VARIATION IN SEDIMENT TEMPERATURE IN THE CLAROMECÓ CREEK BASIN ENERGY BALANCE OF THE SANDS

María Elizabeth Carbone*
María Cintia Píccolo
Gerardo Miguel Eduardo Perillo

Resumen

En este trabajo se describe el comportamiento de la onda térmica de los sedimentos de la playa del estuario del arroyo Claromecó, como así también el balance energético del mencionado ecosistema. Las mediciones fueron realizadas en forma continua y simultánea durante siete días de marzo de 1999 con condiciones meteorológicas de buen tiempo. Se analizaron datos de temperatura obtenidos a través de termistores localizados en la arena, a diferentes niveles de profundidad, 0.05, 0,15 y 0,30 m; en el agua a 0,40 m de profundidad y en el aire a 1,9 m sobre la superficie. Las temperaturas observadas en el sedimento fueron empleadas para calcular el coeficiente de difusividad térmica que resultó con un valor de 0.60 x 10 –6 m-2 s-1 para los niveles superiores. La radiación neta resultó la componente más importante con un valor promedio de 345 W m-2, le sigue en importancia el flujo de calor latente con un valor promedio de 212 W m-2,y el flujo del suelo con un valor promedio de 83 W m-2. Los componentes del balance de energía de las playas del estuario de Claromecó muestran una importante transferencia energética desde la atmósfera hacia los sedimentos.
Palabras Clave: Balance energético, Sedimentos, Estuario.

Abstract

* Instituto Argentino de Oceanografía - CC 804 Florida 4000 (8000) Bahía Blanca- Pcia. Buenos Aires Argentina ecarbone@criba.edu.ar

The thermal variation of the sediments and the energy balance components are computed for a sandy beach in the Claromeco estuary located in the south – east of the Buenos Aires province Argentina. The study covers a seven days period in March 1999. Soil, air and water temperatures were measured continuously employing thermistors at different heights and depth. An air sensor was installed in a shady, ventiled location 1.9 m above the sand. Soil temperature sensors were buried at three levels below the sediment surface at a depth of 0.05m, 0.15m and 0.30m. The water sensor was located 0.40m depth in the water column. The measurement time interval was 10 minutes. Meteorological observation were also obtained from a meteorological station located in the study area.
The calculated mean value of thermal diffusivity was 0.60 x 10^{-6} m^2 , the thermal conductivity was 1.83 W m^{-1} K^{-1} . The ground heat flux averaged is 83 W m^{-2} . The latent heat flux is 212 W m^{-2} . The mean net radiation with 345 W m^{-2} .The net radiation and the latent heat flux resulted the more important components of the balance. The components of the energy balance of the Claromeco estuary show a greater energic transference from the atmosphere to the sediments.
Keywords: Energy balance, sediments, estuary

Introduction

Estuarial ecosystems are affected by human activity. Thus, the importance of studying the physical, chemical and biological characteristics of estuaries. Such studies should include an analysis of marshes, tidal flats, water pollution, coastal management, transport of particulate matter and the dredging of channels. When it comes to analysing the physical and biological aspects of the coastal environment, it is the evaluation of the temperature presented by sediments that is particularly relevant.

Several authors have studied the physical features of the soil from different standpoints. The energy balance of the western intertidal zone of the Hudson Bay was described by Rouse et al. (1988). Their considered the patterns which characterise each season. Meanwhile, Fritschen and Ping (1990) applied the energy balance method to assess the different components of certain vegetated areas near Manhattan. Wang (1999) determined the heat flow of the soil by means of a unidimensional equation with constant diffusion. Such an equation may be applied to obtain the energy balance of the land surface based on observations carried out by remote sensors. Some authors have made a theoretical analysis of the irradiation components present in the balance of several environments (e.g. Hatfield, 1988, Camilo, 1989). In general, the study of the energy balance in different ecosystems is important to determine how solar energy is redistributed locally, creating a singular microclimate. These results enable the analysis of biological diversity in a specific ecosystem.

There is a short-term fluctuation in temperature on the upper layers of estuarial sediment. Such variations result from either the meeting of waters of different temperature during high tide, or changes in atmospheric conditions (Harrison and Phizacklea, 1987). In 1972, Tuller investigated the microclimate variations in the

energy balance of the western beaches in Santa Monica, California. This research was performed under clear sky conditions and taking into account the effect of the soil and the sea breeze. The outcome of the investigation showed quick changes in temperature on the surface due to the influence of the marked microclimatic gradient.

The objective of the present study is to analyse the thermal wave of the sands, water and air at Claromecó Beach in the south-east of the Province of Buenos Aires, Argentina. It also deals with the variations in vertical temperature gradients presented by sediments at different depths during a tidal cycle. It includes an evaluation of the heat transfer at the air-water-earth interface on the sand in autumn. At the same time, it seeks to obtain the heat balance of the sediments in order to observe the thermal dynamics of turbulent flows on the beach sand and their interaction with the atmosphere.

Methodology

The study was carried out between March 22nd and March 29th , 1999 in good weather. Sediment temperature was measured at different pre-determined depths to obtain information about possible variations and, at the same time, to collect data about variations in vertical gradients on the tidal flat and the exposure of the sediment to the direct action of the atmosphere.

Sand, air and water temperatures were gauged continually using several thermistors. Whereas one placed 1.9m above ground measured air temperature, another located 0.40m under water registered water temperature. Meanwhile, the information concerning the sand was obtained by means of thermistors situated at three different depths- 0.0.m, 0.15m and 0.30m (Figure 1).

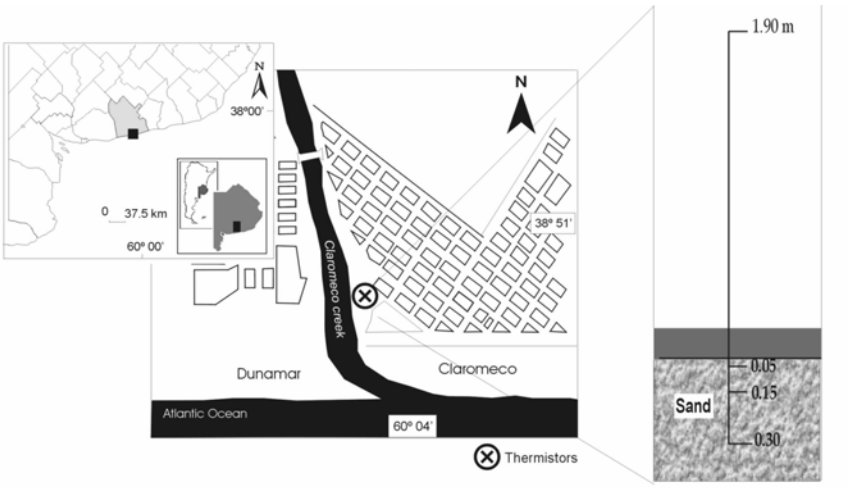

Figure 1. Location map of Claromecó Estuary and base station.

Measurements were taken at 10-minute intervals. The meteorological information was provided by a weather station set up to that end. An interocean mareograph placed in the Claromecó Creek estuary was used to gather data about the tides. In the meantime, the collected information on sediment temperature and the analysis of soil type enabled the determination of thermal diffusion. This parameter helped determine how out of step the thermal wave is deep in the sediments of the Claromecó Creek Beach.

The irradiation components of the heat balance- namely, sensitive heat, soil heat and latent heat were determined by means of aerodynamic mass formulae (Monteih, 1973, Oke, 1978). Incident solar radiation was measured with a pyrometer and long-wave radiation was calculated using a formula (Swinback, 1962). These equations will be introduced later when dealing with each item in particular.

The thermal dynamics presented by the sediments, which favour the thriving of various vegetal and animal species were analysed by determining turbulent flows. The present preliminary study on the thermal properties characterising the sediments of Claromecó Beach, and their interaction with the atmosphere, is essential for the understanding of the behaviour displayed by the different species. Moreover, it will be used in further research to determine the exact composition of this ecosystem.

Sstudy on estuarial sediment temperature

This study was carried out in the inner part of the estuary on an extensive sandy (99.48%) beach which presents outcrops of rock, especially in the east. The temperature of the sand shows a complex wave (Figure 2). On the upper layer- between 0.05m and 0.15m deep- there is an important thermal variation due to atmospheric conditions. Temperature drops at this level during the afternoon, and thermal wave amplitude decreases the deeper the layer is. At the time when measurements were taken there was a vertical gradient lower than 1ºC and both the maximum and the minimum were delayed at 0.30m of depth.

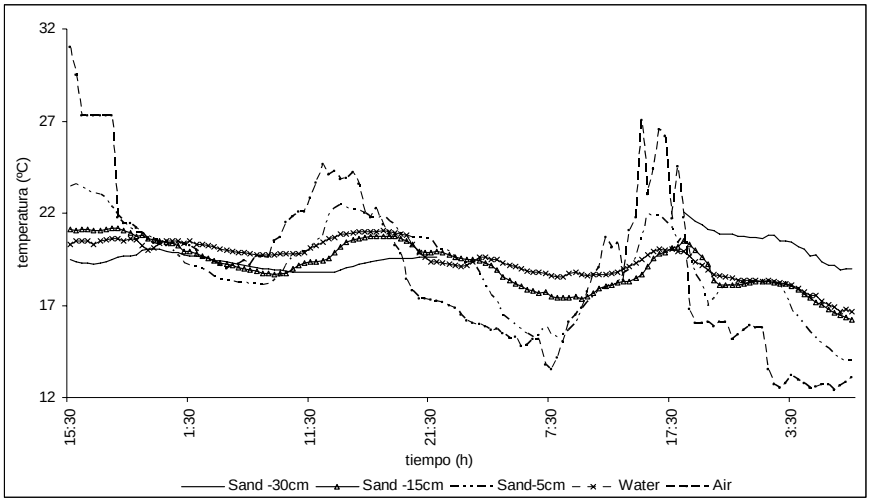

Figure 2. Thermal variation of the sediments in the Claromecó estuary.

The daily fluctuation of the thermal wave was higher at the upper levels. For example, on March 23rd the sediments close to the surface showed temperature variations similar to those of the air. Moreover, there were fluctuations of 3ºC at 0.05m of depth because of temperature changes in the atmosphere.

The cross-section of the first sand layer reveals a higher temperature amplitude at the upper levels than at the lower levels. As to the vertical gradient found in the sediments- particularly at midday when they are exposed to solar radiation- it reached 3.7ºC/m. During the hours of daylight, the surface is under the influence of the sun and therefore, susceptible to bigger temperature changes. Meanwhile, during the night sediments become gradually colder due to low-level radiation (Figure 3).

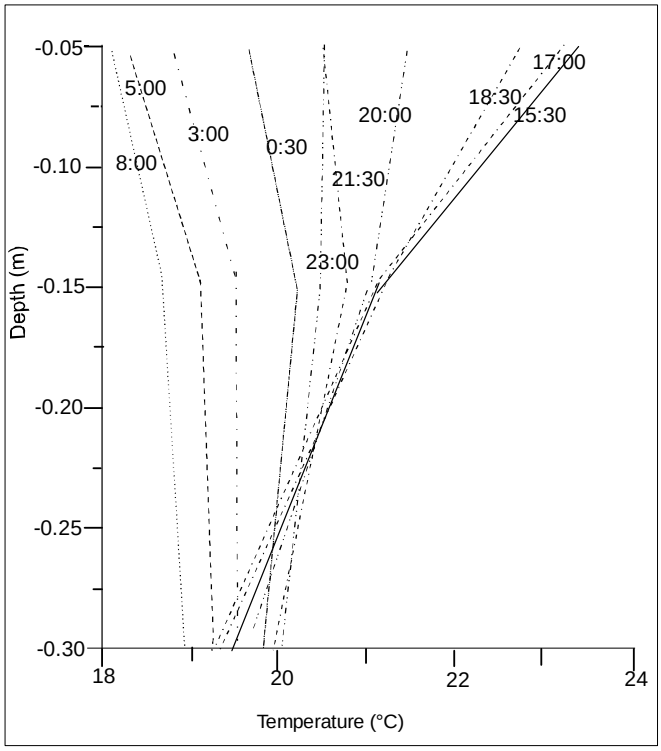

Figure 3. Vertical profiles of temperatures in the sand.

Variations in temperature are very regular in daylight. In fact, whereas the maximums are registered on the plain, which is directly exposed to the sun rays, the minimums are observed during the night. Heat transfer in the sediments involves several mechanisms, which operate simultaneously: molecular conduction, the

movement of water and air, evaporation and radiation. Thermal diffusion is related to thermal conductivity, and this - in turn- depends not only on organic matter but on the porosity and humidity of the soil as well (Oke, 1978). This coefficient shows the capacity for heat transfer and will vary according to soil type, time of day and depth. Since thermal diffusion values are difficult to gauge in the area studied, indirect measurements are preferred (Horton and Wierenga, 1983).
The solution to the thermal conductivity equation for forced oscillation is (Monteith, 1973):

$$T_{(z,t)} = \overline{T} + A_{0e}^{-z/D} \sin(\omega t - z / D) \qquad (1)$$

Where T is the mean temperature of the sediments, A_{0e} is the temperature range on the surface, ω is the oscillation frequency (2π / P) , P is the thermal wave period (86400 seconds) and D is $(2k/w)^{½}$. Thermal diffusion was determined by means of the following formula (Oke, 1978):

$$k = \frac{\pi(\Delta z)^2}{P\left[\ln\left(A_1 / A_2\right)\right]^2} \qquad (2)$$

in which A is thermal wave amplitude of the sediments at $z_1$and z_2 deep, Δz is z_1 - z_2, A_1 and A_2 are the amplitudes between the upper and lower sedimentary levels. The mean value corresponding to the thermal diffusion measured at the upper levels is 0.46 10^{-6} m^2 s^{-1} throughout the trial period. Other studies have obtained similar results using the same methodology (Oke 1978: 0.51 10^{-6} m^2 s^{-1}, Vugts and Zimmerman, 1982: 0.76 10^{-6} m^2 s^{-1}, Harrison and Phizacklea, 1987: 0.47 10^{-6} m^2 s^{-1}). The results in the present study show minimum values of 0.19 10^{-6} m^2 s^{-1} and maximum values of 0.78 10^{-6} m^2 s^{-1} at depths ranging from 0.05m to 0.15m.

At low levels, the temperature range falls and both the maximums and minimums presented are delayed. Such a delay is determined by means of the following equation (Oke, 1978):

$$(t_2 - t_1) = \frac{(z_2 - z_1)(P / \pi ks)}{2} \qquad (3)$$

in which t_1 and t_2 represent the time when the crest of the wave reaches the z_1 and z_2 depths. The average delay at 15cm deep is about 2 hours 20'.

Energy balance of the sediments

The following thermodynamic formulae were applied to calculate the components of the energy balance presented by Claromecó Creek Beach:

$$Q_n = Q_H + Q_G + Q_E \qquad (4)$$

Qn represents the net radiant flow - which is positive when there is excessive radiation, Q_H is the turbulent flow of sensitive heat (which is considered to be positive if it goes straight from the surface to the atmosphere), Q_G is the heat flow in the water or in the sand, Q_E is the latent heat flow produced by evaporation (positive) and condensation (negative). The local advective and storage heat flow was regarded as very small (= 0).Net Qn radiation was not gauged directly.

Whereas a pyrometer was used to measure low-level radiation on the spot, long-wave radiation was calculated by means of the following formula (Swinback, 1963):

$$L*_{(0)} = 0.20\sigma T^4{}_a - 171 \qquad (5)$$

in which σ is 5.67 x 10^{-8} W m^{-2} K^{-4} and T is the air temperature of ºK.

During the experiment, the winds reached an average speed of 3.13 m s^{-1} with maximum gusts of 8.9m s $^{-1}$. The latent heat flow in the sands was a residual obtained by the heat balance equation (Equation 4). The turbulent transfer of sensitive heat in the soil can be determined using the following equation:

$$Q_H(t) = \rho_a c_{ap} D_h \left[T_S(t) - T_a(t)\right] \qquad (6)$$

in which ρ_a is the air density (1.2 kg m^{-3}), c_a is the specific air heat under constant pressure (1.0 x 10^3 J Kg^{-1} $ºC^{-1}$), T_s is the temperature on the sand surface, T_a is the air temperature and D_h is the transfer speed (Munn, 1966) in m^2 which results from applying the following formula:

$$Dh(t) = 0.3\left[1 + W(t)\right]10^{-2} \qquad (7)$$

The heat flow presented by the soil is determined by means of the equation below:

$$Q_G = -\lambda \Delta T / \Delta z \qquad (8)$$

in which thermal conductivity is divided by the vertical gradient of temperature.

The coefficient λ=k/c (thermal conductivity and c = 1.13) measures the capacity the soil has to tranfer heat. Such a capacity varies according to soil type, time of day and depth of the sediment. While the minus sign indicates the direction of the flow, positive values show the flow is further away from the surface (of the sediment).

Sandy soil with a porosity of over 40% was found where the thermistors had been placed. Its thermal conductivity was 1.83 W m^{-1} K^{-1}. The sign of the thermal flow reaches the surface of the sand approximately within four hours. The maximum and minimum values are registered at 3.30 pm and 11.30pm, respectively.

The results corresponding to variation in irradiation components on the sands of Claromecó Beach are shown in Figure 4. Net radiation, latent heat flow and soil heat flow present similar trajectories. When the surface of the sediment is dry, due to direct exposure to the sun, the value corresponding to evaporation is 212 Wm^{-2}.

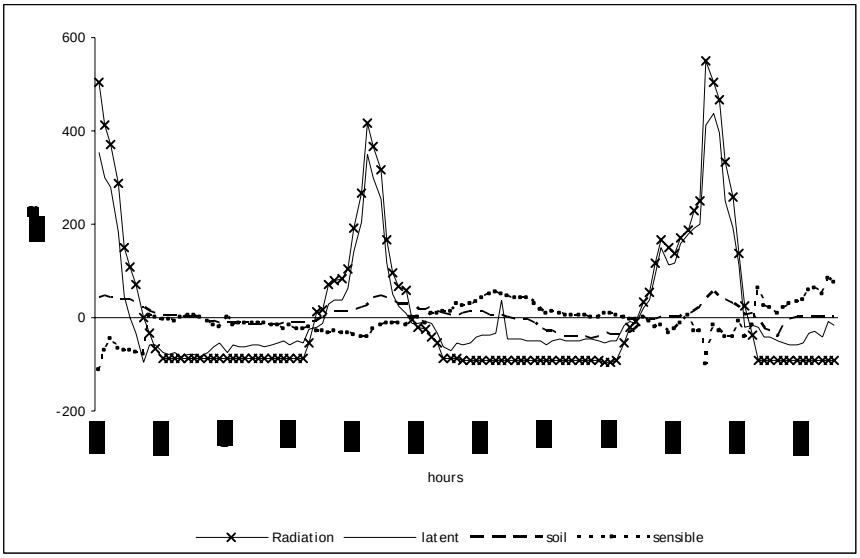

Figure 4. Energy balance of the sediments in the Claromecó beach.

The mean net radiation with 345 W m^{-2} .The net radiation (figure 5) and the latent heat flux (figure 6) resulted the more important components of the balance. The ground heat flux (figure 7) results with a mean value of 83 W m^{-2} , directed into the soil away from the sand surface at 2:30 hs. The amplitude of the sand flux is 59 W m^{-2}.

The evaporation component involves the condensation of dewdrops on the sand. Moreover, when the heat flow increases in the sediments that are not close to the surface, evaporation stops immediately and is replaced by dew - i.e., there is water condensation on the surface. Evaporation will continue if there is an increased influence of direct solar energy. This results from the fact that at 9.30 am air temperature is 2ºC higher than that of the sands. It is at this time that solar radiation evaporates moisture from the surface of the sediment and the latent heat flow corresponding to vaporization presents positive values.

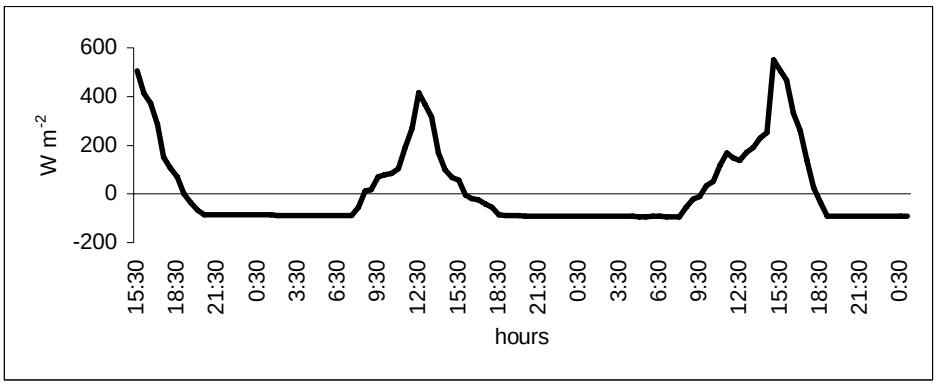

Figure 5. Net radiation flux in the sediemnts.

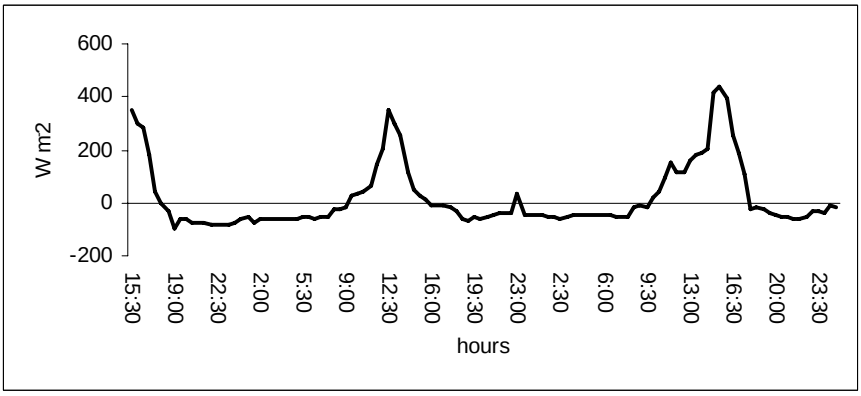

Figure 6. Latent heat flux in the sediments in the Claromecó beach.

The latent heat flow associated with the process of condensation shows minimum values of -90 W m^{-2} and -24 W m^{-2}. As regards thermal balance, latent heat is the most significant component since it involves all the mechanisms which operate on the sediments with a dry surface .

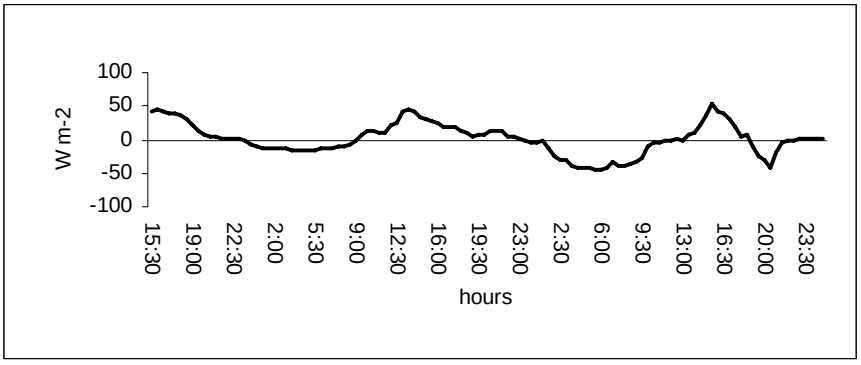

Figure 7. The ground heat flux of the sand.

The components of the energy balance of the Claromeco estuary show a greater energic transference from the atmosphere to the sediments, the heat transfer between the soil – water and air was significant, and the soil heat flux the sensible heat flux result the secondary component of the sand energetic balance.

Conclusions

Sediment temperature on Claromecó Beach is affected by direct insolation and atmospheric conditions. Thermal stratification was significant in the area studied, and the most important exchange of energy between soil and water took place around 5.30pm. The layers which are closer to the surface are the ones which presented a marked difference in temperature.

The thermal wave amplitude on the sand is higher on the upper layers (0.05m-0.15m) than at 0.30m deep. It is sinusoidal and shows a diurnal maximum and a nocturnal minimum for the set of data collected in good atmospheric conditions on the first day.

Concerning the turbulent heat flow, the balance of the sand reveals that net radiation and latent heat flow were the most important components, and that there was a greater energy transfer from the atmosphere to the sediments. The irradiation component of the latent heat flow plays a key role in the redistribution of energy on the sand, 190 W m^{-2} being the mean Q_E value on the sand surface. On the second and third day, the influence of the wind not only contributed to an increased heat transfer from the water to the sediment but to a greater evaporation as well.

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