Slovak University of Technology in Bratislava
Institute of Information Engineering, Automation, and Mathematics

PROCEEDINGS

17^{th} International Conference on Process Control 2009
Hotel Baník, Štrbské Pleso, Slovakia, June 9 – 12, 2009
ISBN 978-80-227-3081-5
`http://www.kirp.chtf.stuba.sk/pc09`

Editors: M. Fikar and M. Kvasnica

Hofreiter, M., Novák, M.: Modelling of Evapotranspiration Field of Ecosystem, Editors: Fikar, M., Kvasnica, M., In *Proceedings of the 17th International Conference on Process Control '09*, Štrbské Pleso, Slovakia, 200–204, 2009.

Full paper online: `http://www.kirp.chtf.stuba.sk/pc09/data/abstracts/062.html`

MODELLING OF EVAPOTRANSPIRATION FIELD OF ECOSYSTEM

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Abstract: This paper deals with the modelling of evapotranspiration of ecosystems. It uses the Penman-Monteith method to estimate evapotranspiration and method based on the use of the Bowen ratio. The aim of the present article is to demonstrate the possibility of more precise methodology for modelling evapotranspiration and to display the evapotranspiration field when the measured data from meteorological stations are supplemented with the information in the form of infrared images of a monitored locality. This approach is demonstrated by the data observed in the selected ecosystem in the southern part of Bohemia. The infrared images of this locality were captured by infrared camera from a plane. The data processing and modelling of the evapotranspiration of the selected ecosystem was done using the Matlab programming environment. This article discusses the method of extraction information from infrared images and contains several images documenting the achieved results.

Keywords: Modelling, evapotranspiration, ecosystem, infrared image.

1 INTRODUCTION

The status of each natural ecosystem in terms of biodiversity and stability is directly dependent on two factors. One is the energy balance, including incoming and outgoing flows of energy, the other is the water balance (hydrological). Monitoring and examination of ecosystems allows us to describe the link between directly and indirectly measured values as well as landscape elements. Observed ecosystems are examples of complex dynamical systems with distributed parameters which have a number of variables that are in interaction (Ward *et al.* 2004).

Of the variables of hydrological balance (precipitation, runoff and evaporation), the most complicated and the most difficult to determine quantities are those of evapotranspiration. Evapotranspiration is a complex of physical and physiological phenomenon. It refers to the evaporation from the soil surface, water and vegetation. The term “evapotranspiration” was established from two words – “evaporation” (evaporation from non-living surfaces such as water, soil, snow, ice) and “transpiration” (evaporation from the tissues of living plants). Interception is often included in evapotranspiration. This is the evaporation from droplets on the surface of plants after rainfall.

Direct measurement of respectively individual components of evapotranspiration is very difficult and expensive. A lysimeter (weighing or compensational) is used, which is a container filled with soil, vegetation, and is eventually deposited on the ground in order to imitate the characteristics of the surrounding environment.

Due to the costs, difficulties and inaccuracies associated with the use of direct measurement of evapotranspiration, computational methods are principally used. There are many algorithms (Pokorný *et al.* 2006), (Allen *et al.* 1998), based on different mathematical models to estimate evapotranspiration. Evapotranspiration is affected by many bioclimatic factors but only some of which are directly measurable. The obtained results reflect this fact. Calculations often do not respect the time and spatial diversity of these factors.

Figure 1 Meteorological station

The aim of the presented article is to demonstrate the possibility of a more precise methodology for calculating evapotranspiration and to display evapotranspiration fields when data from meteorological stations are supplemented with infrared images captured by aerial photography. This new information is obtained by the now affordable device. A thermovision camera can refine the calculations as well as display evapotranspiration fields in the locality sample with use of advanced computational tools for image processing.

2 ESTIMATION OF EVAPOTRANSPIRATION FIELD

To estimate evapotranspiration field under real conditions in the Czech Republic, ecosystems were selected around the city of Třeboň, where meteorological stations (see Figure 1) are deployed. Meteorological stations include recording and control unit M4016 from company Fiedler-Magr. Unit M4016 refers to telemetric stations with encapsulated GSM / GPRS module, a programmable control machine, which, in conjunction with various sensors reads meteorological variables such as temperature, humidity, wind speed /direction, radiation, etc. (see Table 1) and is able to monitor these variables according to pre-set scenarios and store them in a database that is available to all authorized users through the Internet portal www.fiedler-magr.cz.

Matlab programming environment was used for modelling evapotranspiration. Calculations were based on the Penman-Monteith equation according to the Food and Agriculture Organization of the United Nations (FAO) (Allen *et al.* 1998). Besides FAO methodology the Bowen ratio (Pokorný *et al.* 2006), (Hofreiter 2008) was also used for the calculations. These two methods were chosen because of the measurable data from the meteorological stations received in the selected location and the FAO recommendations.

These two methods are based on the fact that the evaporation of water requires relatively large amounts of energy. The energy coming into the evaporation surface must equal the energy leaving the surface in the same time period. Therefore

$$Rn = G + L \cdot E + H + Ph + Ca \, , \qquad (1)$$

where R_n is the intensity of the net radiation (i.e. the difference between incoming and outgoing radiation of both short and long wavelengths), G is the intensity of the soil heat flux, L is the latent heat of vaporization, E is the intensity of evapotranspiration, H is the intensity of the sensible heat flux, Ph is the intensity of the heat flux consumed during photosynthesis and Ca is the intensity of the biomass thermal capacitance change. Since Ph and Ca are much less than the other factors they are negligible. Net radiation (Rn) and soil heat (G) fluxes can be measured or estimated from climatic parameters. However measurements of the sensible heat (H) are complex and cannot be easily obtained. Table 1 shows the measured inputs which were used for E estimation for both of the methods.

relative humidity at the height 0.3 m
relative humidity at the height 2 m
downward shortwave radiation
shortwave radiation reflected by the surface
soil temperature at the depth of 0 m
soil temperature at the depth of 0.1 m
soil temperature at the depth of 0.2 m
air temperature at the height 0.3 m
air temperature at the height 2 m
soil water content
soil organic content in soil
mineral content
altitude
wind speed at 2 m above the ground surface
wind direction at 2 m above the ground surface
crop height

Table 1 Measured inputs for E estimation

The intensity of the latent heat flux LE

$$LE = L \cdot E\,, \tag{2}$$

was calculated using

a) the Bowen ratio (BR) method

$$LE_{BR} = \frac{Rn - G}{1+\beta}\,, \tag{3}$$

where for the Bowen ratio β holds

$$\beta = \frac{H}{LE} = \gamma \cdot \frac{\Delta T}{\Delta e}\,, \tag{4}$$

where γ is the psychrometric constant, ΔT is the difference in air temperature between the two levels, Δe is the difference in specific humidity between the two levels.

b) the Penman-Monteith (PM) method

$$LE_{PM} = \frac{\Delta \cdot (Rn - G) + \dfrac{\rho_a \cdot c_p \cdot (e_s - e_a)}{r_a}}{\Delta + \gamma \cdot \left(1 + \dfrac{r_s}{r_a}\right)}\,, \tag{5}$$

where Rn is the intensity of the net radiation, G is the intensity of the soil heat flux, $(e_s - e_a)$ is the saturation vapor pressure deficit, r_a is the aerodynamic resistance, r_s is the surface resistance, c_p is the specific heat of the air, ρ_a is the air density, Δ represents the slope of the saturation vapour pressure temperature relationship.

For both methods the intensity of evapotranspiration E was calculated using

$$E = \frac{LE}{L}\,. \tag{6}$$

In the first stage there were energy flows and evapotranspiration in the monitored ecosystems identified, provided that the ecosystems could be monitored as lumped parameter systems. More precise results of this classical procedure was obtained when significant improvement were made in 2008 using information about the surface temperatures in monitored ecosystems received from infrared pictures taken by the infrared camera ThermaCam^{TM} S65 from the FLIR company (see Figure 2).

Figure 2 ThermaCam^{TM} S65

Figure 3 Modular glasshouse

In the initial testing phase infrared pictures were first acquired in the modular laboratory glasshouse (see Figure 3) from a height of 3.5 m above the ground from an installed lift (Figure 4). This solution allowed the motion of the infrared camera above the monitored area. Figure 5 is given to illustrate the infrared and visible picture of a bed under glasshouse. This solution simulated the movement of aircraft and airship, which is supposed to be used in outdoor conditions to measure surface temperatures of the landscape using an infrared camera.

An area of the subsequent aerial photography is shown in Figure 6. For practical verification of the newly proposed procedure were chosen two sites in the country: One in the vicinity of meteorological station Vrt-Domanín and the other near the meteorological station Ježek around the city Třeboň. Meteorological station Vrt-Domanín was equipped with radiometer CNR1 from Kipp & Zonen company with a pair of pyranometers CM3 for measuring short radiation and a pair of pyrgeometers CG3 for measuring infrared radiation. Meteorological station Ježek was equipped only with a pair of pyranometers CM3.

Figure 4 Lift with infrared camera

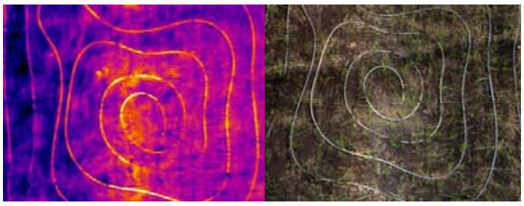

Figure 5 Infrared picture and photography of bed

The software ThermaCAM Image Builder from the FLIR company was used in order to remove the overlay of each infrared image and to create a coherent infrared image (Figure 7) of the entire monitored area. The ThermaCAM Researcher software was used from the same company in order to process the results and determine the surface temperatures from the infrared images. The calculations and display of energy flow and intensity of evapotranspiration, were implemented in the programming environment using Matlab with Image Processing Toolbox from MathWorks, Inc. (Novák, 2008).

New data on the temperature field of the ecosystems helped to put more precisely the calculation of energy flows and evapotranspiration, and obtain the 2D display of energy flow and evapotranspiration. In Figure 8 visible photography of the location is shown. Figures 10 and 11 show the calculated field intensity evapotranspiration at 5:50 a.m. and 12:30 a.m. on 29th July 2008 of the same location as shown in the Figure 9.

In the morning the intensity of evapotranspiration is much lower than at noon, therefore it is chosen another colour range for comparing data at different times, which is shown in Figure 9. Similarly, it is necessary to solve the various locations that are significantly different in their intensity of evapotranspiration.

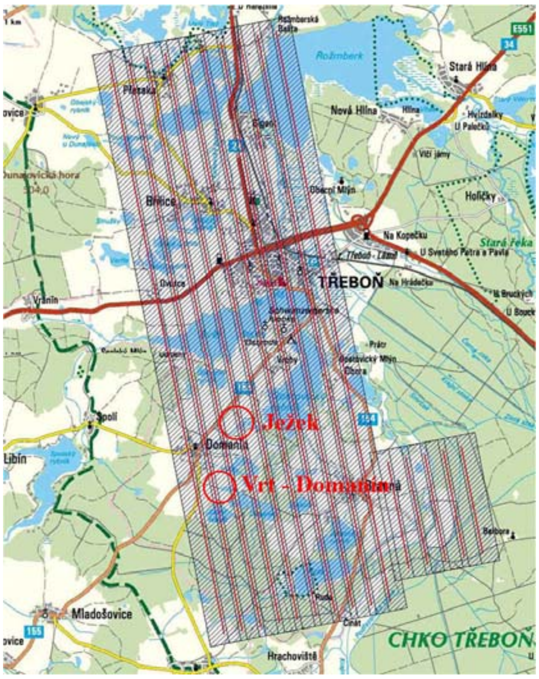

Figure 6 Area of the aerial photography

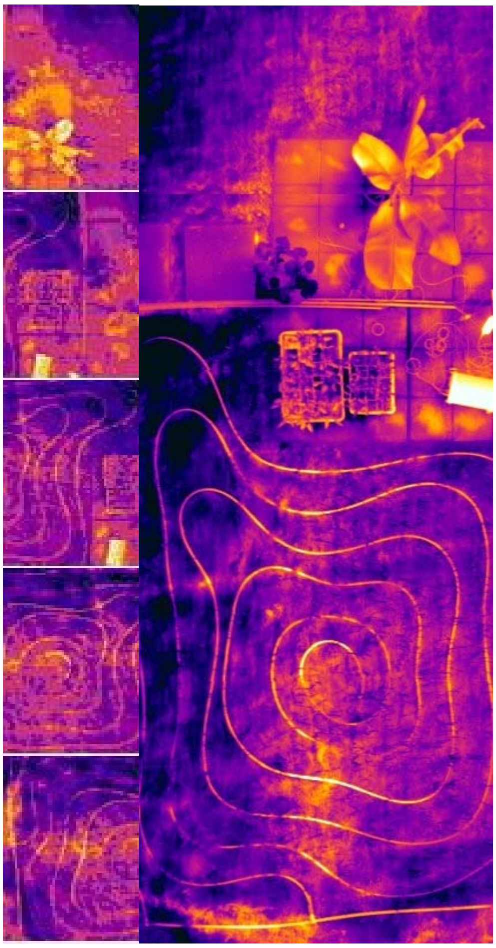

Figure 7 Input images for ThermaCAM Image Builder (left) and output image from ThermaCAM Image Builder (right)

Figure 8 Location Ježek

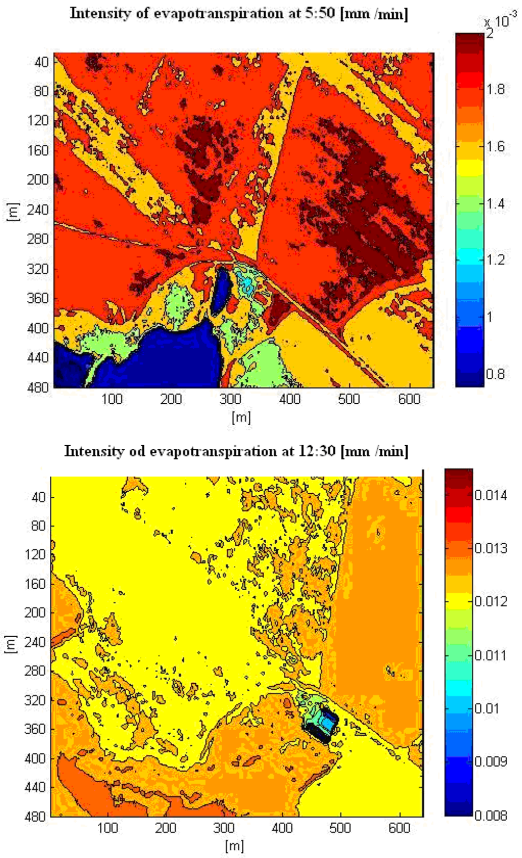

Figure 9 Intensity of evapotranspiration in the vicinity of meteorological station Ježek at 5:50 a.m. and 12:30 a.m. on 29 July 2008 with the different color range

3 CONCLUSION

Apart from the intensity of evapotranspiration, it is possible to illustrate the flow of sensible heat, latent heat flux, the total net radiation, etc. The display will give an illustrative overview of the energy flow and intensity of evapotranspiration in a given locality during a selected time. In cases of a heterogeneous landscape, it will be necessary to refine the calculations of the temperature field of surface temperatures, as well as the variability of other parameters. This can significantly impact the energy flow and thus the intensity of evapotranspiration.

The results have contributed to the improvement of measurement instrumentation by changing the number and location of temperature sensors for determining the soil temperature profile. Additionally, the results have provide a method for more precise calculation of the monitored parameters of the ecosystem.

ACKNOWLEDGMENTS

The work has been supported by the Ministry of Education of Czech Republic under Project TOKENELEK, no. 2B06023.

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