3.4 Diurnal Temperature Cycles in Shallow Water Pools

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INTRODUCTION

The growth and development of cold-blooded water organisms is strongly influenced by temperature. In many ecological models, air temperature or "bulk water" temperature is used as an input parameter. However, organisms that live close to the water surface in shallow waters, such as larvas of mosquito species, are exposed to temperatures, which differ considerably from the air or bulk water temperature (Jetten and Takken, 1994).

The objectives of the present study are: first, to execute outdoor experiments in order to get insight into the behavior of the water temperature in relation to various weather variables.

Second, to develop a simple atmosphere - water model to simulate the behavior of the diurnal water temperature cycle in natural shallow water bodies.

EXPERIMENTAL SET-UP

Three continuous measurement programs were carried out in which the fluxes of heat, mass and momentum were estimated in and around three shallow water bodies (Lucassen., 1996; Kraai, 2004; Paaijmans, 2005). Experiments were carried out in the summers of 1995 and 2003 in the Netherlands (1995: 53^{o} 0' N, 6^{o} 23' E, +11m m.s.l.; 2003: 51^{o} 58' N, 5^{o} 38' E, +7m m.s.l.) and in 2005 in Kenya (0^{o} 5'S, 34^{o} 48'E, +1200m m.s.l.).

At all locations, the mean wind profile was measured with cup anemometers at three heights (*2, 4* and *6 m*) and the wind direction with a wind vane at *6 m*. In addition, at a height of about 0.2 m above the water body, the wind speed was measured with a cup anemometer and a small hot-sphere anemometer or with a sonic anemometer.

The mean air temperature and moisture were measured at heights of *2.0, 4.0* and *6.0 m* with aspirated psychrometers. At a height of *8 m*, a 3-Dim sonic anemometer (Solent A1012R2, Gill Instruments Ltd.) and an additional fast response thermometer were installed. With 2 pyranometers (Kipp & Zonen, CM 10) the incoming and reflected short wave radiation and with 2 pyrgeometers (Kipp & Zonen, CG1) the incoming and outgoing long wave radiation were measured, at a height of about *6.5 m*.

The under water measurements were executed in small shallow water bodies (1995: 6m width and 0.3 m depth; 2003: 1m by 0.28m; 2005: 0.96m by 0.32m). A condensed outline of the 2003 experiment is depicted below in figure 1.

A stable floating system was designed with a reversed "mast" to which small glass coated thermistor thermometers (Beta G22k7 MCD8) were connected at depths of *15, 40, 90 140, 190* and *230 mm.* At the bottom of the water body, an extra soil Pt-100 thermometer and a heat soil flux plate were installed (TNO, WS 31-Cp).

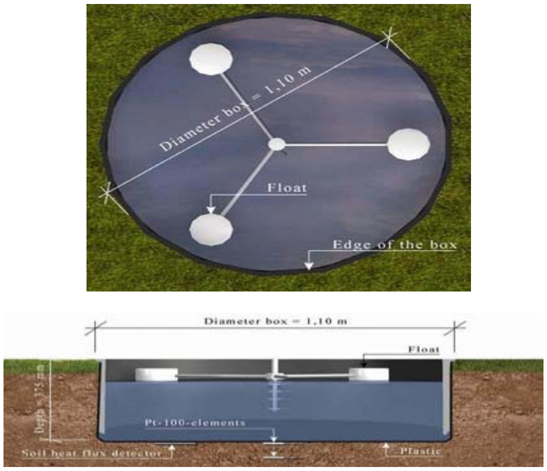

***Figure 1**: Overview of the experimental set-up of the water body of the 2003 experiment.*

MODEL DESCRIPTION

A complex 1-Dim model to simulate the water temperature of a shallow water body was designed and details of this model can be find elsewhere (Jacobs et al., 1997). As we will see later, the water temperature of the water body in Kenya behaved more or less homogeous. This means that in this special case the water body temperature can be simulated with a simple energy budget model. Below this model will briefly be described.

The energy budget of a homogeneous water body can be described by the energy budget:

$$K_{in}(1-\alpha)+L_{in}-L_{out}-H-\lambda E-G_s=\rho_w c_w \delta \frac{\Delta T_w}{\Delta t} \qquad (1)$$

where K_{in} [W m^{-2}] is the incoming short wave radiation, α [-] is the albedo of the water body, L_{in} [W m^{-2}] is the incoming long wave radiation, L_{out} [W m^{-2}] the outgoing long wave radiation at the water surface, H [W m^{-2}] the sensible heat exchange at the water surface, LE [W m^{-2}] the evaporation at the water surface, G_s [W m^{-2}] the conduction heat exchange at the bottom of the water body, ρ_w [kg m^{-3}] is density water, c_w [J kg^{-1} K^{-1}] the heat capacity of the water, δ [m] the depth of the water body, T_w [^{o}C] the temperature of the water body and t [s] is time.

The sensible heat flux, H, was parameterized by taking (Arya, 1988):

$$H=\rho_a c_p U C_h (T_w - T_a) \qquad (2)$$

where, ρ_a [kg m^{-3}] is the density air, c_p [J kg^{-1} K^{-1}] heat capacity air, U [m s^{-1}] is windspeed, C_h [-] is the dimensionless heat transfer coefficient and T_a [^{o}C] is air temperature and, the evaporation λE was parameterized by (Arya, 1988):

$$\lambda E=\rho_a \lambda U C_e (q_w - q_a) \qquad (3)$$

where, λ [J kg^{-1}] is latent heat, C_e [-] is the dimensionless mass transfer coefficient and q [kg kg^{-1}] is specific moisture content.

Equation (1) can easily be integrated and as a result is gives the homogeneous temperature of the water body.

RESULTS AND DISCUSSIONS

For 2003, for three periods (spring, summer and fall) and for three consecutive days, the water, air and soil temperature characteristics will be discussed first. In figure 2 for the three periods the course of the temperatures has been depicted.

From this result we can infer that in the water body there is a clear stratification during daytime and a clear mixed condition during nighttime. Also we can observe from figure 2 that at the water atmosphere interface the water temperature is somewhat lower during the night and deviates from the well-mixed water temperature. This deviation at the interface is caused by evaporation of the water during the night. Second, we can infer from figure 2 that there is a clear seasonal effect on the water temerature as wel as on the soil and air temperature.

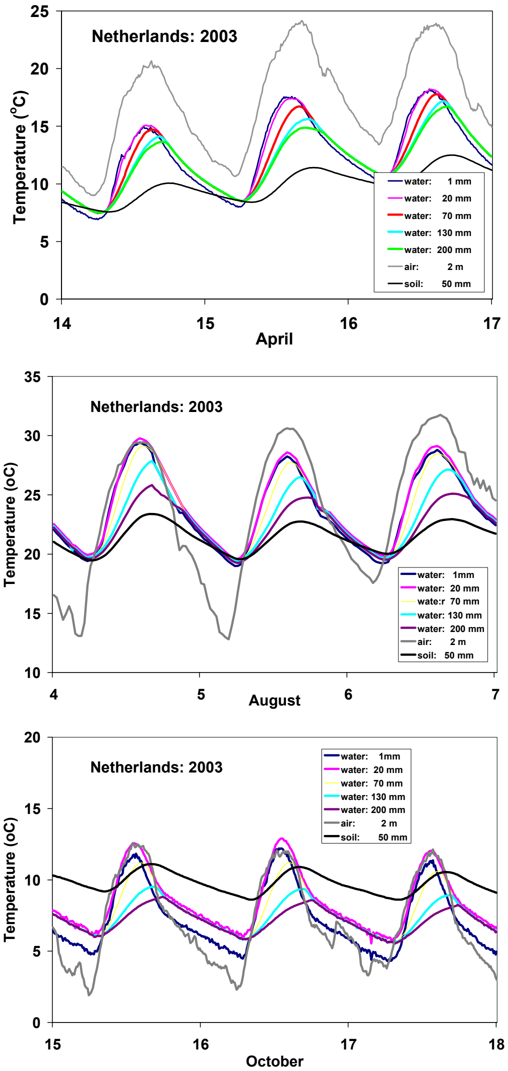

Figure 2: *Experimental results in 2003 in the Netherlands.*

The experimental results executed in Kenya, however, are quite different from those observed in a mid-latitude country. In figure 3, an example of the Kenya observations during three consecutive days has been plotted. First, no seasonal effect could be oberved which is understandable for a country near the equator.

Second, no stratification effect in the water body during daytime could be observed. This absense of any stratification effect is striking and can be caused by different effects. First, the water of the water bodies during the Kenya experiments was relatively clean. This means that most of the incoming short wave radiation is absorbed at the bottom of the water body and causes a well-mixed water condition also during daytime. Whether the clean water is the cause of the well-mixed result will be investigated in a future experiment in 2006.

A second possible reason for a good mixing is the windspeed above the water body. A strong windspeed enhances the turbulent mixing in the water (Jacobs et al., 1998). A well-mixed water body caused by a strong windspeed, however, must be rejected because the Kenya experiments were carried out under relatively low windspeed conditions ($U(2m) < 3\ m\ s^{-1}$).

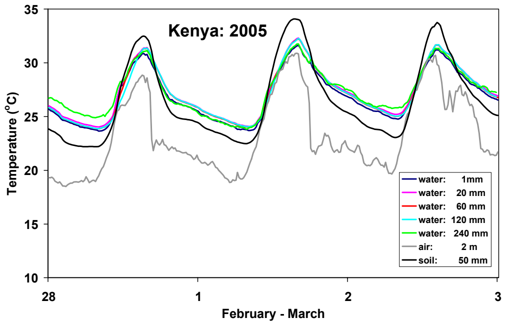

Figure 3*: Experimental results in 2005 in Kenya.*

A third possible reason for a stratification absense during daytime could be the higher solar height during most time of the day in the Kenya. This question will be investigated in a future experiment in 2006 as well.

When we compare the Kenya results with the mid-latitude results, we can observe that the Kenya results can be compared best with the Dutch results during the summer – fall period. During the summer – fall period, the soil in the Netherlands has been sufficiently warmed up which means that during this period the soil effect on the water as well as on the air temperatures can be compared best with the Kenyan conditions.

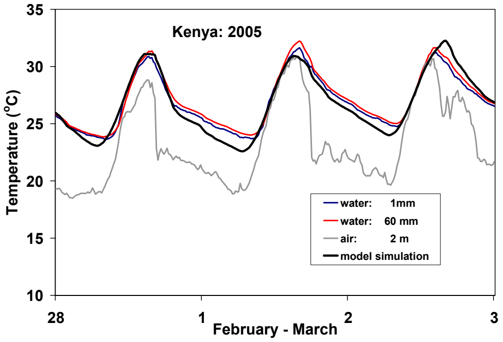

Figure 4*: Experimental and simulated results in 2005 for Kenya.*

The more or less homogeneous water temperature results from the 2005 Kenya experiments can easily be simulated with a simple energy budget model. That is why in figure 4 the experimental results as well as the simulated results have been plotted.

From the results of figure 4 we conclude that the simple energy budget model simulates the water body temperature well within about 1 K.

CONCLUSIONS

From the foregoing results and discussion, the following conclusions can be drawn:

1. During daytime a clear stratification in the water exists in a mid-latitude water body even on windy days.
2. During nighttime a clear mixed layer starts to grow from the atmosphere-water interface in a mid-latitude water body.
3. Under mid-latitude conditions, the relation between water, air and soil temperature is strongly dependent on the season.
4. The water body temperature in a tropical country behaves more or less homogeneous. Until now the reason for this behavior is not clear. Futher experiments are carried out to find out whether this behavior is caused by particles suspended in the water or by a higher solar height.
5. The Kenyan conditions are comparable best with the mid-latitude condition during the summer – fall period.

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