depth of 100 m should be the first to disappear during the dry season, and third layer of water between 200 m and 300 m should be the last to be dissolved in the fourth layer. In fact the layer in contact with cold and windy atmosphere should be the first to be cooled down at the beginning of the dry season, and the third layer should be the last. Temperature fluctuations in surface waters between 30 m and 50 m show frequencies and amplitudes (Figures 1(a) and 5) that indicate that other processes can interfere with the phenomena of disappearance and restoration of the thermal structures of the lake at transitions of seasons such as shown by the wavelet analysis (Figure 7). In addition, one should also try to identify the physical origin of the two wave groups around 25 and 35 days, as well as the prominent component around 60 days seen in Figure 8(b). For instance, they could be related to atmospheric convectively coupled Kelvin waves. As for the latter, one could imagine that it is linked to the Madden Julian Oscillation. At this stage, of course, this is only a guess, that demands further investigations.

Naithani *et al.* [3] had observed oscillations in the same frequency range in the fluctuations of the temperature and of the wind speed at Lake Tanganyika. They also noted the same behavior at the transition between seasons, in particular with regard to the oscillations of 20-25 days and 30-40 days. Referring to previous studies, Naithani *et al*. had clearly recognized that the structure of the lake (its geometry, its length) determines the period of these oscillations. Nevertheless, they concluded that the free oscillations in the lake are forced by intermittent winds and are in resonance with the oscillations of the wind speed. The authors relied on the fact that these free oscillations are in the same frequency range. Naithani and her colleagues did not study the behavior of the diurnal oscillations and were especially interested in the study of data collected at 30 m depth. They also demonstrated the existence of internal Kelvin waves in Lake Tanganyika [13].

The alternation of seasons influences the behavior of water temperatures in the first three layers. Indeed, the highest temperature was obtained during the rainy season, while the lowest temperature was measured during the dry season. However, the seasonal influence becomes less and less perceptible in deep water and disappears completely in the fourth layer beyond a depth of 300 m. The amplitude of temperature fluctuations is almost zero in the deep waters of the third layer. In other words, the third layer tends to disappear in the fourth layer during the dry season. This behavior suggests that, when the lowering of water temperature exceeds some limit during the dry season, the difference in temperature becomes so small between deeper waters (fourth layer) and the surface waters that the thermal stratification of waters disappears completely. This observation is consistent with previous findings.

The behavior of the amplitude of temperature fluctuations (Figure 1(b)) shows that there is heat exchange between the lake and the surrounding air when seasons change. Water releases energy to heat the ambient air during the dry season and absorbs heat energy during the rainy season. We could understand the mode of transmission of the exchanged energy by studying the behavior of the Richardson number as function of the depth of the water mass that exchanges heat with the ambient air (Figure 2(b)).

The Richardson number expresses the mode of transmission of energy in the lake. When it is less than unity, the velocity of water is relatively high, waters are getting muddled and water flow is sufficient to bring the released energy to the surface. The energy exchange between water and ambient air is then controlled by the flow and mixing of waters. When the Richardson number is comparable to unity, buoyancy is important in the water flow. And if the Richardson number is greater than unity, the buoyancy is dominant in the flow of water, in the sense that the water flow is insufficient to transfer the released energy to the lake surface.

The behavior of the Richardson number (Figure 2(b)) reveals three domains, namely, the domain of surface water above 100 m with the Richardson number well below unity (domain of convective mixings), the domain of deep water between 100 m and 200 m with the Richardson number close to 1 (domain of convective and buoyancy processes), and the domain of water between 200 m and 300 m with Richardson number greater than 1 (dominated by buoyancy processes). Figure 2(b) is in good agreement with Figure 1(b).

The temperature of the ambient air can remain lower than that of bottom waters for a long time during the cold season between June and September (Figure 3(b)). Figure 3(b) clearly shows that the temperature of the ambient air can be sufficiently lower than that of the hypolimnion waters at certain times of the year so that the ambient atmospheric air and the hypolimnion waters behave in turn with the seasons, one as a large hot source and the other as a great cold source for water above the hypolimnion. This could lead the Lake Tanganyika to behave as a thermal machine, the waters above the hypolimnion evolving between the two sources of heat. Regime change should occur at each change of season. Therefore the temperature difference between ambient air and hypolimnion water could be the motor of heat and materials flux from the bottom towards the surface during the cold season. The upwellings are indeed observed at Mpulungu during the dry season. The temporal position of the peaks of the ambient air temperature (fluctuations for the 24h period component) corresponds to the position of the peaks of wind speed (Figures 6 and 9), especially from June to September. The amplitude of the wind speed fluctuations is higher during the coldest period between June and September when the air temperature remains long below the water temperatures. These observations suggest that there is a clear correlation between the cooling of the ambient air and the increasing of the amplitude of fluctuations of the wind speed.

Naithani *et al.* [4] had observed the same behavior of water temperatures and were interested in the data obtained at a depth of 30 m. The authors emphasize the role of winds in the behavior of water temperatures at 30 m. For this reason they studied the free oscillations of Lake Tanganyika using a hydrodynamic model of forced oscillations present in the wind-stress. The model predicted the tilt of the thermocline to the north during the dry season and the oscillations of the thermocline throughout the year as they observed in wavelet spectra. They cite, however, other phenomena that could also explain the behavior of water temperature, namely evaporative cooling and convective mixings.

Many authors [1]-[4] have observed the disappearance of thermal stratification of Lake Tanganyika during the dry season. They observed the upwelling of nutrients from deep waters in the extreme south of the lake during this time of the year. According to these authors the strong southerly winds tilt the thermocline and are responsible both for the upwelling of deep waters from the hypolimnion and the activity of seiches on the lake surface. Thus, according to these authors [1, 2, 14], all the processes involved in upwelling of nutrient-rich waters are important for the maintenance of the pelagic food web.

The present analysis indicates that the heat reservoir with variable temperature at the water surface, namely the atmospheric ambient air, ultimately determines the behavior of Lake Tanganyika. Fluctuations in the ambient air temperature during the year should play a major role in the behavior of water and of wind and probably of many other physical processes occurring in the site of Lake Tanganyika.

4 Conclusion

Our analyses of the variation in water temperature of Lake Tanganyika reveals four thermal layers of water, namely the layer of surface waters to the depth of 100 m, the water layer between 100 m and 200 m, the layer between 200 m and 300 m and the layer of waters beyond 300 m. We observed that the waters of Lake Tanganyika, during cooling in the dry season, tend to have the same temperature as the water of the layer beyond the depth of 300 m. Thermal stratification of Lake Tanganyika should completely disappear when the lowering of the water temperature exceeds a certain limit during the dry season. When the ambient air temperature falls below that of water during the dry season, heat and materials fluxes are established from deep waters to the surface to heat the ambient air. This heat exchange between the lake and the surrounding air would then occur through convective mixings or buoyancy processes according to the depth of water.

Thus, disappearance of thermal layers and upwelling of deep waters to the surface are supposed to be consequences of cold dry seasons on Lake Tanganyika.

We detected simple harmonic oscillations of 8h, 12h and 24h in the temperature fluctuations and in those of wind speed. We also detected in both time series intraseasonal wave groups of 20-25 days during the dry season from April to September, and others wave groups of 30-40 days during the rainy season from September to late March. We attribute the first group to free oscillations induced by the disappearance of thermal layers in Lake Tanganyika during the dry season. While the 30-40 days wave groups are related to free oscillations induced by the reestablishment of thermal layers in Lake Tanganyika during the rainy season. Other phenomena related to these groups of oscillations such as water currents entrained by winds have been reported in depths between 30 m and 70 m.

We noted that diurnal oscillations and intraseasonal wave groups in the wind speed and temperature fluctuations remain free and independent of each other.

We observed that the fluctuations in the wind speed reach relatively large amplitudes between April and September. This should also be the consequence of cold dry seasons when the ambient air temperature become for a relatively long time lower than that of the hypolimnion. This work demonstrates the existence of a very large heat reservoir at constant temperature at 23.5 ° C that consists of the great mass of waters of the hypolimnion and of another great heat source at variable temperature that consists of the large mass of atmospheric air surrounding the lake. The present study proposes a new interpretation of the observations made at Lake Tanganyika based on the existence of these two great reservoirs of heat.

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