ANALYSIS OF THE ENERGETIC EXCHANGE PROCESSES WITHIN THE TWO DIFFERENT FOREST ECOSYSTEMS

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Abstract:

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The utilisation of energy within the floodplain forest ecosystem near Lednice – south Moravia, and spruce monoculture ecosystem near Rájec Jestřebí – central Moravia during the years 1988 and 1989 was measured. Net radiation balance, global solar radiation, wet bulb and dry bulb temperatures and soil heat flux directly by instruments and sensors; latent, sensible heat flux and heat flux to the vegetation was calculated. It is possible to say, considering hitherto results, that well watered (groundwater) floodplain forest ecosystem shows greater evapotranspiration and therefore latent heat flux than spruce monoculture. Greater flux of energy was recorded in a daily course of sensible heat flux (65% proportion to net radiation), in contrast with the spruce monoculture. The floodplain forest latent heat flux proportion to net radiation was found to be variable within the growing season; in the middle of the vegetation period (from June to August) it reached the value of about 70%, at the end (in October) of about 20%. The estimation of the floodplain forest actual evapotranspiration was possible almost all over the season, the actual evapotranspiration reached its maximum of about 0.72 mm h^{-1} one hour after the maximum of radiation balance. A time lag of about 4 hours was observed when compared the diurnal course of air humidity gradient to the air temperature gradient above the forest canopy. This phenomenon caused the left side asymmetry of the diurnal course of the Bowen ratio. It was not possible to measure the spruce monoculture latent heat flux all over the season, probably due to smaller gradient of the air humidity although it was measured across at greater distance than in a floodplain forest (12 in comparison with 9 meters). The values of the second half of May and first half of June ones were at our disposal only. The spruce monoculture latent heat flux proportion to radiation balance was found about 25%, the actual evapotranspiration reached maximum of about 0.28 mm h^{-1}, nearly 3 times less than in case of floodplain forest. Daily curve of humidity gradient above spruce monoculture canopy displayed rather symmetric but not sinusoidal course. These values were comparable with the measuring accuracy. That is what considerably determines availability of chosen method within insufficient water conditions environment.

Key words: latent (sensible) heat flux, net radiation, actual evapotranspiration, humidity (temperature) gradient

Introduction:

The energetic exchange between plant communities and the atmosphere when measured close to plant surface can give a lot of information about the internal stage of natural ecosystems. From this point of view plant water consumption is especially important. The main objective of this work is to compare different forest ecosystems, how they differ from each other. On one hand well-watered, almost natural *floodplain forest* ecosystem, regularly inundated from ancient times since 1973, when interrupted drastically by the hydroengineering works. On the other hand artificially established *spruce monoculture* in the lower altitudinal vegetation zone (beechwood veg. zone 4 in comparison with spruce veg. zone 6).

Material and methods

Research site characteristics

One of both research sites of the Institute of Forest Ecology, Mendel University of Agriculture and Forestry - Brno, is situated in a south Moravian floodplain forest (48.8 N, 16.8 E, 161 m). ***Floodplain forest*** types of the groups *Ulmeto-Fraxinetum carpineum* and *Querceto-Fraxinetum* are the most frequent in the region. Dominant trees there are *Quercus robur* (74%) and *Fraxinus angustifolia* (24%), with admixtures of *Tilia cordata* (3%) and *Ulmus carpinifolia* (1%). We could find there more interspersed species like *Carpinus betulus, Acer campestre, Malus sylvestris* and *Alnus glutinosa*. Within the whole area of the floodplain forests, as described by Vašíček (1991), there is a layer of shrubs of varying density and maturity, with *Cornus sanquinea* as the dominant species. The floodplain forest is 110 years old (1988). The mean height of trees of the upper canopy was 29 m, the highest trees reached up to 37 m. The canopy structure surface is irregular, the stand density is 0.9 (Vyskot, 1991).
The long-term annual average value of precipitation is 516 mm, for a growing season IV-X 365 mm respectively (values presented by the meteorological station Mendeleum in Lednice).
The 1988 values of the month precipitation were 18, 33, 29, 22, 44, 57, 41, 48, 57, 12, 19 and 42 millimetres, i.e. 422 mm a year and 281 mm per growing period. With respect to the fact of small amount of precipitation the available soil water content is still considered to be a limiting factor for life and surviving of the plants in this region.
The second research site presents artificially established first generation of pure ***spruce monoculture*** (*Picea excelsa*) on the lower altitudinal vegetation zone types of the groups *Fagetum quercino abietinum*. It is situated in Drahanská upland near small town Rájec, north of Brno (49.5 N, 16.7 E, 620 m). The 1989 values of the month precipitation were measured 16, 19, 18, 71, 38, 100, 70, 72, 55, 14, 21, 18 millimetres, i.e. 512 mm a year and 420 mm per growing period (Mrkva, 1992). The spruce stand is 90 years old (1989), the average height of trees around 28 meters.

The schema of measurements

Following variables were measured: global solar radiation (by SCHENK pyranometer (Austria) for incident and reflected radiation, type 8101), radiation balance (by thermocouple balancemeter SCHENK, type 8111), albedo, air temperature and humidity (with electrically ventilated psychrometers THIES (GERMANY) with glass Pt 100 electrical resistance thermometers). All the sensors were located at the height of 40.5 meters above ground level and approximately 9 meters above floodplain forest and 12 meters above spruce monoculture canopies on a steel tower. Air temperature and humidity were also measured on the same tower at 31.5 m above ground, it means 9 m below the upper sensor level in the floodplain forest and 28.5 m above ground, it means 12 m below the upper sensor level in the spruce monoculture. Additional air temperature was measured at 2 m above ground within the forest (with non-aspirated ceramic Ptk 100 electrical resistance thermometer, ZPA, Czech Republic) in a usual meteo-instrument weather shelter. Soil temperature was measured at 5 and 15 cm below the soil surface (with ceramic Ptk 100 electrical resistance thermometer). Soil heat flux was measured at the depth of 10 cm (with the heat flux plate 100x75 mm, DRUTĚVA, Czech Republic) horizontally located in the ground. All data were recorded by the datalogger at one-hour intervals during the whole growing season.

Data analyses

The data set was processed by the following method: saturation water vapour pressure E [hPa] in both levels above forest canopy was calculated - after correction of psychrometer's temperatures (see below) - by the algorithm (Unwin, 1980):

$$\log E = 9.24349 - \frac{2305}{T} - \frac{500}{T^2} - \frac{100000}{T^3} \quad (1)$$

where T is the dry air temperature in Kelvins [°C + 273]. The accuracy presented by the author is ±0.1 hPa within the range of temperature -5 to +34 ^{o}C. The actual water vapour pressure [hPa] is then:

$$e = E - 0.666\,(T_D - T_W) \quad (2)$$

where E is the saturation water vapour pressure at the wet bulb temperature, T_D is the dry (T_W wet) bulb temperature. Actual evapotranspiration (E_a) was calculated by the energy balance method employing Bowen's ratio (β) method:

$$\beta = \gamma \frac{dT + \Gamma dz}{de} = \frac{C}{\lambda Ea} \quad (3)$$

where γ is the psychrometric constant [66 Pa ^{o}C^{-1}], dT (de) the air temperature (humidity) gradient above forest canopy at distance dz, Γ is the dry adiabatic lapse rate [0.01 ^{o}C m^{-1}], C is the sensible heat flux, λ the latent heat of vaporisation of water [2501 J g^{-1} at 0 ^{o}C], E_a the actual evapotranspiration (Woodward & Sheehy, 1983).

Actual evapotranspiration rate [g m^{-2} s^{-1}] is then equal to:

$$E_a = \frac{H}{\lambda(1+\beta)} \quad (4)$$

Available energy H (= $C + \lambda E_a$) [W m^{-2}] was considered as a difference between the net radiation balance (R_n), the soil heat flux (G) and the heat flux into the vegetation (J_{veg}), the latter two so called flux of energy below the active surface of forest canopy ($B = G + J_{veg}$). Thus $H = R_n - G - J_{veg}$. The first two terms were measured directly, the heat flux into the vegetation was calculated by the following algorithm (Thom in Monteith, 1975):

$$J_{veg} = c.m_{veg}.dT \quad (5)$$

where c is the specific heat of the wood [2.7 kJ kg^{-1} K^{-1} on average], m_{veg} is the weight of vegetation per unit ground area [57.4 kg m^{-2} for floodplain forest, 42.5 kg m^{-2} for spruce monoculture], dT is the air temperature change in the forest within the one-hour interval [°C], by which the real wood temperature is substituted.

The potential evapotranspiration E_p [mm day^{-1}] was calculated by Turc algorithm for a pentad (Wendling, 1975) after a modification for one-day values as applied previously by Židek, 1991:

$$E_p = \left(50 + \frac{R_g}{4.1868}\right)\frac{0.013T}{(T+15)} \qquad (6)$$

where R_g is the global solar radiation [J cm^{-2}day^{-1}], and T is the daily mean air temperature at 2 m [°C].

Albedo (α) was calculated as obviously as an up and down short-wave radiation ratio.

Calibration

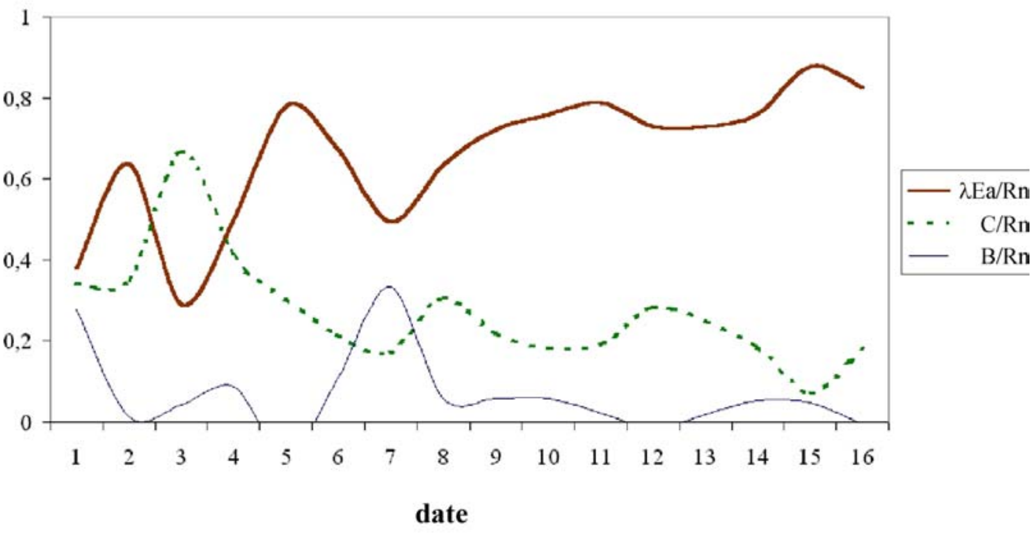
Sensors of global solar radiation were calibrated at the experimental observatory of Czechoslovak hydrometeorology station in Hradec Králové. Their high stability within the long period of time was proved. New, never before exposed instruments were used for the measurement itself as well as the heat flux plate. In the case of balancemeter no extra-calibration was made and we used the original constant of the apparatus, referred by the manufacturer. Thermometers inside psychrometers were calibrated by the linear regression of the simultaneously operated apparatuses without wetting the wicks. The range of temperatures attained was between 8 to 25 deg. C. In this way originated set of 216 values was then used for a mutual regression analysis of the all four temperature sensors (see Pivec, 1994).

Results

Latent, sensible heat flux and heat flux below the active surface

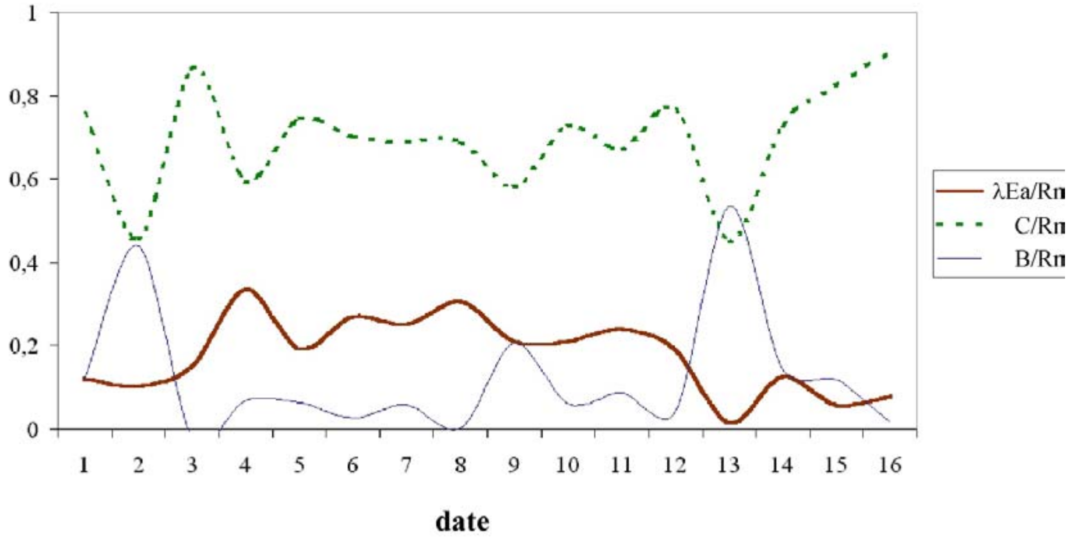
A comparable period when we were able to reviewed measured data in both stands was the first half of June only. The latent heat flux was predominant (66%), while the proportion of sensible heat flux was smaller (28%) in the ***floodplain forest***

Figure 1. Flux of measured energy, proportion to Rn
L88 - June



(Fig.1). The proportion of both fluxes was nearly alike but vice versa in a ***spruce monoculture*** ($\lambda E_a/R_n$ = 17%, C/R_n = 68%) in the same period next year later (Fig.2). The remaining part of radiation balance - the flux of energy below the active surface of forest canopy (*B*) – appeared two times smaller (7%) in a floodplain forest than in a spruce stand (14%).

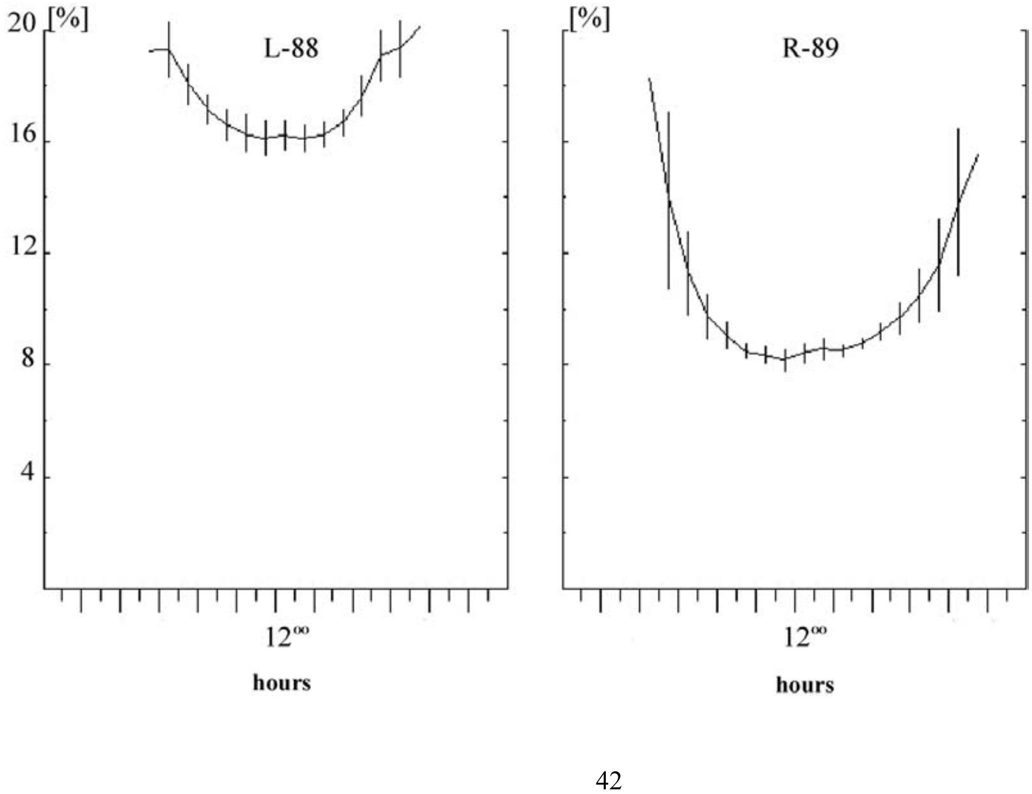
Figure 2. Flux of measured energy, proportion to Rn
R89 - June



Albedo

Albedo values showed significant differences between both sites (Fig.3). In the ***floodplain forest*** ecosystem the albedo average reached about two times greater values (14%) and daily course is smoother. Daily course of albedo in the ***spruce stand*** is more variable from sunrise to sunset. Values are more variable during the

Figure 3. Daily average albedo with standard deviation
1 - 16 June

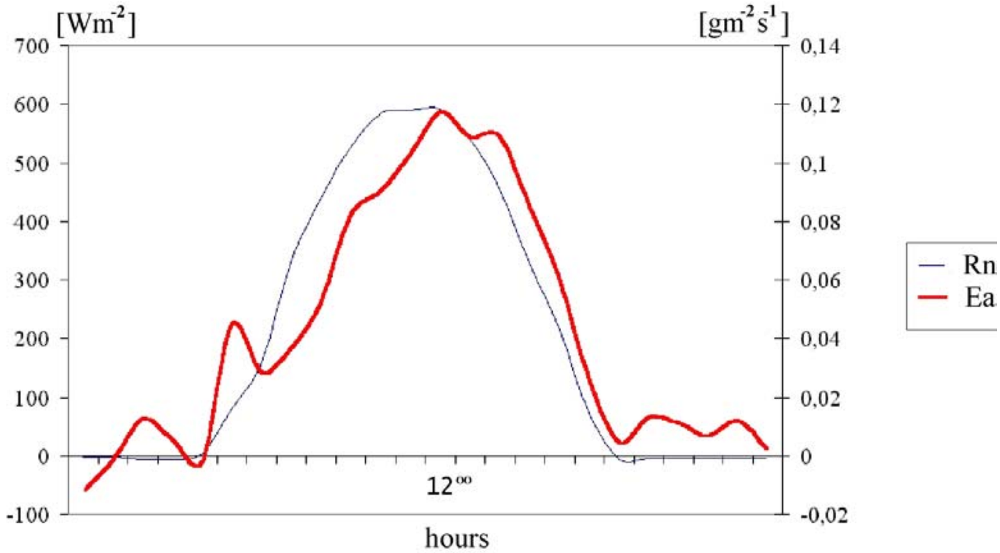


day as it is apparent from standard deviation development (Fig.3). This curve of albedo indicates slight left asymmetry.

Actual evapotranspiration

Everyday values of the actual evapotranspiration could be obtained in the ***floodplain forest*** till the beginning of October (see the below mentioned facts about humidity gradient). Daily maxima of water vapour reached values of about 0.2 g $m^{-2}s^{-1}$, it means 0.72 mm hr^{-1}. During the observed period of the first half of June it was 0.17 g $m^{-2}s^{-1}$, it means 0.6 mm hr^{-1}. This level of evapotranspiration was reached regarding to the available energy from solar radiation especially from the beginning of June to the end of August. The evapotranspiration decreased regardless of the sufficient amount of solar energy from the beginning of September. Roughly, from the mid-October a rather neutral gradient of the air

Figure 4. Time shift between Ea and Rn, L-88, 4. June

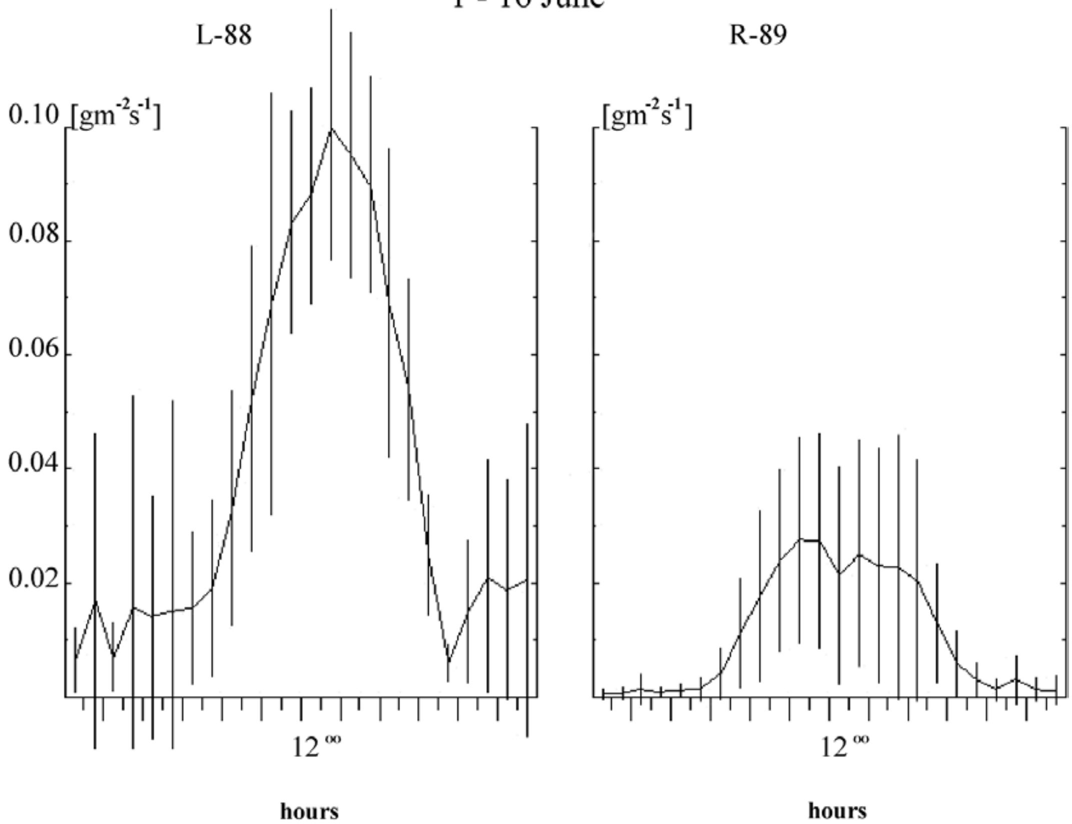


humidity indicates the minimal evapotranspiration, which is hardly measurable by the above mentioned method. Examples of actual evapotranspiration diurnal courses (Fig.4) show regular time shift comparing with the radiation balance curve. The time lag was about one hour at daily maximum (usually at 13.00 hour) and about two hours at the ascending part of the actual evapotranspiration diurnal curve.

Actual evapotranspiration (E_a) in the ***spruce forest*** reached values of about 0.08 g $m^{-2}s^{-1}$, it means 0.28 mm hr^{-1}. Everyday values of the actual evapotranspiration could be obtained till the beginning of the second half of June only due to systematically negative air humidity gradient in the next measuring period.

Daily mean values differences of actual evapotranspiration in both stands are well documented in Fig.5.

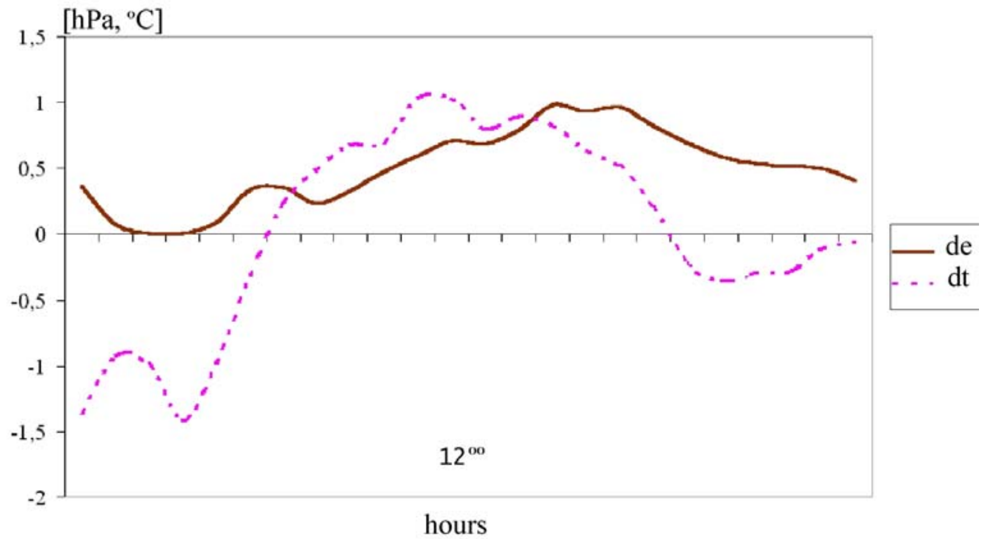
Figure 5. Daily mean evapotranspiration with standard deviation
1 - 16 June



Humidity and temperature gradients

The air humidity gradient course above the ***floodplain forest*** canopy was delayed by about 4 hours comparing with the air temperature gradient (Fig.6). This

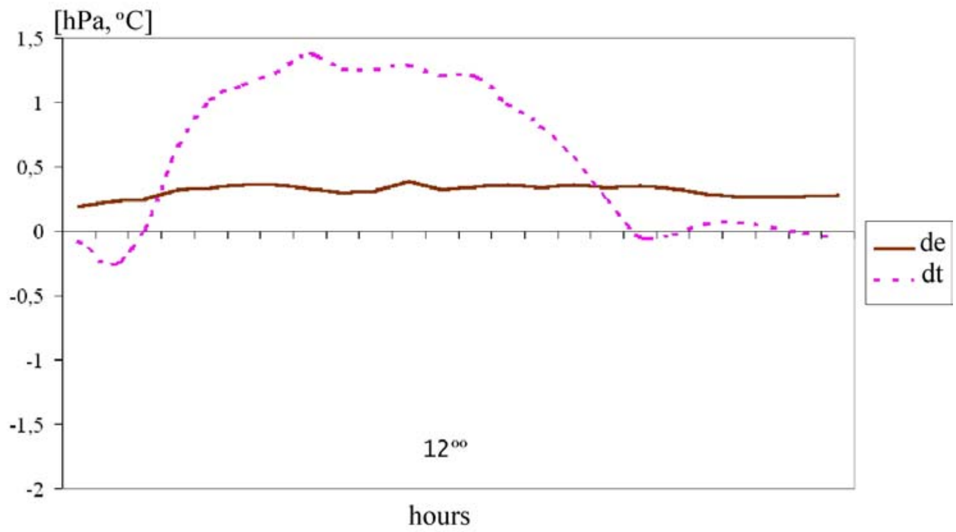
Figure 6. Time shift between de and dt, L-88, 4. June



phenomenon caused diurnal course left side asymmetry of the Bowen ratio. The air temperature gradient hardly ever exceeded +0.5°C and –2°C, the air humidity gradient reached up to 1.5 or 2 hPa (in the rare case negative value about -1 hPa was found in the night hours). During the observed period of the first half of June it was –1.7°C and +1°C for minima and maxima air temperature, and from –0.3 to +1.2 hPa for air humidity gradients respectively. Almost during the whole season the air humidity gradient was positive even during night-time till the end of August. The air humidity gradient decreased during the September and in the beginning of October, than these values oscillated around zero value in the remaining part of October. That is the limiting factor for the presented method of application. At the same time as the air humidity decreased, the air temperature became higher.

Air humidity gradient above the ***spruce monoculture*** canopy fluctuated between -0.1 and +1.2 hPa, air temperature gradient varied in the range from –1.2 to +1.4°C (Fig. 7).

Figure 7. Typical course of de and dt, R-89, 23. May



Relation of the actual evapotranspiration to the evaporation demands of the environment

Evaporation demands were expressed by potential evapotranspiration (E_p) values by Turc algorithm. The comparatively observed first half of June shows greater actual evapotranspiration in the ***floodplain forest*** although the values of precipitation were nearly two times smaller than in June 1989. Precipitation amount of 57mm in the floodplain in June 1988 and 100mm in the spruce forest stand in June 1989 were collected. Regression analysis between potential (as dependent) and actual (as independent variable) evapotranspiration was calculated for comparatively analysed data within the first half of June. The coefficient 0.66 (slope) and 1.20 (intercept) indicates that actual evapotranspiration is higher than potential for values greater than 3.5 mm day^{-1}. Previously published results (from the whole vegetation season, Pivec, 1994) gave values of 0.83 (slope) and 0.59 (intercept), which indicates the same limit value of the actual evapotranspiration 3.5 mm day^{-1}, above which the potential evapotranspiration is lower than actual one. In the case of ***spruce monoculture*** coefficient 1.74 indicates always-higher potential than actual evapotranspiration, as usual.

Bowen ratio

The Bowen ratio maximum was calculated during the daytime in the ***floodplain forest*** from 0.5 to 2 values. It means consumption of the energy for vaporisation

Figure 8. Typical course of Bowen ratio, L-88, 9. June

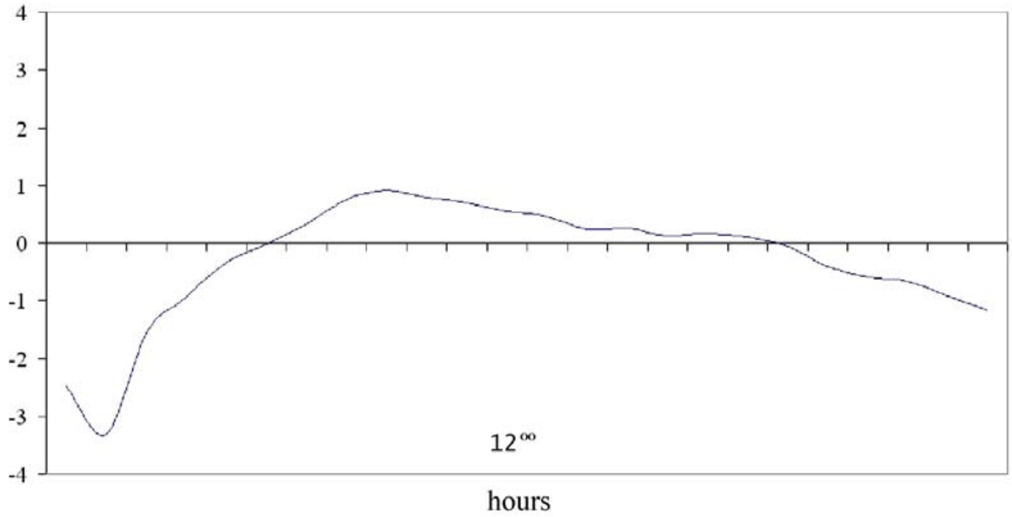
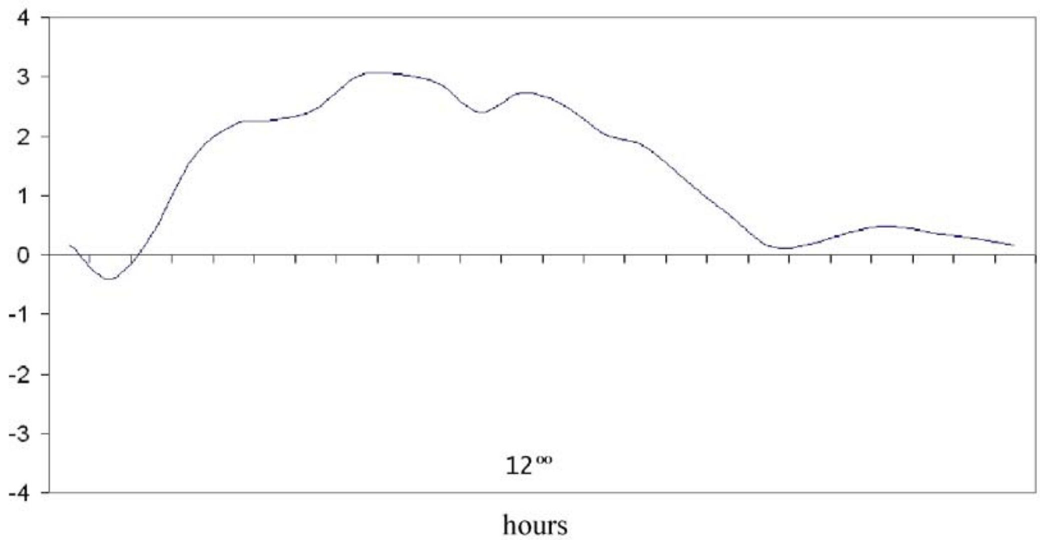


Figure 9. Typical course of Bowen ratio, R-89, 23. May



moves within the range from two times greater to two times smaller than sensible heat flux. The course of Bowen ratio curve during 24 hours shows regular results, often left side asymmetric (Fig. 8). ***Spruce monoculture*** Bowen ratio has another development during the day than the floodplain forest one. Typical diurnal course is shown in Fig. 9. Real values are very heterogeneous. But the maximum is reached at about 5.5 on average.

Discussion

Lindroth (1985) observed the latent heat to radiation balance ratio with the values of 40% in May. It is more than two times greater than in our case.

The energy flux below the active surface of forest canopy (*B*) corresponds well with albedo values $\alpha = 14\%$ in a floodplain and 7% in a spruce stand.

Why is the actual evapotranspiration in the floodplain forest stand after overcoming a certain value higher than potential one? One of the eventual explanations of this phenomenon is well water-saturated ecosystem, which has sufficient water amount at disposal. But this disposability of groundwater (precipitation water amount is negligible) is apparent from certain limit of evaporation demands. Up to this limiting value an increasing resistance to the water vapour exchange between the ecosystem and the atmosphere is apparent close to its surface.

Left side asymmetry of albedo curve in case of spruce forest stand is influenced by eastward oriented slope, where measurement was carried out.

It is evident that the temperature gradient above spruce canopy is higher and not too often below zero than that above floodplain forest canopy, while humidity gradient is more than two times higher above floodplain forest (Fig. 9). Regardless of the fact that both gradients were approximately the same range of values.

Translated by the author

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Pivec, J.: **Analýza procesu energetické výměny ve dvou různých lesních ekosystémech.**

V letech 1988 a 1989 byl zkoumán proces energetické výměny a jejího využití ekosystémem lužního lesa na jihu Moravy poblíž Lednice a smrkovou monokulturou poblíž Rájce-Jestřebí na střední Moravě. Přímo pomocí čidel a přístrojů byla měřena radiační bilance, globální radiace, teplota suchého a vlhkého teploměru a tok tepla do půdy; tok latentního a zjevného tepla byl počítán. V rámci dosažených výsledků je možné konstatovat, že dobře zavlažený (spodní vodou) ekosystém lužního lesa vykázal větší evapotranspiraci a tudíž tok latentního tepla než smrková monokultura. Zato ve smrkové monokultuře byl naměřen větší podíl toku zjevného tepla (65% celkové radiační bilance). Tok latentního tepla v lužním lese byl shledán během vegetační sezóny proměnlivý; uprostřed (červenec - srpen) dosahoval 70%, na konci (v říjnu) 20%. Skutečnou evapotranspiraci bylo možno stanovit v lužním lese téměř po celou sezónu, jeho maximum dosahovalo 0,72 mm h^{-1} asi hodinu po kulminaci radiační bilance. Gradient vlhkosti vzduchu vykazoval vzhledem ke gradientu teploty vzduchu nad porostem lužního lesa asi 4 hodinové zpoždění. Tento jev zapříčinil levostrannou asymetrii denního průběhu Bowenova poměru. Ve smrkové monokultuře nebylo možno měřit skutečnou evapotranspiraci během celé sezóny díky malému gradientu vlhkosti vzduchu nad porostem ačkoliv byl měřen na větší vzdálenost než v případě lužního lesa (12 oproti 9 m). K dispozici bylo pouze měření ze druhé půle měsíce května až první půle měsíce června. Tok latentního tepla činil ve smrkové monokultuře 25% celkové radiační bilance, skutečná evapotranspirace dosahovala maxima kolem 0,28 mm h^{-1}, téměř třikrát méně než v lužním lese. Denní chod gradientu vlhkosti vzduchu zde vykazoval dosti symetrický, nikoliv sinusoidní průběh. Tyto hodnoty byly srovnatelné s přesností měření. Tudíž značně omezily použitelnost dané metody ve vodou nedostatečně zásobeném prostřední.