6.B2 Diurnal Temperature Cycles in Shallow Water Pools

Adrie F.G. Jacobs, Bert G. Heusinkveld and Krijn P. Paaijmans.

Wageningen University, Meteorology and Air Quality Group, Duivendaal 2, NL-6701 AP Wageningen, The Netherlands

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 develop a simple 1-D atmosphere/water model to simulate the behavior of the diurnal water temperature cycle in natural shallow water. The model we used is more or less adopted from the study of Losordo and Piedrahita (1991).

Second, to execute outdoor experiments in order to estimate the various model parameters and to verify the model for various different atmospheric conditions and water pools.

EXPERIMENTAL SET-UP

Two continuous measurement programs were carried out in which the fluxes of heat, mass and momentum were estimated in and around two shallow water bodies (Nieveen *et al.*, 1995; Kraai, 2004). Experiments were carried out during four months in the summer of 1995 and 2003. The locations were situated in The Netherlands (1995: Lat. 53^{o}E 00' N, Long. 6 ^{o}E 23' E, Alt. +11 m; 2003: Lat. 51^{o} E 58' N, Long. 5^{o} E 38' E, Alt. +7 m). In 1995, the dominating vegetation species was *Molinia caerulea*, a grassy type of vegetation and in 2003 it was short cut grass (*Lolium Perenne*).

At both 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 0.2 m above the water body, the wind speed was measured with a cup anemometer and a small hot-sphere anemometer. The mean 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-D 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 *6.5 m*.

In 1995, the under water measurements were executed in a ditch with still water of 6 *m* width and *0.35 m* depth and in 2003 in an artificial cylindrical water body of 1 m width and 0.28 m depth. The condensed outline of

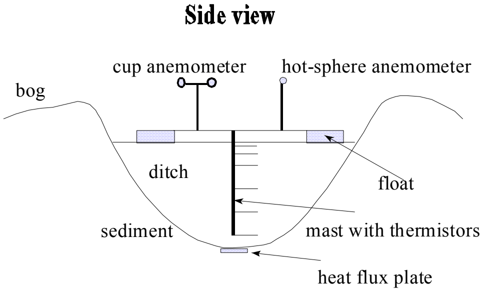

Figure 1: *Outline experimental set-up.*

the 1995 measurement layout has been depicted 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, a heat soil flux plate was installed (TNO, WS 31-Cp).

Estimates of the extinction coefficient were made weekly using Secchi disks (Preisendorfer, 1986) in 1995 and with light meters in 2003 (LiCor, type Bottemanne). In addition, occasionally laboratory tests were carried out with a photo-spectrometer for 3 wave lengths (*400, 500* and *600 nm*).

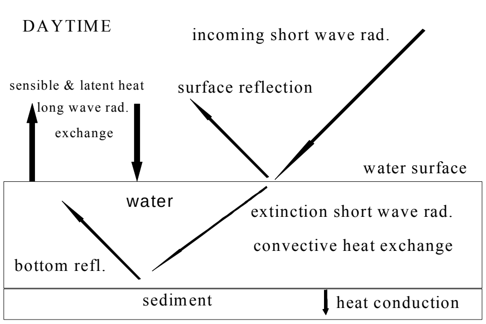

Figure 2*: Overview energy terms during daytime*

MODEL DESCRIPTION

The present 1-D model is based on the energy budget (Figure 2). Here, the driving force during daytime is the incoming short wave radiation. Immediately at the water surface a fraction ß of the net short wave radiation is absorbed (Cathcart, 1987). For the first water layer with thickness δ, the energy budget is:

$$\Delta K + L^{net} - H - LE - G_w = c_w \delta \frac{\Delta T_w}{\Delta t}$$

where, ΔK is the absorbed short wave radiation in this layer, L^{net} the net long wave radiation, H the sensible heat flux and LE the evaporation at the top of this layer, G_W the convective heat at the bottom of this layer, c_W the volumetric heat capacity of water and ΔT_W the mean temperature change of this water layer. For all other water layers the energy budget is:

$$\Delta K - \Delta G_w = c_w \delta \frac{\Delta T_w}{\Delta t}$$

The extinction of the incoming solar radiation in the water is described by Lambert Beer's law (Cathcart, 1987) in which an extinction coefficient was used as measured by the weekly Secchi-disks observations. The absorbed short wave radiation in the aquatic surface layer, $n = 1$, equals:

$$\Delta K(n=1) = K \downarrow (1-\alpha)[\beta + (1-\beta)(1-e^{-\frac{\varepsilon\delta}{xx}})]$$

and in all other water layers, n > 1:

$$\Delta K(n) = K \downarrow (1-\alpha)(1-\beta)e^{-\frac{\varepsilon(n-1)\delta}{xx}}(1-e^{-\frac{\varepsilon\delta}{xx}})]$$

where, $K\downarrow$ the incoming short wave radiation at the water surface, α the albedo at the water surface, ε, the extinction coefficient, xx correction factor for the actual path length (Höhne, 1954) depending on solar height and ratio of the direct and diffusive solar radiation, β the amount of short wave radiation immediately absorbed in the first layer and taken *45%* of the incoming short wave radiation at the water surface (Orlob, 1983; Octavio *et al.*, 1977). In the water heat exchange by convection and conduction occurs. In the present model it was assumed that no mean water flow was allowed, but that mixing was influenced by water density stratification and the wind component at the air-water interface (Bloss and Harleman, 1979). The convective heat transport was taken:

$$G_w(z) = -c_w K_w(z) \frac{\Delta T_w}{\Delta z}$$

where, the eddy diffusivity, $K_w(z)$, is a complex function of the water surface friction velocity, w^*, the depth, z, in the water and the density stratification in the water, expressed by the water Richardson number, Ri_w. More details can be found in Losordo *et al.*, 1991, and Jacobs *et al.*, 1997.

RESULTS AND DISCUSSIONS

For 1995, a period of three consecutive days has been selected (DOYS: 218 - 220) with stronger wind conditions but with a variable radiation load. The measurement results have been plotted in Figure 3 and the model results in Figure 4. During this period the maximum water depth was *0.30 m.*

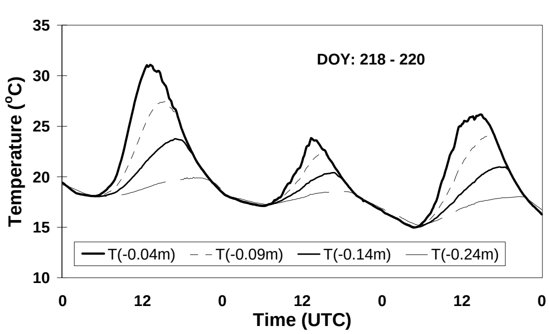

Figure 3: *Experimental results in 1995.*

The comparison between the 1995 experimental results and model simulations is that during daytime, there is a near perfect agreement. Wind causes forced convective mixing in the water. That is why it is expected that suspended fine particles in the water are well mixed. This means also that the short wave extinction coefficient is homogeneous within the whole water body. In the model simulations the extinction coefficient is assumed to be constant with depth all over the water body. This may be why in windy daytime periods the simulated stratification in the water agrees well the measured stratification.

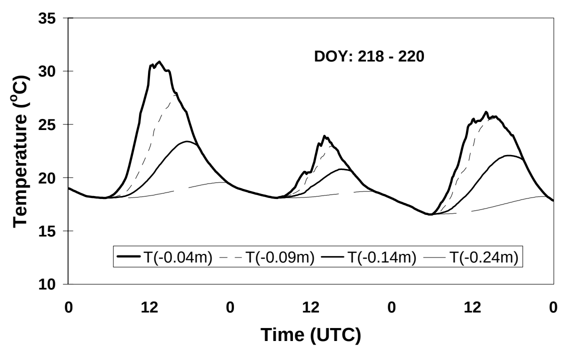

Figure 4*: Model simulation results for 1995.*

In 2003, a period of three days has been selected with about the same weather conditions and the results have been plotted in Figure 5 (DOYS: 104 - 106).

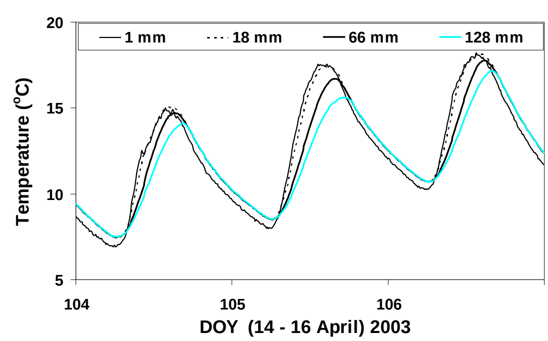

Figure 5*: Experimental results in 2003.*

The same 1-D model was used to simulate the water temperatures. The results, however, deviate from the experimental evidence considerably. It appeared that the reason for this deviation was the size of the small water body, where 3-D boundary effects have to be taken into account.

CONCLUSIONS

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

1. During daytime a clear stratification in the water exists even on windy days.
2. During nighttime a clear mixed layer starts to grow from the atmosphere-water interface.
3. In a small water body with a diameter of order of the depth, the exchange of heat to the sides cannot be ignored. During the night, the water temperature decreases faster than the surrounding soil and heat will be transported from the water to the soil.
4. The model simulations are very sensitive to the short wave radiation extinction coefficient of the water. This quantity in natural water is dependent on the suspension of fine particles. During low wind conditions the forced convection mixing is low and causes a spatially variable extinction coefficient. During windy periods, suspended fine particles are well mixed and as a consequence the short wave extinction coefficient is constant with depth as well.

REFERENCES

Bloss, G, and Harleman, R.F., 1979. Effect of wind-mixing on the thermocline formation in lakes and reservoirs. Techn Rep. 249, Ralph M. Parson Laboratory, MIT, Cambridge, MA, pp. 68.

Cathcart, T.P., 1987. Heat transfer and temperature prediction in small fresh water ponds. PhD thesis, University of Maryland, Dept. of Agriculture Engineering. pp 287.

Höhne, W., 1954. Experimentelle und mikroklimatische Untersuchungen an Kleingewässern. Abh. Met. D. DDR 4, Nr. 26, pp 56.

Jacobs, A.F.G., Jetten, T.H., Lucassen, D.C., Heusinkveld, B., and Nieveen, J.P., 1997: Daily temperature variation in a natural shallow water body. Agric. Forest Meteorol., 88, 269 - 277.

Jetten, T.H. and Takken, W., 1994. Impact of climate change on malaria vectors. Change 18: 10-12.

Kraai, A., 2004. Thermal stratification in a small water body. Msc-thesis, Wageningen University. 66pp.

Losordo, T.M. and Piedrahita, R.H., 1991. Modelling temperature variation and thermal stratification in shallow aquaculture ponds. Ecological Modelling, 54, 189 - 226.

Nieveen, J.P., Jacobs, C.M.J. and Jacobs, A.F.G., 1995: Exchange processes of a natural bog vegetation; In: S. Zwerver, M.M. Berk and R.S.A.R. van Rompaey (Eds.), Climate Change Research: International Conference, Maastricht, Netherlands, 6-9 December 1994, Hydrology and Earth system Sciences, 1, 81 - 91.

Octavio, K.A., Jirka, G.H. and Harleman, D.R.F., 1977. Vertical transport mechanisms in lakes and reservoirs. Techn. Rep. 227, Ralph M. Parsons Laboratory, Mass. Inst. Technology, Cambridge, MA, 131pp.

Orlob, G.T., 1983. Models for stratified impoundments. In A.K. Biswas (Editor), Models for water quality management. McGraw-Hill, New York, pp 273 - 313.

Preisendorfer, R.W., 1986. Secchi-disk science: visual optics of natural water. Limnol. Oceanography, 29, 909 - 926.