EFFECTIVE PARAMETERS OF SURFACE ENERGY BALANCE IN HETEROGENEOUS LANDSCAPE

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Abstract. This paper addresses the problem of estimating surface fluxes at large scale over heterogeneous terrain, and the corresponding determination of effective surface parameters. Two kinds of formulation are used to calculate the fluxes of sensible and latent heat: the basic diffusion equations (Ohm's law type) and the Penman–Monteith equations. The strategy explored is based upon the principle of flux conservation, which stipulates that the average flux over a large area is simply the area-weighted mean of the contributions from the different patches making up the area. We show that the application of this strategy leads to different averaging schemes for the surface parameters, depending on the type of flux (latent heat, sensible heat) and on the type of formulation used to express the flux. It appears that the effective value of a given parameter must be appraised for each individual application, because it is not unique, but differs according to the magnitude being conserved and the equation used to express this magnitude. Numerical simulations are carried out to test over contrasted areas the aggregation procedures obtained. The areal fluxes estimated from these effective parameters, together with the areal fluxes calculated by means of a simple areal averaging of the parameters, are compared to the "true" average fluxes, calculated as area-weighted means of the elementary fluxes. The aggregation procedures obtained prove to be much more accurate for estimating areal fluxes and for closing the energy balance equation than those based upon simple areal averaging of the parameters.

1. Introduction

The formulation of surface fluxes over large and heterogeneous areas has become an acute problem in relation with the parameterization of land surface processes in general circulation models (Henderson-Sellers and Pitman, 1992). The commonly used one-dimensional surface parameterizations, based upon the concept of a homogeneous surface, are generally inappropriate to characterize the subgrid scale variability found in the real world (Avissar, 1992). Two strategies are available to model surface processes at large scale: either to reformulate the physics to suit better the scale of interest, or to "scale up" a model embodying small-scale physics, by using it at larger scales (Short *et al.*, 1993). In the absence of reliable progress in reformulating of surface hydrology at large scale, the second strategy is certainly the easier way of predicting surface fluxes over large heterogeneous terrain. However, the problem encountered is to correctly determine the controlling surface parameters, such as aerodynamic resistance, surface resistance or albedo, taking into account their variability. Because of the non-linearity of surface processes, aggregated values of these parameters are not simple areal averages.

A heterogeneous landscape within a grid square can be seen as a collection or mosaic of different land surface elements, called "patches" or "tiles". Shut-

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tleworth (1988) and Raupach (1991) have distinguished between two classes of heterogeneous landscape: those heterogeneous "on the microscale" and those heterogeneous "on the macroscale". The latter have organized variability and the convective boundary layer (CBL) adjusts to successive surface types. Each patch develops its own CBL; and air characteristics vary from one patch to another. With this type of heterogeneity, it does not seem possible to provide a simple averaged treatment of the composite surface (Raupach, 1993). In landscapes with heterogeneity on the microscale, there is a disorganized variability and the CBL develops as it would over homogeneous terrain. In this case, the flux aggregation problem can be solved by assuming that the different land surfaces making up the grid square interact independently with the overlying atmospheric layer without an advection effect, i.e., they do not interact with each other through the ground or the canopy air (Koster and Suarez, 1992). Each patch is forced by the same incoming radiation and similar air characteristics. The microscale case is close to the pragmatic concept of "blending height", defined by Wieringa (1986) as the height at which the characteristics of the flow become approximately independent of horizontal position. In recent years, this approach has proved to be successful to calculate areally averaged surface fluxes (Mason, 1988; Claussen, 1991; Blyth *et al.*, 1993) .

In this paper, only landscapes with microscale heterogeneity are considered and local-scale advection is neglected, although it can result in substantial changes in regional fluxes (Klaassen, 1992) . Within this framework, attempts to solve the problem of flux aggregation by averaging surface parameters have been undertaken by Raupach (1991, 1993), Dolman (1992), Lhomme (1992), Chehbouni *et al.* (1994) and McNaughton (1994). In the following extension of these papers, we shall discuss aggregation procedures inferred from the principle of flux preservation.

2. Basic Equations and Assumptions

The same set of basic equations is used to describe the energy exchange processes at the land surface both at local scale and at grid-square scale. The sensible and latent heat fluxes are expressed by means of the classical one-dimensional diffusion equations

$$H = \rho c_p(T_s - T_a)/r_a, \tag{1}$$

$$\lambda E = (\rho c_p/\gamma)[e^*(T_s) - e_a]/r_v, \tag{2}$$

where ρ is the mean air density, c_p is the specific heat of air at constant pressure, γ is the psychrometric constant, T_a and e_a are the temperature and the water vapour pressure of the air in the well-mixed layer, $e^*(T_s)$ is the saturated vapour pressure at the surface temperature T_s, r_a is the aerodynamic resistance to heat and water vapour transfer from the surface to the well-mixed layer and r_v is the total resistance to water vapour transfer

$$r_v = r_a + r_s, \tag{3}$$

with r_s the surface resistance. Latent heat and sensible heat fluxes are linked by the energy balance equation

$$H + \lambda E = A = R_n - G, \tag{4}$$

where A is the available energy, R_n is the net radiation and G is the soil heat flux. R_n is

$$R_n = (1 - \alpha)R_s + \epsilon(R_l - \sigma T_s^4), \tag{5}$$

with α and ϵ the albedo and the emissivity of the surface, R_s and R_l the incoming short-wave and long-wave radiation, and σ the Stefan-Boltzmann constant.

The convective flux of latent heat can also be expressed in the form of the Penman–Monteith equation (Monteith, 1963), obtained by linearizing the saturated vapour pressure curve and by eliminating the surface temperature between the flux equations and the energy balance equation. This equation is

$$\lambda E = \frac{sA + \rho c_p D_a / r_a}{s + \gamma(r_v/r_a)}, \tag{6}$$

where s is the rate of change of the saturated vapour pressure with temperature, and D_a is the water vapour pressure deficit of the air in the well-mixed layer. A similar equation can be written for sensible heat flux

$$H = \frac{\gamma A - \rho c_p D_a / r_v}{\gamma + s(r_a/r_v)}. \tag{7}$$

The topic of this paper is the derivation of the aggregation procedures to be used to calculate the controlling parameters of the energy balance at grid-square scale. At this scale, these parameters are called "effective" and will be denoted by angle bracket. The air characteristics (T_a, e_a, D_a) in the well-mixed layer and the incoming radiation (R_s, R_l) are assumed not to vary over the whole area. The controlling parameters are albedo α, surface emissivity (ϵ), aerodynamic resistance r_a and global resistance to water vapour transfer r_v. In our approach, soil heat flux G is also considered as a controlling parameter although it is not like the others. But this assimilation can be legitimized by the fact that G acts only as a corrective term to net radiation (it is usually expressed as a fraction of R_n).

The strategy used consists in determining the effective parameters in such a way that the flux equations, valid at local scale, give the correct areal fluxes at grid-square scale. From the definition of a flux of mass or energy, the spatially averaged flux over a grid-square (denoted by angle bracket) is simply the area-weighted mean of the flux contributions from each patch. So, it is possible to write

$$\langle \phi \rangle = \sum_i a_i \phi_i \quad \text{with} \quad \phi = H, \lambda E, A, \tag{8}$$

where a_i is the fractional area of patch i. Aggregation rules will be derived which allow the fluxes to be preserved when passing from patch scale to grid-square scale. The basis of the derivation consists in requiring that the individual terms of the equation written as a summation over the different sub-areas, with local scale parameters, should match those of the equation written with effective parameters at coarser scale. This ensures that the effective parameters obtained in this way are irrespective of the meteorological forcing variables. Let us suppose we are interested in some aggregate quantity, denoted by Z (representing H, λE or A), which is expressed as a summation of m terms Y_k, each one a function of the surface properties x_j (x_j stands for α, ϵ, r_a, r_v, G or T_s)

$$Z = \sum_{k=1}^{m} Y_k(x_j). \tag{9}$$

Preserving this quantity leads to

$$\langle Z \rangle = \sum_i a_i Z_i = \sum_i a_i \sum_{k=1}^{m} Y_k(x_j^i) = \sum_{k=1}^{m} \sum_i a_i Y_k(x_j^i). \tag{10}$$

The same quantity, written with effective parameters, gives

$$\langle Z \rangle = \sum_{k=1}^{m} Y_k(\langle x_j \rangle). \tag{11}$$

Matching Equations (10) and (11), term by term, yields

$$Y_k(\langle x_j \rangle) = \sum_i a_i Y_k(x_j^i). \tag{12}$$

These m equations can be solved to express the effective surface parameters $\langle x_j \rangle$ as a function of local parameters x_j^i provided that the number of surface parameters is equal to the number (m) of terms in the expression of Z.

3. Theoretical Development

3.1. Procedures Derived from the Basic Flux Equations

After linearization of the saturated vapour pressure curve, the areal flux of latent heat, given by Equation (2) and denoted by angle brackets, can be rewritten with effective parameters as

$$\langle \lambda E \rangle = (\rho c_p/\gamma) \left[\frac{s\langle T_s \rangle + (D_a - sT_a)}{\langle r_v \rangle} \right]. \tag{13}$$

Applying Equation (8) to the linearized latent heat flux yields

$$\langle \lambda E \rangle = (\rho c_p/\gamma) \left[s \sum_i \frac{a_i T_{s,i}}{r_{v,i}} + (D_a - sT_a) \sum_i \frac{a_i}{r_{v,i}} \right]. \tag{14}$$

Matching term by term Equations (13) and (14) gives

$$\frac{\langle T_s \rangle}{\langle r_v \rangle} = \sum_i \frac{a_i T_{s,i}}{r_{v,i}}, \tag{15}$$

$$\frac{1}{\langle r_v \rangle} = \sum_i \frac{a_i}{r_{v,i}}. \tag{16}$$

These two equations provide an averaging procedure for the surface temperature T_s and the global resistance to water vapour transfer r_v.

Applying the same procedure to sensible heat flux by writing Equation (1) with effective parameters and as an area-weighted mean of individual fluxes leads to the following averaging scheme:

$$\frac{\langle T_s \rangle}{\langle r_a \rangle} = \sum_i \frac{a_i T_{s,i}}{r_{a,i}}, \tag{17}$$

$$\frac{1}{\langle r_a \rangle} = \sum_i \frac{a_i}{r_{a,i}}. \tag{18}$$

Available energy can be preserved according to Equation (8) as an independent magnitude, irrespective of flux Equations (H and λE). Developing R_n by taking account of Equation (5) leads to

$$\begin{aligned} \langle A \rangle &= (1 - \langle \alpha \rangle)R_s + \langle \epsilon \rangle (R_l - \sigma \langle T_s \rangle^4) - \langle G \rangle \\ &= \sum_i a_i[(1 - \alpha_i)R_s + \epsilon_i(R_l - \sigma T_{s,i}^4) - G_i], \end{aligned} \tag{19}$$

from which the following averaging procedures can be derived

$$\langle X \rangle = \sum_i a_i X_i \quad \text{for} \quad X = \alpha, \epsilon, G, \tag{20}$$

$$\langle T_s \rangle^4 = \frac{\sum_i a_i \epsilon_i T_{s,i}^4}{\sum_i a_i \epsilon_i}. \tag{21}$$

3.2. Procedures derived from the Penman–Monteith equations

Using the Penman–Monteith formulation, the areal flux of latent heat can be written as a function of the effective surface parameters as

$$\langle \lambda E \rangle = \frac{s[(1 - \langle \alpha \rangle) R_s + \langle \epsilon \rangle (R_l - \sigma \langle T_s \rangle^4) - \langle G \rangle] + \rho c_p D_a / \langle r_a \rangle}{s + \gamma(\langle r_v \rangle / \langle r_a \rangle)} \tag{22}$$

because R_s, R_l and D_a do not change over the whole area. Replacing λE_i in Equation (8) by its Penman–Monteith expression, and putting

$$\delta_i = \frac{1}{s + \gamma(r_{v,i}/r_{a,i})} \tag{23}$$

yields

$$\langle \lambda E \rangle = s \left[R_s \sum_i a_i \delta_i (1 - \alpha_i) + R_l \sum_i a_i \delta_i \epsilon_i - \sigma \sum_i a_i \delta_i \epsilon_i T_{s,i}^4 - \right. \\ \left. - \sum_i a_i \delta_i G_i \right] + (\rho c_p D_a) \sum_i a_i \delta_i / r_{a,i}. \tag{24}$$

Matching Equations (22) and (24), term by term, gives

$$\frac{1}{s + \gamma(\langle r_v \rangle / \langle r_a \rangle)} = \sum_i a_i \delta_i, \tag{25}$$

$$\frac{\langle \alpha \rangle}{s + \gamma(\langle r_v \rangle / \langle r_a \rangle)} = \sum_i a_i \delta_i \alpha_i, \tag{26}$$

$$\frac{\langle \epsilon \rangle}{s + \gamma(\langle r_v \rangle / \langle r_a \rangle)} = \sum_i a_i \delta_i \epsilon_i, \tag{27}$$

$$\frac{\langle \epsilon \rangle \langle T_s \rangle^4}{s + \gamma(\langle r_v \rangle / \langle r_a \rangle)} = \sum_i a_i \delta_i \epsilon_i T_{s,i}^4, \tag{28}$$

$$\frac{\langle G \rangle}{s + \gamma(\langle r_v \rangle / \langle r_a \rangle)} = \sum_i a_i \delta_i G_i \tag{29}$$

$$\frac{1/\langle r_a \rangle}{s + \gamma(\langle r_v \rangle / \langle r_a \rangle)} = \sum_i a_i \delta_i / r_{a,i}. \tag{30}$$

We have six Equations with six unknown variables, $\langle T_s \rangle$, $\langle \alpha \rangle$, $\langle \epsilon \rangle$, $\langle G \rangle$, $\langle r_v \rangle$ and $\langle r_a \rangle$. Combining Equations (26), (27), (29) and (30) with Equation (25), the following averaging procedure is obtained for albedo, emissivity, soil heat flux and aerodynamic conductance

$$\langle X \rangle = \frac{\sum_i a_i \delta_i X_i}{\sum_i a_i \delta_i} \quad \text{for} \quad X = \alpha, \epsilon, G, (1/r_a). \tag{31}$$

Combining Equations (28) and (27) yields

$$\langle T_s \rangle^4 = \frac{\sum_i a_i \delta_i \epsilon_i T_{s,i}^4}{\sum_i a_i \delta_i \epsilon_i}. \tag{32}$$

And combining Equations (25) and (30) leads to

$$\frac{1}{\langle r_v \rangle} = \frac{\sum_i a_i \theta_i / r_{v,i}}{\sum_i a_i \theta_i}, \tag{33}$$

with

$$\theta_i = \frac{1}{\gamma + s(r_{a,i}/r_{v,i})} = \delta_i \frac{r_{v,i}}{r_{a,i}}. \tag{34}$$

Using the Penman–Monteith form of the sensible heat flux with effective parameters leads to

$$\langle H \rangle = \frac{\gamma[(1 - \langle \alpha \rangle) R_s + \langle \epsilon \rangle (R_l - \sigma \langle T_s \rangle^4) - \langle G \rangle] - \rho c_p D_a / \langle r_v \rangle}{\gamma + s(\langle r_a \rangle / \langle r_v \rangle)}. \tag{35}$$

In the same way as for latent heat, one can infer the following expression from Equation (8)

$$\begin{aligned} \langle H \rangle \; = \; \gamma \Bigg[& R_s \sum_i a_i \theta_i (1 - \alpha_i) + R_l \sum_i a_i \theta_i \epsilon_i - \sigma \sum_i a_i \theta_i \epsilon_i T_{s,i}^4 - \\ & - \sum_i a_i \theta_i G_i \Bigg] - (\rho c_p D_a) \sum_i a_i \theta_i / r_{v,i}, \end{aligned} \tag{36}$$

with θ_i given by Equation (34). Matching Equations (35) and (36), term by term, yields six equations with six unknowns, as for latent heat flux. Combining these equations leads to the following averaging procedures:

$$\langle X \rangle = \frac{\sum_i a_i \theta_i X_i}{\sum_i a_i \theta_i} \quad \text{for} \quad X = \alpha, \epsilon, G, (1/r_v), \tag{37}$$

$$\langle T_s \rangle^4 = \frac{\sum_i a_i \theta_i \epsilon_i T_{s,i}^4}{\sum_i a_i \theta_i \epsilon_i}, \tag{38}$$

$$\frac{1}{\langle r_a \rangle} = \frac{\sum_i a_i \delta_i / r_{a,i}}{\sum_i a_i \delta_i}, \tag{39}$$

with δ_i given by Equation (23).

4. Discussion and Numerical Results

From the above, it appears that there are different averaging schemes to calculate the effective parameters according to the type of flux and the type of equation used. The effective parameters preserving latent heat flux, sensible heat flux and available energy are not calculated in the same way. And the results inferred using the Penman–Monteith Equations are different from those inferred from the basic flux Equations. It does not seem possible to conserve the three fluxes (H, λE and A) at the same time with the same set of effective parameters. There is one averaging scheme for each circumstance, depending on the results desired, and these different averaging schemes are not compatible amongst themselves. Tables I and II summarize the available procedures as a function of the type of equation used and the result expected. If the fluxes are calculated by the basic transfer Equations (1) and (2), the set of weighting factors given in Table I has to be used. If the fluxes are expressed by means of the Penman–Monteith equations, one must employ the aggregation procedures given in Table II. In this last case, one can notice that the effective resistances are expressed in the same way for conserving latent and sensible heat. It is also worthwhile noting that the energy balance equation (Equation (4)) is always closed at grid-square scale if the surface fluxes (H, λE and A) are simultaneously conserved according to Equation (8) (using for each flux the corresponding effective parameters), since the following equations hold

$$\begin{aligned} \langle \lambda E \rangle + \langle H \rangle &= \sum_i a_i \lambda E_i + \sum_i a_i H_i = \sum_i a_i (\lambda E_i + H_i) \\ &= \sum_i a_i A_i = \langle A \rangle. \end{aligned} \tag{40}$$

TABLE I

Weighting factors w_i (in the equation $\langle X \rangle = \sum w_i X_i / \sum w_i$) to be used for preserving the convective fluxes estimated by the basic diffusion equations (Ohm's law type formulations) and the available energy

Flux preserved	$\langle T_s \rangle$	$\langle X \rangle$ $X = \alpha, \epsilon, G$	$1/\langle r_a \rangle$	$1/\langle r_v \rangle$
λE	$a_i/r_{v,i}$	–	–	a_i
H	$a_i/r_{a,i}$	–	a_i	–
A	$a_i \epsilon_i^*$	a_i	–	–

*Applied to T_s^4.

TABLE II

Weighting factors w_i (as defined in Table I) to be used for preserving the fluxes estimated by the Penman–Monteith formulations

Flux preserved	$\langle T_s \rangle^4$	$\langle X \rangle$ $X = \alpha, \epsilon, G$	$1/\langle r_a \rangle$	$1/\langle r_v \rangle$
λE	$a_i \delta_i \epsilon_i$	$a_i \delta_i$	$a_i \delta_i$	$a_i \theta_i$
H	$a_i \theta_i \epsilon_i$	$a_i \theta_i$	$a_i \delta_i$	$a_i \theta_i$

With $\delta_i = 1/[s + \gamma(r_{v,i}/r_{a,i})]$ and $\theta_i = \delta_i(r_{v,i}/r_{a,i})$.

When each areal flux is calculated using its own effective parameters, the addition of the fluxes $\langle \lambda E \rangle$ and $\langle H \rangle$ automatically gives the areal available energy $\langle A \rangle$.

TABLE III

Characteristics of the surfaces considered in the numerical simulations

Parameters	Forest	Crop	Desert	Water
α	0.1	0.2	0.3	0.05
ζ	0.01	0.05	0.3	0.6
z_0 (m)	1.0	0.1	0.01	0.001
r_s (s m^{-1})	100	100	10000	0

α: albedo; $\zeta = G/R_n^*$; z_0: roughness length; r_s: surface resistance.

TABLE IV

Comparison between the areal fluxes calculated by means of the basic flux Equations (1) and (2). The areal value is obtained from Equation (8). The areal estimates use two types of aggregation procedure: (a) simple areal averaging of the parameters ($w_i = a_i$), and (b) averaging procedures given in Table I. The climatic conditions are: R_s = 800 W m^{-2}, R_l = 350 W m^{-2}, and at z_m = 50 m, T_a = 25 °C, e_a = 1500 Pa, u_m = 5 m s^{-1}

	Patch 1	Patch 2	Areal value	Areal estimates	
				(a)	(b)
Case 1:	Crop	Desert			
λE (W m^{-2})	342	11	176	261	176
H (W m^{-2})	140	213	177	207	177
A (W m^{-2})	482	224	353	361	360
r^* (%)	0	0	0	–30	2
Case 2:	Forest	Water			
λE (W m^{-2})	358	244	301	297	300
H (W m^{-2})	236	12	124	93	124
A (W m^{-2})	595	257	426	433	433
r (%)	0	0	0	10	2
Case 3:	Desert	Water			
λE (W m^{-2})	11	244	127	234	126
H (W m^{-2})	213	12	113	94	113
A (W m^{-2})	224	257	240	249	247
r (%)	0	0	0	–32	3

$^*r = 1 - (H + \lambda E)/A$.

A numerical simulation has been carried out to assess the performance of the different averaging procedures. Each scheme can be represented by the generic Equation

$$\langle X \rangle = \frac{\sum_i w_i X_i}{\sum_i w_i}, \tag{41}$$

where X stands for a controlling surface parameter (α, ϵ, G, $1/r_a$, $1/r_v$, T_s), and w_i are weighting factors. A heterogeneous surface consisting of just two patches of equal area has been considered. Three cases, corresponding to three different combinations of two contrasted patches, have been analysed: crop-desert, forest-water, and desert-water. The patch characteristics are given in Table III. Since surface emissivity does not vary markedly among the natural surfaces and much less than the other parameters, it is assumed to be constant over the whole area

TABLE V

Comparison between the areal fluxes calculated by means of the Penman–Monteith Equations (6) and (7). The areal value is obtained from Equation (8). The areal estimates use two types of aggregation procedure: (a) simple areal averaging of the parameters ($w_i = a_i$), and (b) averaging procedures given in Table II. The climatic conditions are the same as in Table IV

	Patch 1	Patch 2	Areal value	Areal estimates	
				(a)	(b)
Case 1:	Crop	Desert			
λE (W m^{-2})	334	8	171	196	171
H (W m^{-2})	149	216	182	158	182
A (W m^{-2})	482	224	353	361	360
r^* (%)	0	0	0	2	2
Case 2:	Forest	Water			
λE (W m^{-2})	353	244	299	311	299
H (W m^{-2})	241	12	127	115	127
A (W m^{-2})	595	257	426	433	433
r (%)	0	0	0	2	2
Case 3:	Desert	Water			
λE (W m^{-2})	8	244	126	178	126
H (W m^{-2})	216	12	114	64	114
A (W m^{-2})	224	257	240	249	247
r (%)	0	0	0	3	3

$^*r = 1 - (H + \lambda E)/A$.

and is taken equal to 0.98. The aerodynamic resistance r_a is calculated between the surface and a reference height (z_m) within the well mixed layer, assuming conditions of neutral atmospheric stability

$$r_a = \frac{\ln^2(z_m/z_0)}{k^2 u_m}, \tag{42}$$

where z_0 is the roughness length, k is the von Karman constant (0.4), and u_m is the wind velocity at the reference height z_m set to 50 m. Soil heat flux is calculated as a given fraction of the isothermal net radiation $G = \zeta R_n^*$ (R_n^* is defined by Equation (5) in which T_s is replaced by T_a). For each component of the whole area, the albedo (α), the surface resistance (r_s), the roughness length (z_0) and the coefficient ζ are specified as input. The surface temperature of each patch is calculated by solving the energy balance equation.

The simulation results are presented in Tables IV and V. In Table IV, the fluxes of sensible and latent heat are calculated by the basic Equations (1) and (2). In Table V they are calculated by the Penman–Monteith Equations (6) and (7). For each patch and for the whole area, the three fluxes (H, λE and A) are given. For the whole area, the flux is obtained by areally averaging the component fluxes according to Equation (8). This value is considered as the true areal flux and is used as a reference. Two areal estimates are given. The first one (a) is based upon a simple areal averaging of the surface parameters following Equation (41) with $w_i = a_i$. The second one (b) involves the averaging procedures issuing from the preservation of the corresponding flux. The closure of the energy balance Equation is tested by calculating the ratio

$$r = \frac{A - (H + \lambda E)}{A} \tag{43}$$

expressed in percentage. The results show that the simple areal averaging of the parameters (a) leads to a rather bad estimate of the areal fluxes of sensible and latent heat in both cases (basic equations and Penman–Monteith equations), and to a rather bad closure of the energy balance equation in the first case. The other procedure (b), which consists of using the appropriate aggegation scheme for each flux (H, λE and A), effectively preserves the fluxes, but also permits a good closure of the energy balance equation.

5. Conclusion

The main point is that there is no single correct way to define effective surface parameters over heterogeneous terrain. The effective value of a given parameter is not unique, but differs according to the magnitude being conserved and the equation used to express this magnitude. The different aggregation procedures obtained apply different weightings to the component parameters in forming their averages. These weighting factors are generally expressed as the product of the relative area of the patch (a) by a coefficient which involves a given combination of the patch resistances (r_a and r_v). The aggregation procedure to be used to preserve latent heat flux is *a priori* different from that preserving sensible heat flux and different from that preserving available energy. The procedure also depends on the type of formulation used (basic diffusion equations or their Penman–Monteith forms). It is worthwhile noting that when each areal flux is calculated using its own effective parameters (i.e., those allowing the flux conservation), the energy balance equation is automatically closed at large scale.

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