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THE METHOD OF ESTIMATION OF BOWEN RATIO AREAL DISTRIBUTION BY PARAMETERIZATION BASED ON METEOROLOGICAL AND LAND-USE DATA

Abstract: New empirical equations for Bowen ratio estimation are discussed. The Bowen ratio parameterisation is based on some meteorological data (global radiation, temperature, saturation water pressure deficit and wind speed). Because of the set of input data this method can be used for Bowen ratio estimation under present climate condition and also can be coupled with GCMs results about future climate conditions. The parameterization can be used for estimation of areal distribution of heat balance components if land-use data are available. An example of modelled areal distribution of Bowen ratio using meteorological data from 1993 was shown.

Key words: Bowen ratio, head balance of an active surface, evapotranspiration, measurement system.

1. Introduction

The development of industry and agriculture in 19th and 20th centuries leads to irreparable changes in the natural environment. At present, when these changes are commonly recognised, also in the global scale, it is important to stop, or at least to minimise the effects of the processes, which have negative influence on the Earth environment. The crucial question is "how to manage the environment to create conditions which will enable us to return (if possible?) to the ecological equilibrium?" (Stigliani 1989; Freedmen 1992; Kędziora 1995). To know how, first we have to learn more about interactions between the atmosphere and the Earth surface. One of the ways to achieve better understanding of all the processes, which occur in the natural environment, is to model them. There are many models which describe explicit the physical processes in the environment but to use them in the global scale is very difficult because of small computer power availability and input data limitations. Therefore, sometimes an empirical model can be used and after modelling procedure its output result can be coupled with a global scale model (e.g. GCMs) (Kundzewicz, Somlyódy 1993). Even empirical models do not explain different phenomena themselves, but results from these models can be very helpful by quantitative description of many environmental processes.

One way of describing environmental processes in different scales (from micro to global scale) is the analysis of heat balance structure. The knowledge of heat balance structure of an active surface brings information not only about the energy fluxes in the environment but also about water fluxes and can be helpful for water balance estimation of different areas. Therefore, the analysis of heat balance structure is one of the best descriptions of environmental condition in a local but also in the global scale (Paszyński 1972; Rosenberg 1974; Kim, Verma 1990; Olejnik 1996).

In this paper the kernel equation of an empirical model for heat and water balance components estimation is discussed. The equation based on Bowen ratio parameterisation can be used for modelling of evapotranspiration in different scales

2. Method

The heat balance equation can be written as follows

$$Rn + G + LE + S = 0 \qquad (1)$$

where: Rn is the net radiation flux density, LE is latent heat flux density (L is heat of water vaporisation and E is evapotranspiration), S is sensible heat flux density and G is soil heat flux density.

By definition, the Bowen ratio can be written as follows:

$$\beta = S/LE \qquad (2)$$

Using equations 1 and 2 it is possible to calculate the latent and sensible flux density using the so called Bowen ratio method:

$$LE = -(Rn + G) / (1 + \beta) \qquad (3)$$

$$S = -(Rn + G) / (1+1/\beta) \qquad (4)$$

It was shown by many authors that latent (LE) and sensible (S) heat fluxes density are proportional to wind speed gradients, as well as water vapour and air temperature gradients respectively (e.g. Monteith 1975), and therefore the Bowen ratio can be written as follows:

$$\beta = \gamma \ \frac{\delta T}{\delta z} \Big/ \frac{\delta e}{\delta z} \qquad (5)$$

The measurement system and calculations were modified for heat balance component estimation in a patchy landscape (with strong fetch requirements). The details of these procedures are described in Olejnik et al. (1999).

In the Department of Agrometeorology, Agricultural University of Poznań the investigations on heat and water balance components have been carried out for many years, Olejnik (1988, 1996). The mobile measurement system has been used during many research expeditions in numerous places in Asia and Europe. The system has been based on quartz psychrometers an is described in detail in some papers (Olejnik 1988; Olejnik et al. 1999).

3. Results

The measurements were carried out during 20 one-week long, measurement periods in central and western Europe. The locations of measurement sites are shown in Figure 1. The heat balance components were measured for 10 different plant canopies in different plant development stages. The whole set consists of 2784 hourly measurement results of heat balance components from which 116 daily averages were calculated. From the whole set of daily average data the extreme were chosen and are shown in Figure 2. These selected results of measurement present the range of volume of particular fluxes of heat balance of an active surface.

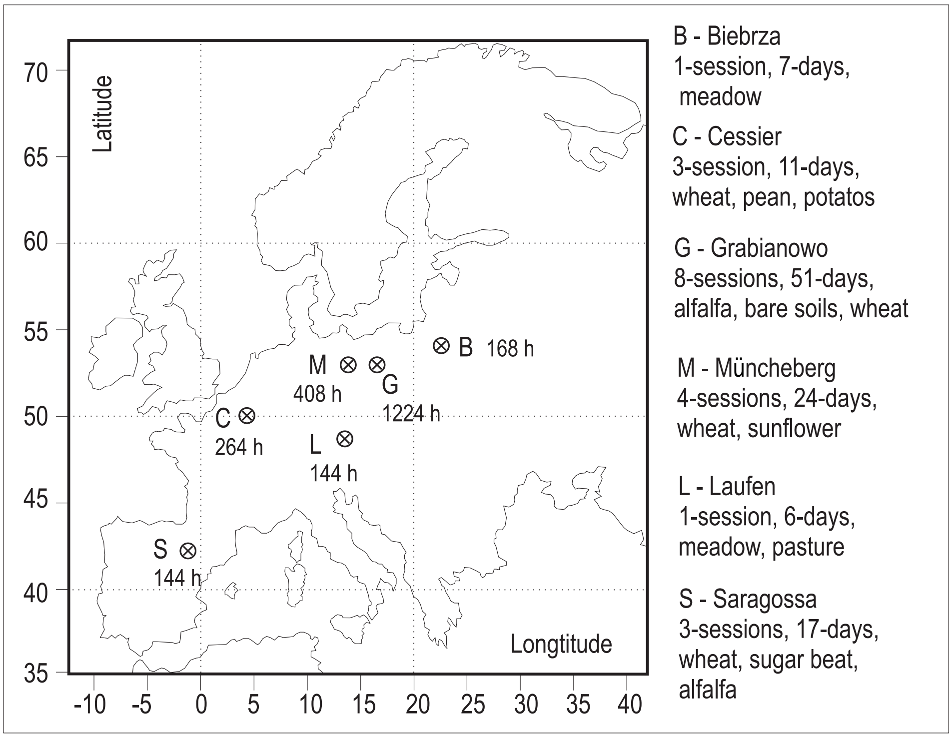

Fig.1. The location of measurement sites in Europe.

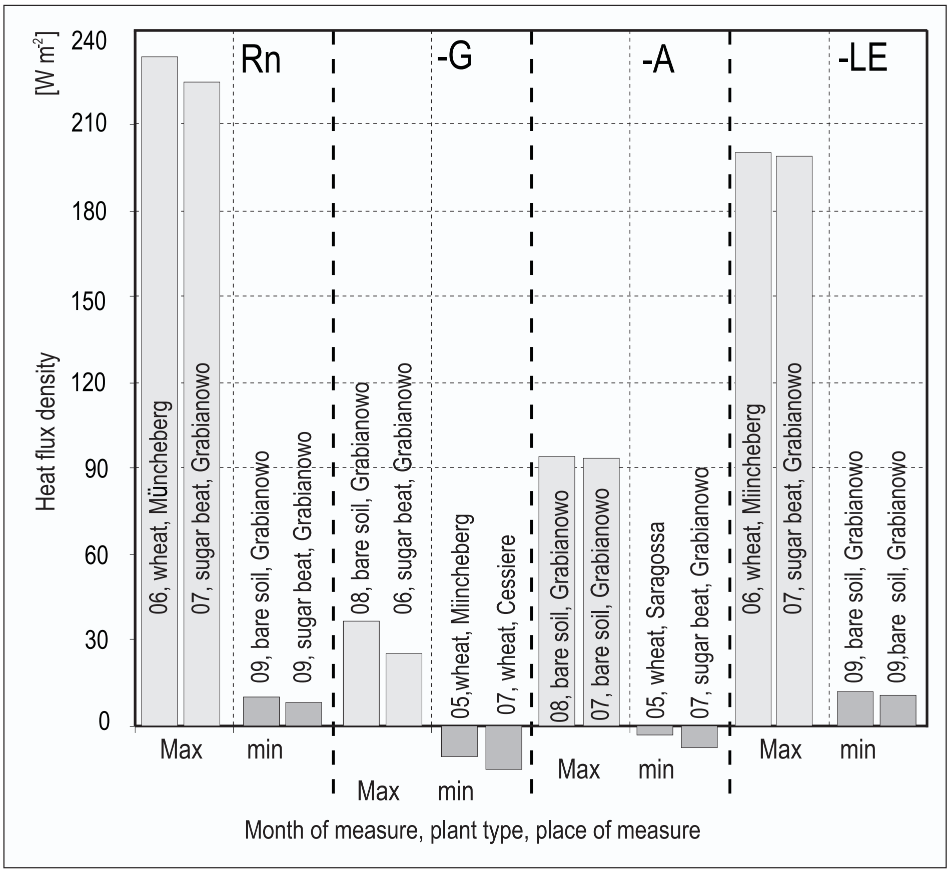

Fig.2. The extreme values of heat balance components chosen from the whole set of measurement data (116 days).

4. Discussion and Concluding Remarks

In 1986 an agrometeorological index was proposed (Olejnik 1988). Using the results of heat balance structure measurements and statistical methods, the empirical equation of Bowen ratio estimation was proposed (Olejnik 1988). On the basis of additional measurements carried out in different climatic conditions (see Fig. 1) a new structure of agrometeorological index W has been proposed recently (Leśny 1998):

$$W = \frac{10 \cdot V}{t} \cdot \left(\frac{D \cdot \sqrt{R_0}}{0.5 + u} \right)^{arctg(\pi \cdot 0.33 \cdot f)} \tag{6}$$

Where: D is saturation vapour pressure deficit in [hPa], R_0 is global radiation measured on horizontal surface above the atmosphere in [W×m^{-2}], t is air temperature in [°C], u is relative sunshine, f is plant development stage (from 0 to 1), V is wind speed in [m. s^{-1}].

Using the proposed index the empirical equation for Bowen ratio estimation was proposed (Leśny 1998):

$$\beta(W) = \frac{1.671}{W - 0.33} + 0.042, \qquad R^2=0.76. \qquad (7)$$

The comparison of measurement of Bowen ratio with the curve described by equation 7 is shown in Figure 3. In equations 6 and 7 all symbols represent the average daily values (including the Bowen ratio). Similar analysis was done for ten-day period, and the final equation for the average ten-day Bowen ratio estimation is as follows (Leśny 1998):

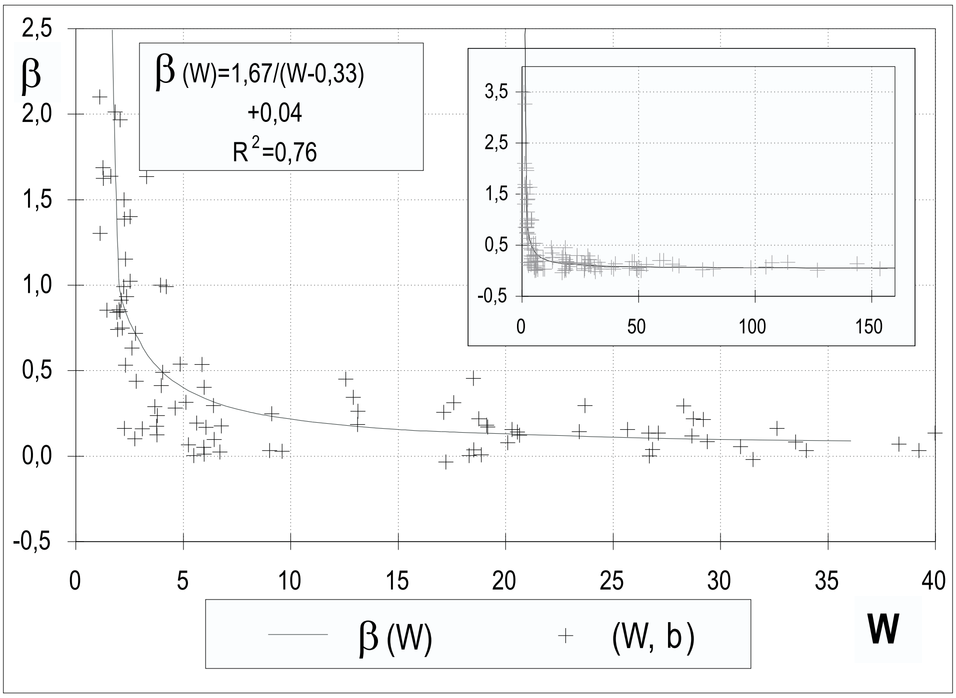

Fig.3. The relationship between agrometeorological index (Eq. 5) and Bowen ratio, dots represent measurements and the curve is obtained using statistical methods.

Tab. 1 Annual average values of heat balance components and evapotranspiration in 1993 in Turew region estimated by modified MBC model.

	Rn [W·m^{-2}],	G [W·m^{-2}],	LE [W·m^{-2}],	S [W·m^{-2}],	ETR [mm],
Sugar beat	48.4	6.3	39.5	2.7	517.8
Winter wheat	48.3	4.1	41.1	3.0	539.6
Meadow	47.9	4.4	46.3	-2.9	606.6
The average for the whole area	48.2	4.9	42.3	0.9	554.7

$$\beta_{uS}(W_u) = \frac{2.10}{W_u - 0.08} + 0.03, \qquad R^2=0.90. \qquad (8)$$

At the end of the eighties the MBC model for areal heat and water balance estimation was proposed and later developed (Olejnik, Kędziora 1991). Using the above equations the MBC model was modified in the part of Bowen ratio estimation. A detailed description of all parts of the MBC model can be found in Olejnik and Kędziora (1991) and Olejnik (1996). As in the previous version, also after the model modification, it can be used for heat and water balance component estimation in different scales (Leśny 1998).

The modified equation of Bowen ratio estimation (eq. 7) was applied in the previous version of MBC model. The input meteorological data were taken from 1993 in Turew (West Poland). The calculations of heat balance components and evapotranspiration were made for hypothetical area where 3 types of plants were cultivated. Sugar beat, winter wheat and meadows in the same proportion covered the area. In Table 1 the results of MBC model application are shown.

It is easy to see that in 1993 in Turew most of the available energy (Rn) was used for the latent heat flux. The ratio LE/Rn is equal to 0.88 which means that for evapotranspiration process about 88% of available energy was used.

The annual precipitation in Turew region in 1993 was equal to 695 mm. Using the results of evapotranspiration estimation by MBC model, one can combine these water balance component data and calculate the difference between precipitation and evapotranspiration:

$$695 \text{ mm} - 555 \text{ mm} = 141 \qquad (9)$$

The value of 141 mm (retention plus runoff) is relatively high for that region but in 1993 about 112% of long term average precipitation was noted.

After the described modification, the MBC model can be used in any land use structure conditions (also patchy landscape, so typical in Central Europe). The meteorological input data set consists of easy available data, which is very important during modelling procedure applied for large areas. Due to the MBC model structure it can be applied for modelling of heat balance components under future climatic conditions and for new expected land use structure changes.

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