Heat exchanges between water and sediment in extremely-shallow lagoons on the Altiplanic region of Chile

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EXTENDED ABSTRACT

Introduction

Extremely shallow lagoons of a few centimetre depths are found in the Andean region called Altiplano. These shallow lagoons are located in the desert at about 3500 masl, thus supporting the life of a unique ecosystem. Previous studies (de la Fuente and Niño 2010; de la Fuente 2014) showed that water temperature varies 20 to 30^{o}C in a day, while the air temperature varies 0 to 30 °C in a day, and that the sediments act as a heat reservoir that retains heat during the day and releases it during the night. As a consequence, the amplitude of water temperature fluctuation in a day is reduced by heat exchanges with sediments. The aim of this article is study periodic heat exchanges across the water-sediment interface (WSI) based on the combination of laboratory experiments and numerical simulations.

Materials and methods

Experiments were conducted in a tank that contains sediments collected from an artificial lagoon located near the university campus, and a water column of 4 cm was used for this experiments. Artificial lights were mounted above the water, and were periodically turned on and off to emulate the diurnal cycle. Three periods of these cycles were used: T =1, 2 and 4 hours, with a maximum downward radiation of approximately H_o=500 W/m^2. Water temperature was recorded with a standard WTW probe, while water temperature at the water-sediment interface (WSI) was recorded with temperature micro profile Unisense TP-200. Governing equations of the problem are heat conservation in the water column, and heat diffusion in the sediments with a source term that accounts for the heat absorbed in the sediments. Both equations are linked each other by temperature and heat flux continuity at the WSI (de la Fuente 2014). Accordingly to de la Fuente 2014, 65% of the solar radiation is retained in the water column, while the rest is absorbed in the sediments. The set of governing equations were numerically solving as detailed by de la Fuente (2014). Turbulence that drives heat diffusion in the water-side of the WSI was induced by convection (Necati 1977). A simplified version of heat exchanges with the atmosphere was assumed. Particularly, the upward heat flux toward the atmosphere was assumed constant equal to $H_o/2$.

As the external forcing is periodic, water temperature can also be assumed periodical, the water temperature can be written as the superposition of periodic functions. Consequently, the sediment temperature can be described by the second problem of Stokes (Batchelor 1967). Following this spectral formulation of the solution, the dimensionless number $\Pi = \left(\rho c_p\right)_w h\omega / \left(\rho c_p\right)_s \alpha\kappa_s$quantifies the influence of sediments in heat budget of water temperature. $\left(\rho c_p\right)$ denotes the heat capacity of the water or the sediments, h the water depth, $\omega = 2\pi/T$ the frequency κ_s the heat diffusion coefficient in the sediments, and $\alpha =$

$\sqrt{\omega/2\,\kappa_s}$. The limit $\Pi = +\infty$ represents the case when there is no heat storage in the sediments, while $\Pi = 0$ represents the case when there is not heat storage in the water column, and sediments captures/releases the entire heat exchanges with the atmosphere. Results are presented in terms of deviation with respect to the temporal average temperature, and the temperature scale $\mathcal{T} = H_o/\left(\rho c_p\right)_w h\omega$ was used to present the results in dimensionless form.

Results and discussion

Figure 1 shows the main results. First of all, the comparison between observed and simulated water and WSI temperatures was good. Particularly, amplitude of oscillation was well captured by the model; however, the detailed shape of the time series was not entirely reproduced by the model. This disagreement can be attributed to the simplicity of the model that considers the upward radiation constant and independent on the water temperature.

Figure 1C shows the water and WSI temperature as a function of the dimensionless number Π. Figure 1C shows that Π is able to capture the influence of sediments in the water temperature. In particular, both numerical simulations and laboratory experiments shows that larger values of Π (associated to shorter periods) produce larger values of dimensionless temperatures. Some problems were identified with water temperature measurements and $T = 30$ min that need to be confirmed.

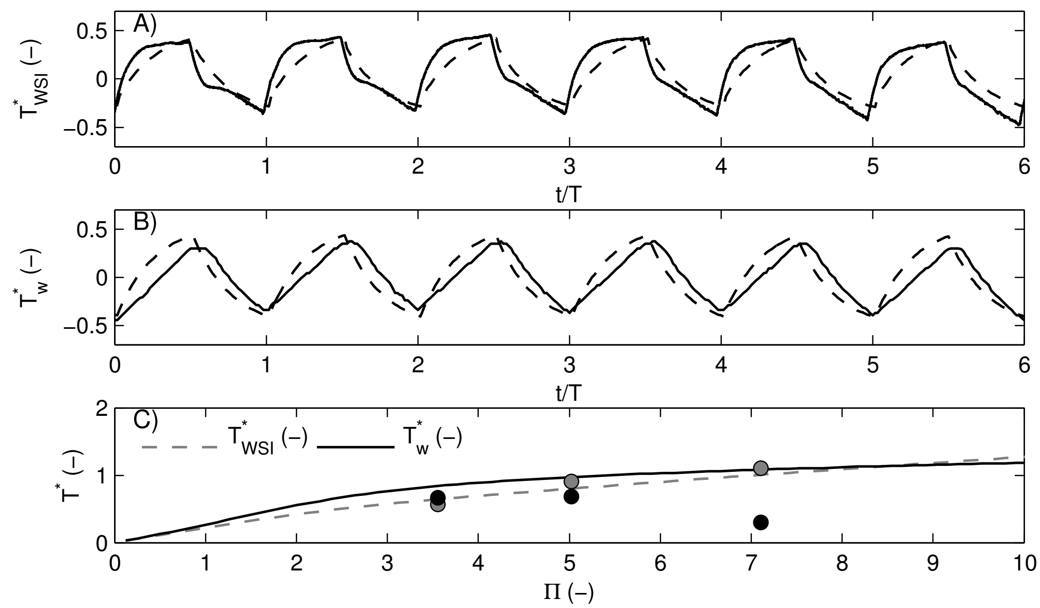

Figure 1: A) Comparison between observed (solid line) and simulated (dashed line) water temperature for experiment with T=60min. B) Same as A) for temperature at the WSI. C) Dependence of water and WSI temperature on the dimensionless number Π. Circles denotes laboratory observations (water temperature in black circles and WSI temperature in grey circles).

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