ESTIMATION OF SAHELIAN SURFACE FLUXES FROM ATMOSPHERIC BOUNDARY LAYER CHARACTERISTICS.

J.-P. Lhomme*, B. Monteny* et P. Bessemoulin**

* Laboratoire d'Hydrologie, ORSTOM, BP 5045, 34032 Montpellier, France.
** CNRM, 42 Av. G. Coriolis, 31057 Toulouse, France.

ABSTRACT

Regional scale fluxes of sensible heat, latent heat and CO_2 are estimated by means of a method based upon an integrated form of the conservation equation for a given scalar. This method, which involves the heat and mass budget of the convective boundary layer (CBL), is used with data collected at several days of measurements of HAPEX–Sahel, during the rainy season and the beginning of the dry season in 1992. The regional estimates of sensible heat flux agreed well with surface values, without any correction for advection (Hipps et al., 1994). For latent heat flux, only four days out of eight gave satisfactory agreement, and the advection term did not improve the agreement for the rest of the days. For CO_2 flux calculation, the method designed by Raupach et al. (1992), linking regional fluxes to concentrations measured within the surface layer, is used. The estimates obtained for the CO_2 uptake at regional scale differ from those measured on a fallow savannah, but the overall trend (a decrease of the CO_2 uptake due to soil depletion and vegetation drying–out) is respected.

INTRODUCTION

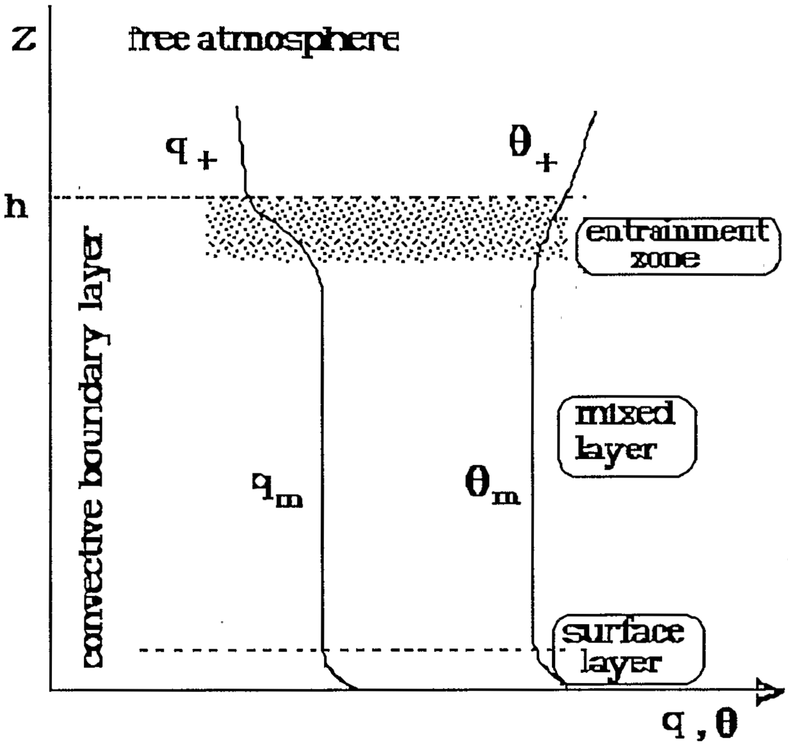
The convective boundary layer (CBL) consists of a progressively growing layer of strong convective turbulence, which moves across the land surface in response to the mean wind field. Its properties change by incorporating surface fluxes (heat, water vapour, carbon dioxyde) and overlying air into itself. This kind of change occurs in most fair–weather conditions, but not when the atmosphere is disturbed by fronts, by deep cumulus convection (Raupach, 1992), or by storms. The CBL acts as a large natural integrator of patch–scale surface heterogeneities, and its characteristics can be used to infer regional surface fluxes over heterogeneous terrain. The determination of exchanges of mass and energy at regional scale is a key issue in our understanding of land surface–atmosphere interactions. There exist two main appoaches for evaluating surface fluxes from properties of the CBL. One uses similarity theory and infers surface fluxes from flux–gradient relationships (Abdulmumin et al., 1987; Brutsaert and Sugita, 1991). Surface roughness and surface concentrations must be specified together with wind velocity. The other approach is based upon conservation equations for scalar entities. These equations, which describe the overall behaviour of the CBL, have been examined and used by several authors (McNaughton and Spriggs, 1986; McNaughton, 1989; Hipps et al., 1994; Lhomme et al. 1996). Munley and Hipps (1991) compared the two approaches and concluded that the one involving conservation equations have a more sound basis than similarity approaches and produced better evaporation estimates. Diak and Whipple (1994) made accurate estimates of the regional daytime fluxes of sensible and latent heat using the time–change of the height of the CBL interpreted by a surface layer– mixed layer model.

The experimental data used in this paper come from the Hydrologic Atmospheric Pilot Experiment in the Sahel denominated HAPEX–Sahel (Goutorbe et al., 1994; Prince et al., 1995). It was a coordinated experiment of field measurements, aiming at a better understanding of biosphere – atmosphere exchange processes at diffferent scales of space and time, in a semi–arid environment. Its main objective was to bridge the gap between the local and the GCM grid box scale. The Sahelian environment is characterized by a highly variable rainfall, much less than potential evaporation, which results in a very sparse vegetation cover and highly intermittent streamflow. Within this context, this paper intends to link the atmospheric characteristics (temperature and water vapour) measured by radiosoundings to the corresponding regional surface fluxes using CBL budgets. It also intends to infer CO_2 surface flux from concentration measurements made within the surface layer and from the heights of the CBL (Lhomme et al. 1996). A previous study on the Sahelian convective boundary layer and the prediction of this growth has been carrried out by Culf (1992).

THEORETICAL ASPECTS

Integral form of the CBL budget equation

It is possible to infer regionally averaged surface fluxes of scalar entities (water vapour, carbon dioxide) from concentration C measurements by using the daytime CBL as a semi–closed region. The CBL comprises a relatively thin surface layer, where the gradients of scalar entities may be significant, and a well–mixed layer.



Above the capping inversion of the mixed–layer is the free atmosphere, whose properties are determined by synoptic scale processes. The figure gives the schematic structure of potential temperature θ and specific humidity ρq profiles through the convective boundary layer. In the absence of subsidence, the integral form of the CBL budget (McNaughton and Spriggs, 1986) is :

$$I_c = \int_{t1}^{t2} F_c(t)\, dt = h_2 C_{m2} - h_1 C_{m1} - \int_{h1}^{h2} C_+(h)\,.\, dh \qquad (1)$$

$$\text{with} \int_{h1}^{h2} C_+(h)\,.\, dh = (h_2 - h_1)\,(C_{+2} + C_{+1})/2$$

where I_c is the cumulative surface flux between t_1 and t_2 and C_+ varies linearly with h. This equation can be rewritten as :

$$I_c = h_2(Cm_2 - C_+) - h_1(Cm_1 - C_+) \quad (2)$$

where C_+ is defined as the mean value $(C_{+1}+C_{+2})/2$. McNaughton (1989) proposed a similar formula to estimate the drawdown in CO_2 during the convective hours of the day. If t_1 is chosen as the time when $C_m=C_+$, Equation (2) simplifies into the equation given by Raupach et al. (1992) :

$$Ic(t) = h(t)[Cm(t) - C+,]$$

It should be noted that Equation (1) or (2) does not account for any effects due to large scale advection or subsidence. Hipps et al. (1994) subtracted to the right–hand member of Equations (1) or (2) an explicit term A describing horizontal advection. Its calculation is based upon the assumption that advection is constant throughout the CBL and related to the temporal change, between t_1 and t_2, of the scalar concentration in the layer of air just above the CBL at the height h_2. If this concentration passes from $C_{+2}(t_1)$ to $C_{+2}(t_2)$, is written as :

$$A = \int_{C_{+2}(t_1)}^{C_{+2}(t_2)} h.(C_{+2}) \,.\, dC_{+2} \quad \text{or} \quad A = \Delta C_{+2}(h_1 + h_1)/2 \quad (3)$$

by assuming a linear variation of h as a function of C_{+2} and by putting $\Delta C_{+2}=C_{+2}(t_2)-C_{+2}(t_1)$,

Equations (2) and (3) will be used to evaluate the time–integrated flux of sensible heat and water vapour from radiosoundings measurements (Table 1). For sensible heat C stands for $\rho c_p q$ where ρ is air density, c_p is the specific heat of air at constant pressure and θ is the potential temperature. For water vapour C must be substituted by ρq, where q is the specific humidity of air (Table 2).

CBL budget equation involving surface concentrations

Very often the height where concentration measurements are made is located within the surface layer. Consequently, a correction is required to account for the concentration difference between the measurement height (C_s) and the well–mixed layer (C_m). Raupach et al. (1992) developed a correction based upon the rough approximation $I_c \approx F_c\,(t_2-t_1)$, and the flux–gradient relationship $F_c=(C_s-C_m)/r_a$ where r_a is the aerodynamic resistance between the measurement height and a height within the well–mixed layer. Combining these two relationships with Equation (1) yields

$$I_c = \frac{h_2[C_{s2} - C_+] - h_1[C_{s1} - C_+]}{1 + r_a(h_2 - h_1)/(t_2 - t_1)} \quad (4)$$

where C_+ is the mean concentration just above the CBL. The aerodynamic resistance r_a between the height z_1 within the surface layer, at which concentration is measured, and a height z_2 within the well–mixed layer (say z_2 =100 m), is calculated from surface layer similarity theory and written as (Brutsaert, 1984)

$$r_a = \frac{1}{ku^*}[\ln(\frac{z_2 - d}{z_1 - d}) - (\Psi_H(\zeta_2) - (\Psi_H)\zeta_1))] \quad (5)$$

where k is the von Karman constant (0.4), $u*$ is the friction velocity, d is the zero plane displacement height. Ψ_H is the integral diabatic function for heat and mass in unstable conditions as given by Dyer (1974) :

$$\Psi_H(z) = 2\ln[\frac{1+(1-16\zeta)^{1/2}}{2}] \quad \text{and} \quad u* = \frac{ku}{\ln[(z-d)/z_o}] - \Psi_M(\zeta)$$

with $\int=(z-d)/L$, a dimensionless parameter, function of the Monin–Obukhov length L, defined as $L=-(u^{*3}\rho c_p T_a)/(kgH)$, where g is the acceleration of gravity, H is sensible heat flux, and T_a is air temperature in Kelvin. The friction velocity is calculated by an iteration process from the wind speed u at a given height z above the surface with the expression. ¥M(∫) is the stability function for momentum and z_0 is the roughness length. Equations (4) and (5) will be used to determine the time–integrated CO_2 flux from measurements of the CBL heights (h_1 and h_2) and of the corresponding concentrations within the surface layer (C_{s1} and C_{s2}).

METHODS

Site description and surface measurements

The vegetation within the 1°x 1° experimental area of HAPEX–Sahel is typical of the southern Sahelian zone with three main types : millet fields, fallow savannah, and tiger bush (Goutorbe et al., 1994). Millet is a sparse crop sowed at the beginning of the rainy season. The fallow savannah consists of woody shrubs of *Guiera senegalensis* scattered above a sparse annual herbaceous cover. The tiger bush (sparse dryland forest) only occurs on the laterite plateaux. It is characterized by dense strips of vegetation, made of woody perennials and trees, separated by areas of completely bare soil. The proportion of each vegetation within the square degree is about 30% for the tiger bush, 40% for the fallow savannah, 30% for the millet fields (Prince et al., 1995).

The surface measurements used in this study are those of the East–Central site of the HAPEX–Sahel square degree. Surface fluxes of sensible and latent heat were measured on millet and fallow savannah by the Energy Balance–Bowen Ratio technique (Monteny et al., 1996). The CO_2 flux was determined on fallow–savannah by means of the same method. To measure the CO_2 gradient, air was sampled by two pumps at the same two heights as the temperatures and air moistures, and drawn via burried copper tubes to the gas analyser (IRGA, model III, ADC Ltd, UK). The zero drift of the gas analyser was continuously monitored by drawing a known CO_2 concentration in the sample cells to give a zero reading. From an other mast, air was sampled at a height of 12 m, and CO_2 concentration was measured by a second gas analyser and recorded (Monteny et al., 1996). The CO_2 concentrations are expressed in mol fraction (ppm). They have to be multiplied by 1.79, at the temperature of 30°C, to obtain concentrations in kgm^{-3}. To calculate the CO_2 regional flux from Equation (4), C_+, just above the CBL, was taken as constant and determined by adjustment as explained below. The aerodynamic resistance r_a was calculated from Equation (5) with d=1.4 m and z_0=0.25 m (Troufleau et al., 1996). These values were determined on fallow savannah following Choudhury and Monteith (1988), who fitted simple functions to the curves obtained by Shaw and Pereira (1982) from second–order closure theory. The wind velocity on fallow savannah was measured at the same height of 12 m, where air was sampled.

Determination of CBL characteristics

The radiosoundings were performed by the CNRM (Centre National de Recherche Météorologique) from facilities installed in Hamdallaye not very far from the East–Central site. DIGICORA equipments, manufactured by Vaisala (Helsinki, Finland), were used in conjunction with RS80 radiosondes measuring pressure, temperature and humidity (Bergue and Bessemoulin, 1993). The inversion height, which defines the top of the CBL, was graphically defined from the profiles of potential temperature (θ) and specific humidity (q) plotted versus height (z). It was located at the top of the entrainment zone, as visualized in Fig. 2. The concentration within the well–mixed layer (C_m) was calculated as the mean value of all the data points below the inversion height, and the concentration above the inversion height (C_+) was determined as the mean value of the first three data points above h (Raupach et al., 1992). At each level of the radiosounding, the value of ρ is calculated from temperature (T) and pressure (p) by means of the gas law ($\rho=0.0035p/T$ in SI units).

RESULTS AND DISCUSSION

The cumulative fluxes of heat and water vapour were calculated following Equation (2) for eight days between August 21 (DOY 234) and October 8 (DOY 282). Two radiosondings were used, one in the morning at 0900 UT, and one in the afternoon at about 1500 UT. Tables 1 lists the regional estimates of sensible and latent heat fluxes. H_r and λE_r are the fluxes calculated by Equation (2). H_r' and $\lambda E_r'$ are the fluxes calculated by the same equation, taking into account the advective term (Equation (3)) introduced by Hipps et al. (1994). The surface fluxes measured on two of the three types of vegetation encountered on the site, millet field and fallow savannah, are also listed.

Table 1 – Regional estimates and surface values of sensible and latent heat flux.. H_r and λE_r are calculated from Equation (2), H_r' and $\lambda E_r'$, from Equation (3). R_s is the incoming solar radiation. (values are expressed in Wm^{-2}).

DOY	H_r	λEr_r	H_r'	$\lambda E_r'$	H_{millet}	λE_{millet}	H_{fallow}	λE_{fallow}	R_s
234	136	141	127	145	113	167	247	117	780
242	99	312	120	221	88	326	129	321	839
250	139	300	137	363	93	256	135	296	876
253	134	–225	123	–102	113	281	67	372	879
261	171	7	171	17	184	256	93	405	904
269	213	53	219	–271	– –	– –	123	318	845
277	113	3	98	–152	210	164	161	221	848
282	146	127	171	74	225	137	267	159	857

The regional estimates of sensible heat flux, listed in Table 1, seem to be plausible, albeit it is difficult to use the surface data as ground truth since they are not representative of the area covered by the CBL. The temporal change in potential temperature above the CBL being rather small ($\Delta C_{+2}\approx 0$), the advective term A does not alter substantially the results. The regional estimates of latent heat flux inferred from the conservation equation are not as good as for sensible heat. For one day (DOY 253), the estimated value is of the wrong sign, and for three other days (261, 269, 277), the estimates are manifestly too low. During DOY 253, the average wind direction within the CBL in the afternoon is North, which could explain a strong advection effect coming from the North, where the air mass is much drier than over the measurement area. Nevertheless, the advection corrected flux is still negative. Apparently, the advection term A (Equation (3)) does not improve the results, since for DOY 269 and 277 the advection–corrected estimates of latent heat flux are negative, instead of positive without correction. Fig. 3 exemplifies, for DOY 277, the change in wind direction between 0900 UT and 1500 UT (the change in air water content results from the advection of drier air coming from the North), and the corresponding change in the specific humidity profiles. In the morning, the mean wind direction is South, whereas it is North in the afternoon. This day is typical of the conditions prevailing during the southwards shift of the Inter–Tropical Convergence Zone (ITCZ), when two distinct air masses are superposed.

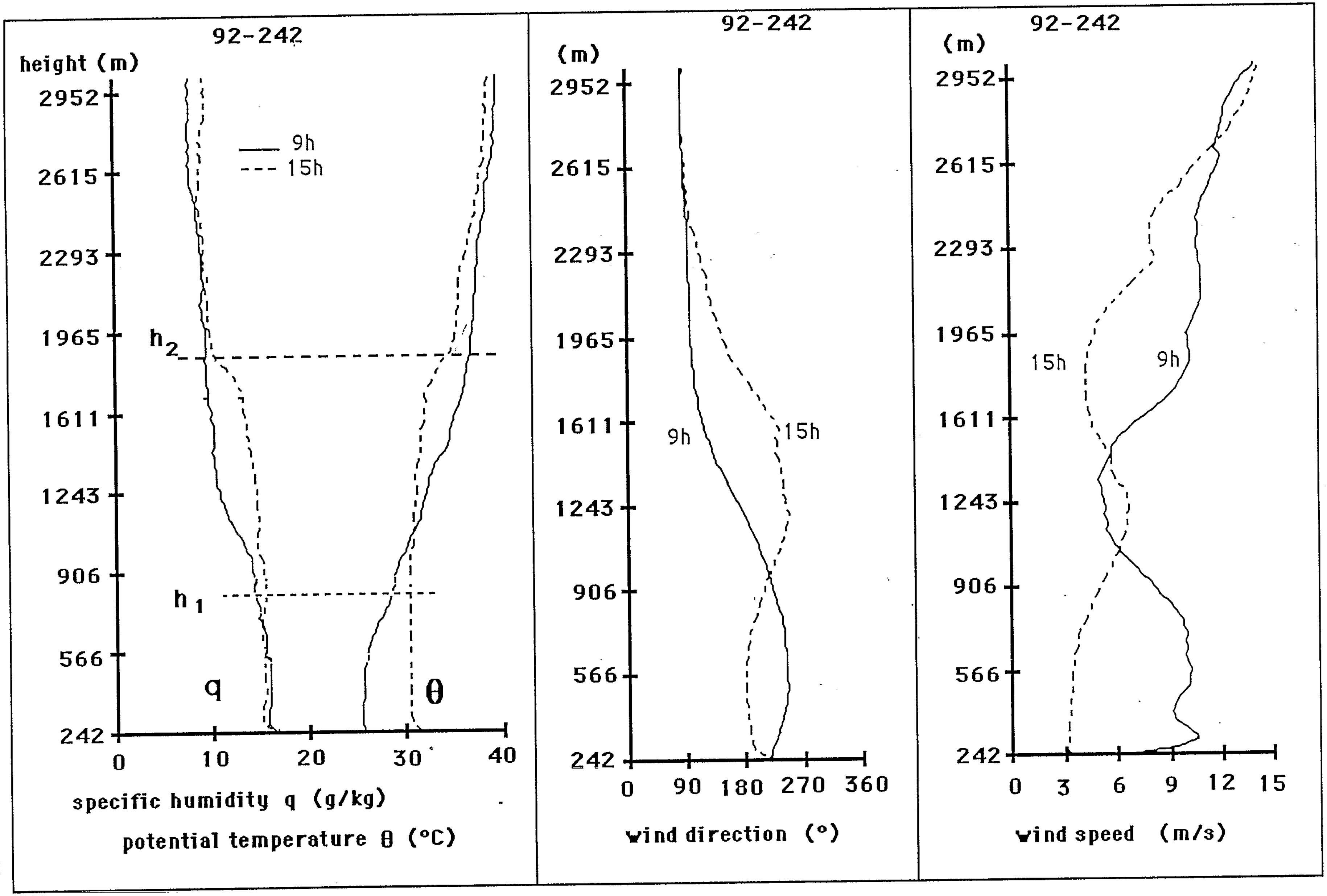


Fig. 2 : Vertical profiles of potential temperature, specific humidity and wind. day 242

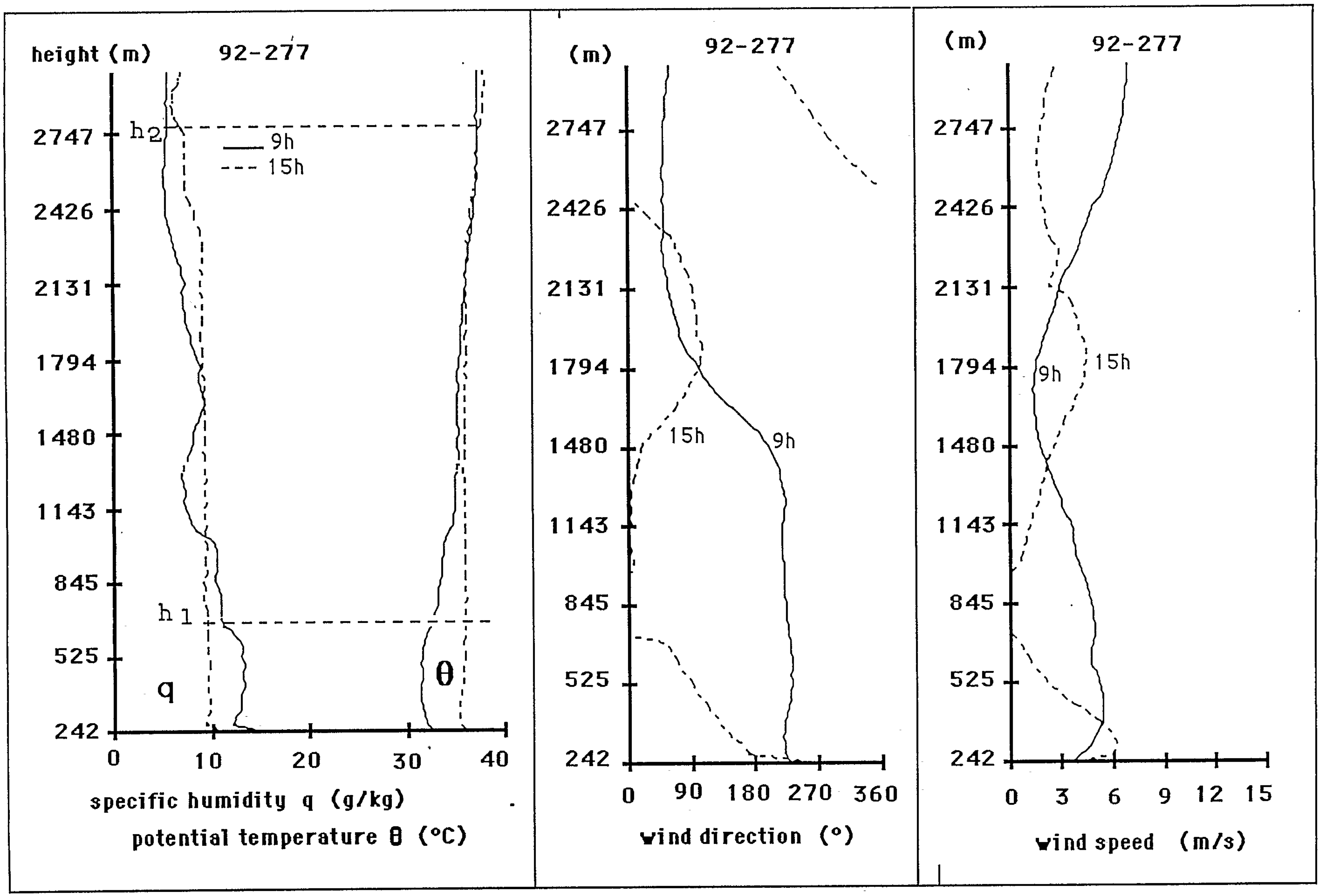


Fig.3 : Vertical profiles of potential temperature, specific humidity and wind. day 277

The sensitivity of the cumulative flux I_c of heat or water vapour, calculated from Equation (2), to errors made on the determination of the inversion heights h_1 and h_2 can be assessed by means of the following equations obtained by deriving Equation (2) :

$$\partial Ic = (Cm2 - C)\, \partial h2 \quad and \quad \partial Ic = (C+ - Cm2)\, \partial h1$$

We consider the following conditions h_1=1000 m at t_1=0900 UT, h_2=2000 m at t_2= 1500 UT, ρq_{m2}=9 gm^{-3}, ρq_{m1}=12 gm^{-3}, and ρq_+=3 gm^{-3}. These data, which are typical of a clear day of the wet season in the Sahelian environment, lead to an average evaporation of 340 Wm^{-2} between t_1 and t_2. The relative error on the cumulative flux I_c is about 6 % for an error of 30 m on h_2 and 9 % for an error of 30 m on h_1 (30 m corresponding to the average distance between two heights of measurement in a radiosounding).

The CBL and surface layer characteristics needed to calculate the cumulative uptakes of CO_2 by means of Equation (3), are listed in Table 2 for several days. They are calculated between t_1=1100 UT and t_2=1500 UT. Time t_1=1100 was used instead of t_1=0900, because, very often, the values of the cumulative uptake calculated from t_1=0900 did not give plausible results. We assumed that it was due to the fact that the surface concentration C_s in the morning can be greater than the mixed layer concentration C_m because of the nocturnal accumulation of CO_2 within the surface layer, due to plant and soil respiration (and also fires from surrounding villages). This situation leads to a flux oriented upwards, between the level of measurement and the mixed layer, whereas it is oriented downwards between this level of measurement and the surface. In this case, there is a breakdown of Equation (4), which is no more valid. By considering the surface concentration at t_1=1100, we are sure that this case does not occur and that the CO_2 flux is conservative between the vegetation and the bottom of the well-mixed layer. To calculate I_c from Equation (4) the value of C_+ is needed. Since this value was not measured and is a priori unknown, it was inferred by minimizing the RMSE (root mean square error) between the calculated values of I_c and the values measured on fallow savannah for the 5 days available. The value obtained, and used to calculate the estimates of I_c listed in Table 2, was 325 ppm.

Table 2 : Regional estimates of CO_2 uptake ($I_{c,r}$), integrated from t_1=1100 UT to t_2=1500 UT, (Equation 4), and surface values measured on fallow savannah ($I_{c,fallow}$). LAI = Leaf Area Index and S = the soil water content (layer 0–60 cm), measured in a millet field and in the fallow savannah; C_+ has been set as 325 ppm; h_1 and h_2 = height of the CBL at t_1 and t_2; C_s1 and C_s12 = CO_2 concentrations at 12 m at t_1 and t_2.; r_a is the aerodynamic resistance between z_1=12 m and z_2=100 m, calculated by Equation (5).

DOY	h_1 (m)	h_2 (m)	C_{s1} (ppm)	C_{s2} (ppm)	r_a (sm^{-1})	$I_{c,r}$ (gm^{-2})	$I_{c,fallow}$ (gm^{-2})	LAI millet	S millet (mm)	LAI fallow	S fallow (mm)
261	1480	1919	334	320	4.5	-36	-2.6	2.3	61	0.5	75
269	1407	2181	336	330	3.9	-6.8	-5.1	1.5	39	0.7	51
270	1656	1950	336	329	3.9	-17	– –	– –	– –	– –	– –
272	1227	2130	332	328	3.9	-3.2	– –	– –	31	– –	46
274	1942	2620	333	328	3.4	-12	-3.4	1.4	27	0.95	40
277	1313	2748	332	329	3.4	+2.4	-3.4	– –	– –	– –	– –
281	1168	2830	337	331	3.3	+3.8	+0.2	0.9	21	0.4	32

The results listed in Table 2 show a decrease of CO_2 regional uptake parallel to soil drying–out and vegetation LAI decreasing. For the two last days of the sample, the flux of CO_2 is positive, which means that the assimilation rate is so low that it is exceeded by the respiration rate. The matching between regional estimates and fluxes measured on fallow savannah is not very good, but we do not know if the latter are really representative of fluxes at regional scale. The sensitivity of the cumulative assimilation flux I_c, expressed by Equation (4), to variation of C_+, can be assessed by For CO_2 uptake, asssuming the same conditions as for latent heat with C_{s1}=335 ppm, C_{s2}=325 ppm, C_+=330 ppm and r_a=5sm^{-1}, I_c is equal to –22 gm^{-2} and an increase of 1 ppm on C_+ leads to a decrease of 1.5 gm^{-2} on I_c, which represents about 7%. So, I_c is relatively sensitive to C_+ value.

CONCLUSION

The CBL budget method, based upon a simplified form of the integrated scalar conservation equation, provides simple equations which can be used to estimate surface fluxes at regional scale from radiosounding data. Our specific conclusions are as follows. (a) For sensible heat, the method seems to work rather well. All the estimates obtained from Equation (2) are plausible. The advection term does not change drastically the results because the changes in potential temperature just above the CBL are very small. (b) For water vapour, the cumulative fluxes appear to be correct only for half the days of measurement (4 out of 8), and the advection term does not improve the results. Caution is recommended when the ITCZ shifts southwards leading to the superposition of two air masses with different characteristics. Generally, the CBL budget method does not apply in this case. (c) For CO_2 . Equation (4) has been used. It involves the concentrations measured in the surface layer and leads to results which exhibit a decrease of the CO_2 uptake following the vegetation drying–out. The calculated regional fluxes are fairly different from those measured on fallow savannah, but it is hazardous to draw general conclusions given the poor representativeness of only one point of surface measurement, and the way the CO_2 concentration above the CBL has been determined. The crudeness of the derivation of Equation (4) is also questionable.

REFERENCES

Abdulmumin, S., Myrup, L.O. and Hatfield, J.L., 1987. An energy balance approach to determine regional evapotranspiration based on planetary boundary layer similarity theory and regularly recorded data. Water Resour. Res., 23: 2050–2058.

Bergue, P. and Bessemoulin, P., 1993. Catalogue of CNRM radiosoundings during HAPEX–Sahel. Note de travail, groupe de météorologie expérimentale et instrumentale. CNRM, Toulouse.

Brutsaert, W., 1984. Evaporation into the atmosphere. Reidel Pub., pp. 299.

Brutsaert, W. and Sugita, M., 1991. A bulk similarity approach in the atmospheric boundary layer using radiometric skin temperature to determine regional surface fluxes. Boundary Layer Meteorol., 51: 1–23.

Choudhury, B.J. and Monteith, J.L., 1988. A four–layer model for the heat budget of homogeneous land surfaces. Q. J. R. Meteorol. Soc., 114: 373–398.

Culf, A.D., 1992. An application of simple models to Sahelian convective boundary layer growth. Boundary Layer Meteorol., 58: 1–18.

Diak, G.R. and Whipple, M.S., 1994. A note on the use of radiosonde data to estimate the daytime fluxes of sensible and latent heat: a comparison with surface flux measurements from the FIFE. Agric. For. Meteorol., 68: 63–75.

Dyer, A.J., 1974. A review of the flux–profiles relationships. Boundary Layer Meteorol., 7: 363–372.

Goutorbe, J.P., Lebel, T., Tinga, A., Bessemoulin, P., Brouwer, J., Dolman, A.J., Engman, E.T., Gash, J.H.C., Hoepffner, M., Kabat, P., Kerr, Y.H., Monteny, B., Prince, S., Said, F., Sellers, P., and Wallace, J.S.,1994. HAPEX–Sahel: A large scale study of land–atmosphere interactions in the semi–arid tropics. Ann. Geophysicae, 12: 53–64.

Hipps, L.E., Swiatek, E. and Kustas, W.P., 1994. Interactions between regional surface fluxes and the atmospheric boundary layer over a heterogeneous watershed. Water Resour. Res., 30: 1387–1392.

Lhomme, J.P., Monteny, B., and Bessemoulin, P. 1996. Inferring regional surface fluxes from convective boundary layer characteristics in a sahelian environment. (submitted to WRR.)

McNaughton, K.G., 1989. Regional interactions between canopies and the atmosphere. In: G. Russel et al. (Editors) Plant Canopies: Their Growth, Form and Function, SEB seminar series, 31. Cambridge University Press. pp. 63–82.

McNaughton, K.G. and Spriggs, T.W., 1986. A mixed–layer model for regional evaporation. Boundary–Layer Meteorol., 34: 243–262.

Monteny, B., Lhomme, J.P., Chehbouni, A., Troufleau, D., Amadou, M., Sicot, M., Galle, S., Saïd, F., Verhoef, A., and Lloyd, C.R., 1996. The role of the Sahelian biosphere in the water and the CO_2 cycle during the HAPEX–Sahel experiment. J. Hydrol., Special issue (accepted).

Munley, W.G. and Hipps, L.E., 1991. Estimation of regional evaporation for a tall grass prairie from measurements of properties of the atmospheric boundary layer. Water Resour. Res., 27: 225–230.

Prince, S.D., Kerr, Y.H., Goutorbe, J.P., Lebel, T., Tinga, A., Bessemoulin, P., Brouwer, J., Dolman, A.J., Engman, E.T., Gash, J.H.C., Hoepffner, M., Kabat, P., Monteny, B., Saïd, F., Sellers, P., and Wallace, J., 1995. Geographical, biological and remote sensing aspects of the Hydrologic Atmospheric Pilot Experiment in the Sahel (HAPEX–Sahel). Remote Sens. Environ., 51: 215–234.

Raupach, M.R., Denmead, O.T. and Dunin, F.X., 1992. Challenges in linking atmospheric CO_2 concentrations to fluxes at local and regional scales. Aust. J. Bot., 40: 697–716.

Shaw, R.H. and Pereira, A.R., 1982. Aerodynamic roughness of a plant canopy: a numerical experiment. Agric. For. Meteorol., 26: 51–65.

Troufleau, D., Lhomme, J.P., Monteny, B. and Vidal, A., 1996. Sensible heat flux and radiometric surface temperature over sparse sahelian vegetation. J. Hydrol., Special issue (accepted)

FIGURE CAPTIONS

Fig. 2 – For a typical day of the rainy season, DOY 242 (August 29), vertical profiles of potential temperature (_), specific humidity (q), wind direction and wind velocity at the soundings of 0900 UT and 1500 UT.

Fig. 3 – For a day with large scale advection, DOY 277 (October 3), vertical profiles of potential temperature (_), specific humidity (q), wind direction and wind velocity at the soundings of 0900 UT and 1500 UT.

TOULOUSE

ATELIER DE MODELISATION DE L'ATMOSPHERE

28 - 30 novembre 1995

EVALUATION REGIONALE DES FLUX DE SURFACE A PARTIR DES CARACTERISTIQUES DE LA COUCHE LIMITE CONVECTIVE SAHELIENNE.

LHOMME, J.P.*, MONTENY, B.A.* ET BESSEMOULIN, P.**

*** ORSTOM - Département T.O.A ,**
Groupe de Bioclimatologie, Montpellier
**** CNRM - Av. Coriolis, Toulouse**

CENTRE NATIONAL DE RECHERCHES METEOROLOGIQUES

42, Avenue Coriolis
31057 TOULOUSE CEDEX