Methods to Aggregate Turbulent Fluxes over Heterogeneous Surfaces:

Application to SALSA data set in Mexico

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Abstract

The issue of using remotely sensed surface temperature to estimate the area-average sensible heat flux over surfaces made up of different vegetated patches has been investigated. The performance of three aggregation procedures, ranging from physically based through semi-empirical, to entirely empirical has been assessed by comparing measured and simulated area-average sensible heat flux. The results show that the physically based scheme perform very well. The performance of the entirely empirical scheme was reasonable but that of the semi-empirical scheme, which actually takes full advantage of remotely sensed data, was very poorly. This result suggests that unlike the case of surface fluxes, it is not appropriate to use relationships between model and observational variables (here radiative and aerodynamic surface temperature) that were developed and calibrated at a local/patch scale, for an application at a larger/grid scale just by scaling the parameters. Therefore, future research should be directed towards building robust relationships between model and observational variables directly at the large-scale.

Keywords: aerodynamic and radiative surface temperatures, effective parameters, aggregation rules, blending height, surface heterogeneity.

1. Introduction

It is well known that land characteristics vary across a wide range of spatial scales, from a few meters to hundreds of kilometers. Yet most large-scale atmospheric models assume homogeneity within a grid square and use the dominant vegetation type to specify the surface flux-controlling parameters. The issue of improving the representation of sub-grid scale heterogeneity in regional and global climate models has been an active research topic during the past decade. Consequently, substantial progress has been made in the development of aggregation schemes to estimate area-average surface fluxes over heterogeneous surfaces (Koster and Suarez 1992; Braden 1994).

Two main approaches have been used in developing such schemes: a stochastic-dynamic approach and a deterministic one. The stochastic approach consists of describing the heterogeneity of a surface parameter using a probability density function PDF (Avissar, 1992; Li and Avissar, 1994; Boulet et al. 1998). The unsolved issue here is to establish relationships between the PDFs of different surface parameters knowing their link at the local scale (through the water or energy balance for example). The deterministic approach, also called “the conceptual” approach, consists of formulating grid-scale surface fluxes using the same equations that govern the patch-scale behavior but whose arguments are the aggregate expressions of those at the patch-scale.

The strategy for linking local and aggregate or effective surface parameters can also be divided into two categories. The first one is essentially empirical and consists of postulating hypothetical rules such as considering that aggregate parameters can be derived as area-weighted averages of the local ones (Shuttleworth 1991; Blyth et al. 1993; Sellers et al. 1997; Noilhan and Lacarrere, 1995; Arain et al. 1996; Noilhan et al. 1997). The second is theoretical, where the relationships between local and effective surface parameters are derived analytically, through the matching of the model equations between scales (Raupach 1991 and 1993; McNaughton 1994; Raupach and Finnigan, 1995; Lhomme , 1992 and Lhomme et al. 1994; Chehbouni et al. 1995).

Research is currently under way to use remotely sensed data to improve the representation of surface heterogeneity in large-scale models (Sellers et al. 1997; Bastiaansen et al. 1998; Avissar, 1998). In this regard, Pelgrum and Bastiaansen (1996) used Landsat Thematic Mapper (TM) images in conjunction with an energy balance model to derive area-average surface fluxes during the European Field Experiment in a Desertification-Threatened Area (EFEDA). Moran et al. (1997) address the issue of sensible heat flux aggregation using several sets of spectral images with different spatial resolution taken during the MONSOON'90 Experiment. They conclude that there was substantial error in aggregation of sensible heat flux for sites with differences in surface roughness. Arain et al. (1996) have shown that the incorporation of remotely sensed land-cover classes improves the performance of global climate model simulations.

To take full advantage of the increasingly available remotely sensed data, one needs to establish, at different scales, relationships that link remote sensing observations to the variables needed to formulate surface fluxes (Njoku et al. 1996). Remotely sensed surface temperature is believed to be very useful for estimating surface fluxes since it results from the thermal equilibrium of the land-surface. Yet it represents a perfect example of the difficulties encountered in using remotely sensed data to infer surface fluxes over heterogeneous surfaces. From a theoretical viewpoint, sensible heat flux should be expressed in terms of the aerodynamic surface temperature since it is the aerodynamic surface temperature, which determines the loss of sensible heat flux from a surface. Aerodynamic surface temperature can be defined as the extrapolation of air temperature profile down to an effective height within the canopy located at the same height as the effective sink of momentum, at which the vegetation components of sensible and latent heat flux arise. Since aerodynamic surface temperature cannot be directly measured, it is often replaced by radiative surface temperature in the formulation of sensible heat flux. This usually requires, especially over sparsely vegetated surfaces, that a supplementary resistance, called excess resistance, be added to the aerodynamic resistance so that the simulated fluxes fit the measured ones. Adding such a resistance is fundamentally equivalent to establishing a relationship between radiative and aerodynamic surface temperatures. This issue has been heavily investigated during the past two decades (Kustas et al. 1989; Moran et al. 1994; Stewart et al. 1994; Lhomme et al. 1997; Chehbouni et al. 1996 and 1997; Sun and Mahrt 1996; Troufleau et al. 1997; Stewart et al. 1994; Cahill and Parlange, 1997). However, most of these studies have been confined to a patch-scale. The situation where different patches exist in the same grid has received less attention.

The objective of this study is to examine the performance of three different aggregation schemes or procedures to estimate area-average sensible heat flux over heterogeneous surfaces using radiative surface temperature. The surface is made up of two distinct and adjacent patches: sparse grass of about 0.8 km x 1 km and sparse mesquite of about 1 km x 1 km. Measurements, which were taken during the Semi-Arid Land-Surface-Atmosphere (SALSA) Research Program, are used to compare the performance of the three different aggregation schemes. Finally the possibilities and limitations for using aggregation rules in conjunction with remotely sensed data in free running predictive mode (stand-alone mode) are discussed.

2. Site and data description

The Upper San Pedro Basin was identified as the focus area for SALSA research (Goodrich et al. 1998). The basin embodies a number of characteristics, which make it an exceptional outdoor laboratory for addressing a large number of scientific challenges in arid and semi-arid areas. The basin represents a transition area between the Sonoran and Chihuahuan deserts. It is an international basin spanning the Mexico-United States border with significantly different cross-border legal and land use practices, as well as significant topographic and vegetation variation. Major vegetation types include desert grasslands, shrub-steppe, mesquite, oak Savannah, Pinyon-juniper, and Ponderosa pine.

The specific objective in the Mexican part of the basin was to investigate the effect of land degradation (grass-mesquite transition) on the partitioning of available energy into sensible and latent heat flux. To achieve this objective, two contrasting sites representing different situations with respect to surface degradation have been instrumented. The first site is a native and well managed grassland, which represents the pre-degradation conditions in the basin; the second is a mesquite site representing the ultimate stage of the degradation process.

Toward the end of the growing season, a degraded grassland site adjacent to the mesquite site was instrumented for this particular study. This provides a grid made up of two adjacent sites / patches of about 1 km^2 each . The vegetation cover was sparse, about 35 % in the grass (*Bouteloua*) patch and about 30% in the mesquite (*Prosopis velutina*) patch. The aerodynamic characteristics of the two vegetation types were very different: the average grass height was about 0. 25 m while the average mesquite height was about 4.26 m. Values of leaf-area-index (LAI) for the grass and for the mesquite were estimated to be 0.3 and 0.85 respectively.

A meteorological tower of 12 m height was installed in the middle of the mesquite site and one of 3 m in that of the degraded grassland site. These towers were equipped with a set of standard meteorological instruments to measure the air temperature, relative humidity, incoming solar radiation, wind speed, wind direction, and precipitation. These standard meteorological measurements were sampled every ten seconds and an average was recorded every 30 minutes. Over the mesquite site, sensible and latent heat fluxes were measured using a 3D sonic anemometer, a fast response thermocouple and a fast response hygrometer (Campbell Scientific Inc., USA). Over the grass site sensible heat flux was measured using a 3D sonic anemometer (Applied Technology, USA). T the end of the experiment, these two eddy correlation devices have been run side by side over a homogeneous grassland site. A linear regression, forced through the origin, gave a slope of 0.97 and a correlation coefficient of 0.93 with a standard error of 22 Wm^{-2}.

Over each site, net radiation was measured using Q7.1 net radiometers (REBS

Inc., USA), soil heat flux was measured using 6 HFT3 plates (REBS Inc., USA), soil temperature and soil moisture were measured at different depths using 6 108 temperature probes and 6 CS600 TDR (Time Domain Reflectometer) probes respectively (Campbell Scientific Inc., USA). Radiative surface temperature over the grass site was measured using Everest Interscience (USA) infrared radiometer (IRT) with a 15^o field of view. Over the mesquite site, two IRTs has been used. One IRT was installed over a representative mesquite tree. Since the mesquite trees are very close, a radiative measurement made over the mesquite will integrate the thermal emission of the leave and the trunk as well as that over the soil underneath (shaded bare soil). The second one was installed over open bare soil so that temperature of illuminated bare soil is measured. Radiative temperature was then computed as an area-weighted average of the component temperatures. The band pass of these radiometers is nominally 8-14 μm. Surface temperature measurements were then corrected using an effective emissivity value of 0.98 for both sites following the investigation performed by Humes et al. (1994) in the same basin. Here also, it is worthwhile to mention that a systematic calibration between a black body and all the infrared radiometers used in this study has been performed. The average slope (correlation coefficient) was about 0.98 (0.99) and the average error was less than 0.5 °C.

For this particular study, data collected over the mesquite site and the adjacent degraded grassland site are considered. Daytime data over each patch from Day of

Year (DOY) 265 to DOY 274 have been used, which corresponds to the end of the growing season. Figure 1 presents the differences in measured sensible flux between mesquite and grass patches. This figure shows that there are significant differences between the two patches. The observed differences can be up to 130 Wm^{-2} for sensible heat flux. At first glance, the contrasting behavior can be explained in terms of the difference in canopy height and cover (which influences the aerodynamic flow above the canopy) and the differences in the rooting depth between the grass and the mesquite (which determines the availability of soil moisture to the plants). However, in contrast to the wet season, sensible heat measured over the mesquite during the dry season was larger to that over the grass. The soil in the mesquite was very degraded with a large proportion of rocks/stones. This leads to high sensible heat flux production especially from the bare soil component. As shown in Figure 2, this is the consequence of the fact that under such low soil moisture condition, radiative surface temperature observed over the mesquite was much larger than that of the grass (by up to 6 °C).

3. Modeling approach

Sensible heat flux at a given spatial scale is formulated in terms of aerodynamic surface temperature as:

$$H = \rho Cp \frac{T_o - T_a}{r_a} \tag{1}$$

where ρ is the air density (kg m^{-2}), C_p is the specific heat of air at constant pressure (*J kg^{-1}K^{-1}*). T_a (K) is the air temperature at a reference height above the surface; T_o is the aerodynamic surface temperature (K), defined at the mean canopy source. r_a is the aerodynamic resistance in (sm^{-1}) corrected for the stability / unstability effects following Choudhury et al. (1986). The zero plane displacement height (d) and the roughness length for momentum (z_o) are determined following Choudhury and Monteith (1988) who fitted simple functions to curves obtained by Shaw and Pereira (1982) from second-order closure theory (the mean drag coefficient was taken to be equal to 0.2). This formulation presents two main advantages compared to the rule of thumb one. First, the vertical structure of the vegetation is taken into account through the use of LAI. Second, the effect of substrate is included in the roughness length calculation.

Sensible heat flux can be re-written in terms of radiative surface temperature and an excess resistance as:

$$H = \rho Cp \frac{T_r - T_a}{r_a + r_{ex}} \tag{2}$$

where T_r is the remotely sensed radiative surface temperature, r_{ex} is the additional resistance required to take into account the difference between radiative and aerodynamic surface temperature (Hall et al. 1992). Alternatively, Chehbouni et al. (1996) showed that sensible heat flux can also be written using the following equation:

$$H = \rho C p \, \beta \frac{T_r - T_a}{r_a} \tag{3}$$

where β is an empirical function of the LAI that relates aerodynamic to radiative surface temperature. Based on the investigation of Chehbouni et al. (1996), β can be expressed for low LAI values as:

$$\beta = \frac{T_o - T_a}{T_r - T_a} = \frac{1}{\exp(L/(L - LAI)) - 1} \tag{4}$$

L is a site specific calibration coefficient that has been calibrated using the 1997 data set to a 1.5 (Watts et al., this issue). It is important to emphasize that the excess resistance and β approaches are functionally equivalent. In fact there is a reciprocal relationship between them ($r_{ex} = r_a (\beta^{-1} - 1)$). Therefore the expression in Eq. 3 will be used in the remainder of this study.

Before addressing the aggregation issue, we first verified the performance of

Equations 3 and 4 at the patch-scale. Figure 3 and Figure 4 present a comparison between observed and simulated sensible heat flux for the grass and mesquite patches, respectively. The Root Mean Square Error (RMSE) between observed and simulated flux values was 27 W m^{-2} for the grass and 51 W m^{-2} for the mesquite. These results are similar to those reported in Chehbouni et al. (1996 and 1997). It is worthwhile to mention that the excess resistance approach, with an appropriate calibration, can provide similar results, but this is not the thrust of the present study.

3.1. Aggregation procedures

The non-linear nature of the transfer processes dictates that only the scalar fluxes can be linearly averaged to give area-average values. Therefore grid-scale sensible heat flux can be obtained as:

$$< H >= fH_m + (1 - f) H_g \qquad (5)$$

where H_g and H_m are the sensible heat flux emanating respectively from the grass and from the mesquite, and f is the fraction of the grid covered by the mesquite (about 0.55 here). Grid-scale sensible heat fluxes can also be expressed in terms of the effective surface controlling parameters (denoted by angle brackets) using Equations (1) and (3) as:

$$< H >= \mathbf{r}\, Cp \frac{< T_o > - T_a}{< r_a >} \tag{6}$$

$$< H >= \mathbf{r}\, Cp < \mathbf{b} > \frac{< T_r > - T_a}{< r_a >} \tag{7}$$

According to Shuttleworth (1988) and considering the size of the patches, the heterogeneity of the surface can be considered *disorganized* (micro-scale heterogeneity) where the air above the surface is sufficiently mixed so that the atmospheric boundary layer responds only to the composite surface structure. Thus atmospheric forcing parameters are common to both patches and the air temperature and wind speed is assumed constant over the grid. The values measured at 10.8 m over the mesquite site have been used here.

By substituting Equation 1 into Equation 5 and matching term by term with Equation 6, effective aerodynamic resistance and the effective aerodynamic temperature can be analytically derived as:

$$\frac{1}{< r_a >} = \frac{f}{r_{am}} + \frac{1 - f}{r_{ag}} \tag{8}$$

$$< T_o > = \left(\frac{f\, T_{om}}{r_{am}} + \frac{(1-f)\, T_{og}}{r_{ag}} \right) \Bigg/ \left(\frac{f}{r_{am}} + \frac{1-f}{r_{ag}} \right) \tag{9}$$

where the subscript g stands for grass and m for mesquite. Similarly, using Equations 3, 5 and 7, effective radiative temperature and effective β are obtained as:

$$< Tr > = \left(\frac{f\; T_{rm}\, \beta_m}{r_{am}} + \frac{\beta_g\, (1-f)\, T_{rg}}{r_{ag}} \right) \Bigg/ \left(\frac{f\, \beta_m}{r_{am}} + \frac{(1-f)\, \beta_g}{r_{ag}} \right) \tag{10}$$

$$< \beta > = \left(\frac{f\, \beta_m}{r_{am}} + \frac{(1-f)\, \beta_g}{r_{ag}} \right) \Bigg/ \left(\frac{f}{r_{am}} + \frac{1-f}{r_{ag}} \right) \tag{11}$$

Equation (10) indicates that the effective surface temperature is not a direct area-average of the component temperatures but is weighted by the component resistances r_a and coefficients β. It also indicates that, in principle, the only straightforward case where effective radiative temperature can be precisely equated to composite surface temperature (simple area-weighted component temperatures) is where the ratio (β / r_a) are the same for the entire grid. Similarly Equation 11 indicates that the effective β is not an area-weighted average of individual components, but the weighting also involves aerodynamic resistance. One should mention that this aggregation procedure (Equations 8 to 11: scheme 1) does not deal directly with the primary surface variables such as roughness length, displacement height, and LAI, involved in the expression of resistance to heat transfer which can be empirically derived from remotely sensed data.

A second aggregation scheme (scheme 2) can be derived following the idea suggested by Shuttleworth (1997). He stipulates that the "*effective area-average value of land surface parameters is estimated as a weighted average over the component cover types in each grid through that function involving the parameter which most succinctly expresses its relationship with the associated surface flux*". The application of this rule to sensible heat flux allows the derivation of the following set of relationships between local and effective surface parameters as:

$$\ln^{-2}\left(\frac{z_b - \langle d \rangle}{\langle z_o \rangle}\right) = f \ln^{-2}\left(\frac{z_b - d_m}{z_{om}}\right) + (1-f)\ln^{-2}\left(\frac{z_b - d_g}{z_{og}}\right) \qquad (12)$$

$$\langle d \rangle = f\, d_m + (1-f)\, d_g \qquad (13)$$

$$\langle \boldsymbol{b} \rangle = \frac{1}{\exp(L/(L - \langle LAI \rangle)) - 1} \qquad (14)$$

$$\langle LAI \rangle = f\, LAI_m + (1-f)\, LAI_g \qquad (15)$$

$$\langle T_r \rangle = f\, T_{rm} + (1-f)\, T_{rg} \qquad (16)$$

where z_b is the so-called blending height defined as a level in the atmosphere where turbulent mixing is sufficient so that it can be assumed that the atmosphere has became blended to the differing types of land cover on the ground below (Wieringa, 1986). The blending height was estimated to of the order $l/100$, where l is the characteristic horizontal scale of the different patches making up the grid (roughly about 1 km in the present study). Finally, a third aggregation scheme (scheme 3) can be obtained by considering that effective surface temperature and effective β can be obtained as an area weighted average of their corresponding component values and effective aerodynamic resistance can be obtained as a mid-point of series and parallel expressions (Blyth et al. 1993, Blyth and Harding, 1995; Blyth and Dolman, 1995).

Before comparing the performances of the 3 schemes, it is of interest to analyze their differences and the assumptions associated with each of them. It can be said that the resulting set of relationships between local and effective parameters in scheme 1 is exact (within the limits of the equation assumed to apply at the local scale) while the relationships associated with scheme 3 are purely empirical. Scheme 2 can be considered as semi-empirical. In fact, Equations 12 and 13 lead to the formulation of effective aerodynamic resistance given in Equation (8) under neutral conditions (Shuttleworth et al. 1997). It is important to notice that Equation (14) assumes that the relationship between observational and model parameters (here radiative and aerodynamic temperatures) is generic or universal, in the sense that it is can be expressed in a similar manner at both patch and grid scales. Besides this assumption, which needs to be verified, scheme 2 has a major advantage with respect to schemes 1 and 2 since it does not require subgrid-scale information such as individual (component) resistance. In this regard, Scheme 2 makes full use of surface parameters that can be obtained from remote sensing.

4. Results

Area-average sensible heat flux values derived using the three aggregation schemes are compared against measured area-average values obtained by weighting the values measured of each patch by their fraction cover. We recognize that area weighted values of measured flux over individual patches may not be adequate to represent a true area-averaged heat flux over such complex terrain. Many more flux stations might be required to give an accurate estimate of the true area-average flux. However, Chehbouni et al. (this issue) showed these area weighted averages compared well with scintillometer measurements which provide a direct estimate of area-average sensible heat flux.

Figure 5 presents a comparison between simulated and measured fluxes using scheme 1. It can be seen the correspondence is very good. The RMSE between observed and simulated area-average fluxes was 30 W m^{-2} and the correlation coefficient and the slope associated with the linear regression forced to the origin were 0.91 and 1.04, respectively. This indicates that scheme 1 is very effective in deriving area-average sensible heat flux over heterogeneous surfaces, at least under the prevailing conditions at this study site. Figure 6 presents the same comparison but using scheme 2. It is clear that this scheme overestimates area-average fluxes. The RMSE between measured and simulated values was 88 Wm^{-2} which is about more than 2.5 times that of scheme 1. The correlation coefficient and the slope associated with the linear regression forced to the origin were 0.91 and 1.57, respectively. Figure 7 presents the same comparison for scheme 3. This scheme also presents a slight overestimation of the observed fluxes. The RMSE was about 52 W m^{-2} and the correlation coefficient and the slope associated with the linear regression forced to the origin were 0.91 and 1.23, respectively. However, despite the observed overestimation, especially at large flux values, the overall performance of this scheme is correct considering the difficulty in estimating surface fluxes over such complex terrain.

To interpret these results, we present in Table 1 the average surface temperature and the average of the ratio between effective values of aerodynamic resistance and β associated with each of the three aggregation schemes. This table shows that effective and composite surface temperatures (Equation 16) are similar despite the expected non-linearity caused by the Planck function. This is of interest since composite surface temperature can be directly measured from remote sensing. The ratio $<r_a>/<\beta>$

associated with scheme 3 is closer to that of scheme 1, as compared to scheme 2. It is precisely this ratio which really determines the transfer coefficient. This explains the better performance of scheme 3 versus scheme 2.

The influence of changing the fractional area of each patch on the performance of the three schemes has been numerically explored by re-running the three procedures using different proportions of mesquite / grass patches. The results showed that scheme 2 can perform similarly to scheme 3 for large fractional cover of the mesquite patch. In the same vein, the effect of changing vegetation characteristics on the results of the aggregation models model has also been investigated. The results showed that, for example, by dividing the mesquite height by 2 or by multiplying the LAI of the grass by 2, scheme 3 performed much better than scheme 2. This may indicate that the reported good performance of similar empirical schemes in previous studies might be specific to the conditions where these studies were performed.

5. Discussion and conclusion

Recently, several studies have been carried out to investigate the issue of aggregating surface fluxes and parameters over heterogeneous surfaces. The results reported are conflicting. Numerical simulation studies have emphasized the need to develop theoretically-based aggregation schemes which take into account the non-linear nature of the relationships between surface fluxes and surface parameters (Raupach and Finnigan 1995; Braden, 1994, Lhomme et al. 1994, Chehbouni et al. 1995). However, other studies where field measurements are used suggest that the simple empirical aggregation rules may provide accurate estimates of area-average surface fluxes, at least for clear weather conditions (Noilhan et al. 1997; Blyth and Harding, 1995; Arain et al. 1996; Moran et al. 1997, Sellers et al. 1997).

In this study, the issue of estimating area-average sensible heat flux using remotely sensed surface temperature over surfaces presenting heterogeneity at both patch and grid-scales has been investigated. The performance of three aggregation schemes ranging from physically-based through semi-empirical to entirely empirical has been assessed by comparing measured and estimated area-average sensible heat flux. The results show that the physically based procedure (scheme 1) provides very good estimates of area-averaged sensible heat flux. However, this procedure requires the knowledge of surface parameters such as radiative temperature and more importantly aerodynamic resistance and β or its equivalent at the patch scale which cannot be obtained from remote sensing at the appropriate time-space scale. The performance of scheme 3 was reasonable, but this scheme also required patch scale component resistance. This is actually a major limitation of this type of procedure. As pointed out by Shuttleworth et al. (1997), these exact aggregation procedures cannot be routinely applied to a model which is operating at the grid scale in free running predictive mode.

In this regard, the semi-empirical procedure (scheme 2) seems more practical, but it did not perform very well in the present study. One possible explanation of the poor performance of scheme 2 might be that the relationships between model and observational variables (here between radiative and aerodynamic temperatures) are not universal or generic, but are scale dependent. This might only be true for the particular nonlinear relationship used here (Eqs. 4 and 14), but this is unlikely since most, if not all, relationships between observational and model variables are non-linear. Therefore, to take full advantage of the increasing availability of multi-spectral remotely sensed data, future research should be directed towards building robust relationships between model and observational variables directly at the grid-scale. More importantly, these relationships need to be validated using data taken over a range of surface type combinations. It is the intention of the authors to test this approach during the coming years.

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Figure Captions

Figure 1: Difference in sensible heat flux values measured over mesquite and over grass.

Figure 2: Difference in radiative surface temperature values measured over mesquite and over grass.

Figure 3: Comparison between measured and simulated sensible heat fluxes for the grass patch.

Figure 4: Comparison between measured and simulated sensible heat fluxes for the mesquite patch.

Figure 5: Comparison between measured and simulated area-average sensible heat flux using the physically based aggregation procedure (scheme 1).

Figure 6: Comparison between measured and simulated area-average sensible heat flux using the semi-empirical procedure (scheme 2).

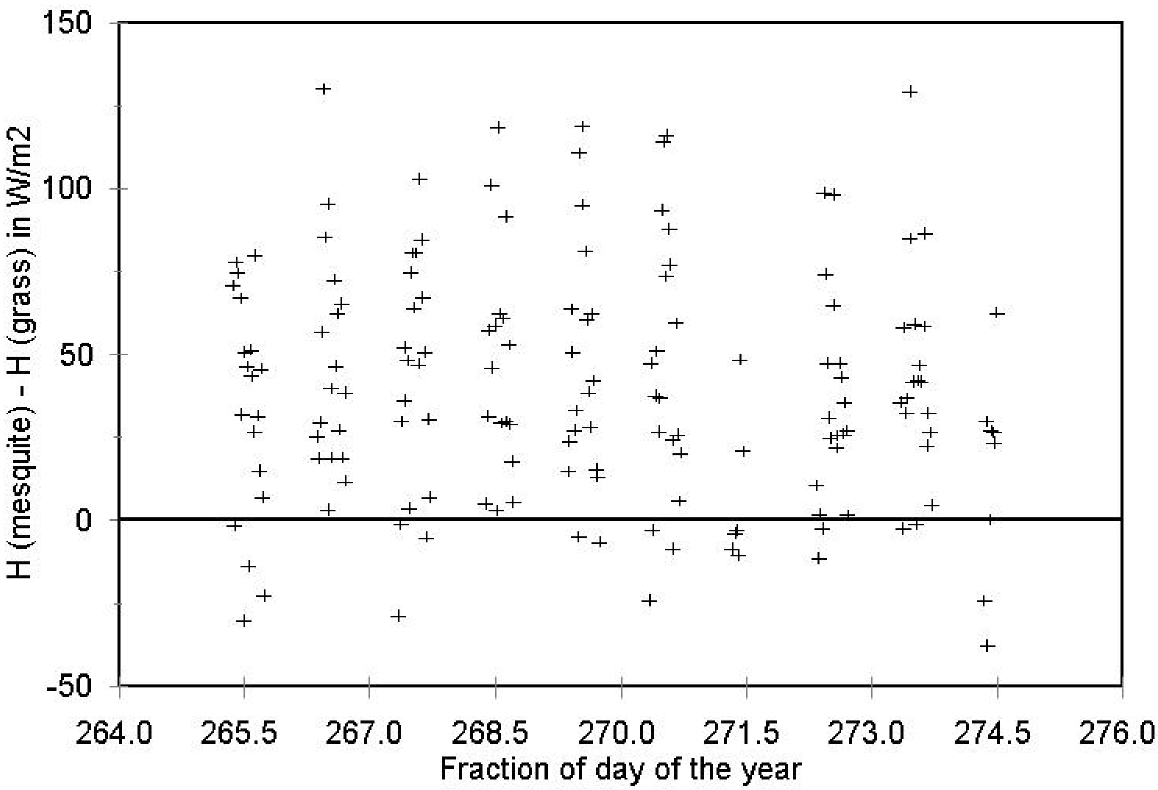
Figure 7: Comparison between observed and simulated area-average sensible heat flux using the entirely empirical procedure (scheme 3).

Table 1: Time average of the ratio between effective values of aerodynamic resistance and β coefficient and effective radiative surface temperature simulated by each aggregation schemes.

Scheme number	$<r_a> / <\beta>$	$<T_r>$
Scheme 1	91.19	41.34
Scheme 2	59.35	41.24
Scheme 3	76.14	41.24

(Chehbouni, *Ref. # S-07)*

Fig1



(Chehbouni, *Ref. # S-07)*

Fig2

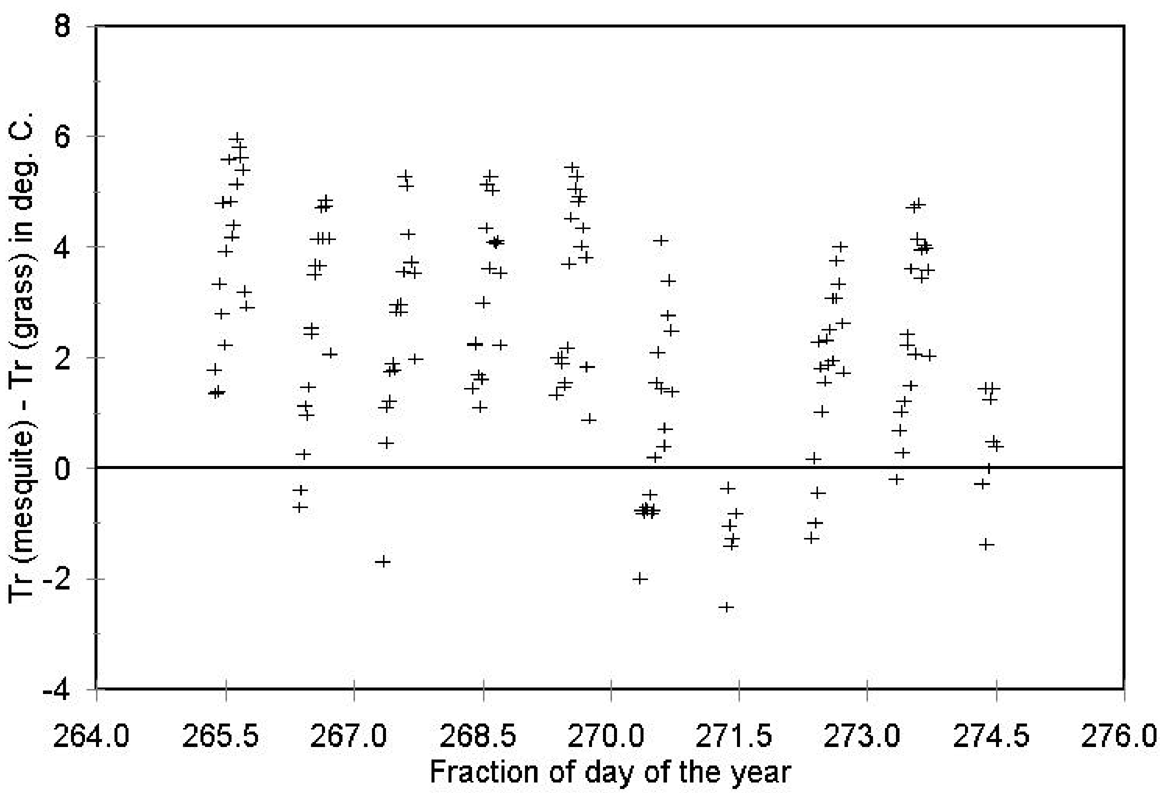


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Fig3

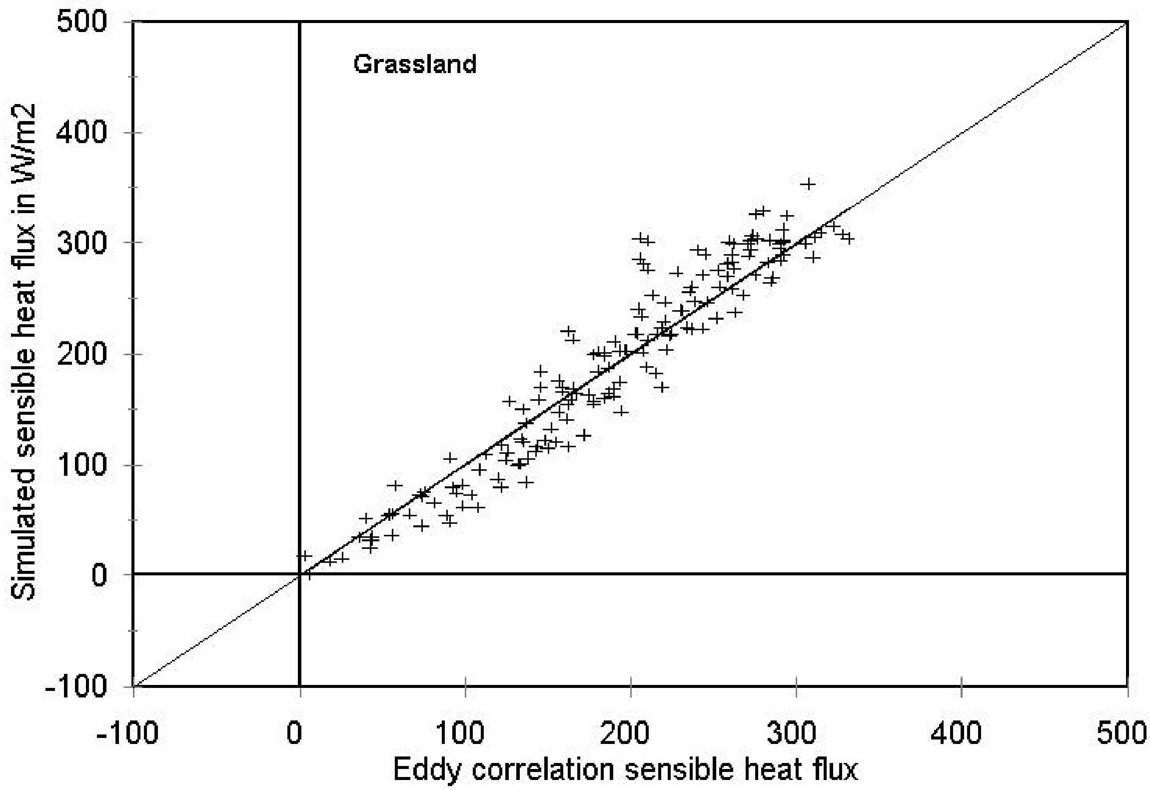

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Fig4

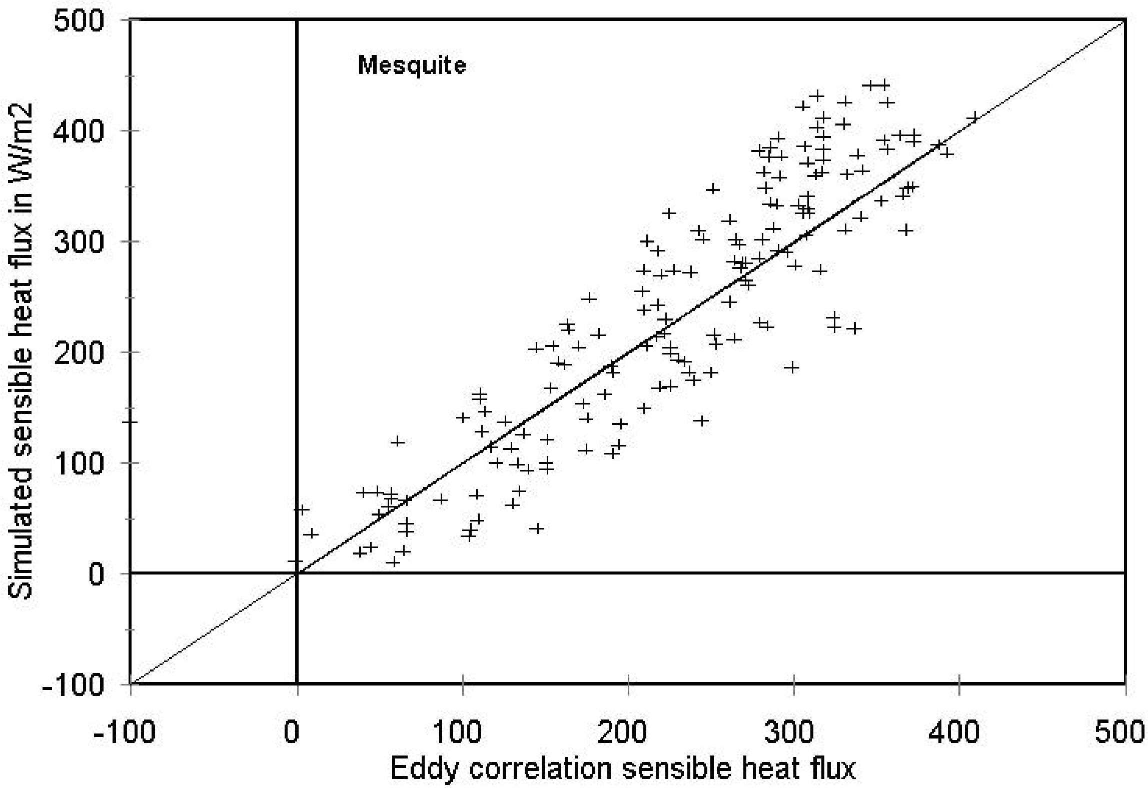

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Fig5

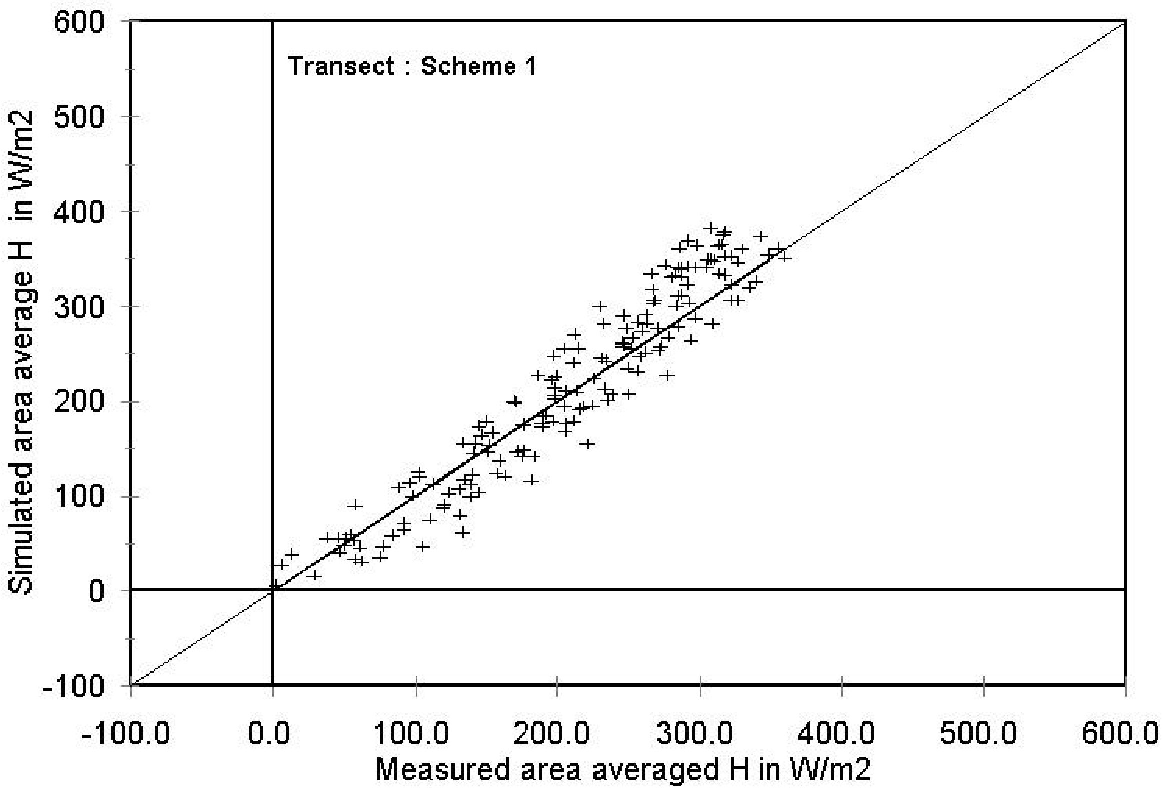

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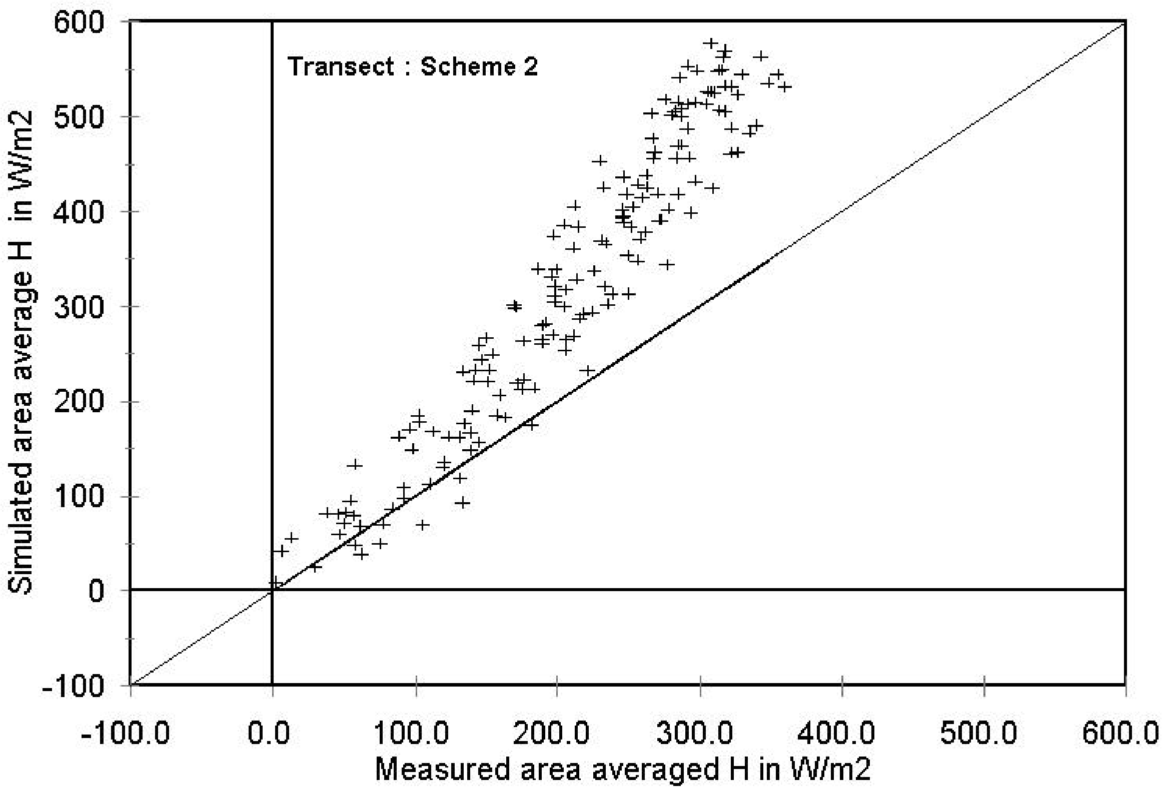
Fig6



(Chehbouni, *Ref. # S-07)*

Fig7