Journal of Agrometeorology 3(1 & 2) : 143 - 147 (June-December-2001)

Evaluation of moisture flux and relative humidity in the surface layer from sonic anemometer data

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ABSTRACT

In this paper an attempt is made to evaluate the moisture parameters, such as, the moisture flux, and relative humidity in the surface boundary layer, indirectly, from the heat fluxes measured by a sonic anemometer, which was installed on the micrometeorological tower at Anand. Relative humidity values computed by this method, was compared with those obtained from direct measurements by a capacitor type humidity sensor mounted at the same level. The agreement between the two values was good for relative humidities around 60%, deteriorating at higher and lower values. It is also seen that during the periods when the stability regimes in the lower surface layer change, the agreement between the two values is not very good.

Key words: Humidity, Moisture flux, Sonic anemometer

The task of evaluating moisture flux and relative humidity in a field experiment has always been problematic. The reasons being the high sensitivity of the measuring instruments to the prevalent dust particles, deterioration of the windows by the moisture in the air, as in the case of the Lyman - α hygrometer and several other exposure problems. The accuracy of the humidity measuring devices drop sharply over a period of time, rendering them unreliable. Hence, there is an urgent requirement to devise indirect methods of evaluating the moisture parameters, using other devices. A very accurate and reliable instrument for measuring wind component, air temperature and temperature-wind covariance, is the sonic anemometer. Its fast- response sensors enable the computation of the covariance, (wT_s), averaged over a short period of time. The temperature (T_s) measured by the anemometer includes the moisture component, as well. It is possible to separate the moisture component and compute the moisture parameters.

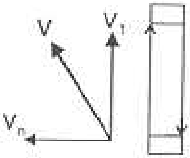
Shotanus *et al.* (1983), showed that the sonic anemometer measures the dry-bulb temperature fluctuations *T*, only when the humidity and normal velocity fluctuations are zero. They also derived a relation between the covariances $(\overline{w'T'}_s)$, as measured by the sonic anemometer, and the covariance $(\overline{w'T'})$. The moisture covariance $(\overline{w'q'})$ was obtained by them, by using the energy balance equation to derive a relation between $\overline{w'q'}$, $\overline{w'T}_s$, $\overline{u'w'}$, the net radiation, R_N, and the ground heat flux, G. This equation was used to calculate the heat and moisture fluxes from the sonic heat flux, $\rho c_p \overline{w'T'_s}$, and the net radiation, using the Cabauw field experiment data. The ground heat flux, (R_N) was assumed to be $0.1\ R_N$. In this study, the ground heat flux G was taken as a time-varying fraction of R_N.

MATERIALS AND METHODS

The operating principles of the sonic anemometer are well known. Sound pulses are transmitted back and forth between transducers. Assuming a uniform wind and temperature field, the transit times for the two pulses are given by:

$$t_1 = \frac{\ell}{c\,\mathrm{Cos}(\alpha) + V_l}$$

$$t_2 = \frac{\ell}{c\,\mathrm{Cos}(\alpha) \pm V_l}$$



ℓ is the path length; V_l is the wind component along the sound path and V_n is the wind component normal to the sound path, V is the resultant wind velocity and α is the angle between V and V_l, given by

$$\alpha = \mathrm{Sin}^{-1}(V_n/c),$$

where c is the velocity of sound. The sum of the reciprocals of the transit times is proportional to the sound velocity, which is a function of the absolute temperature of air and the specific humidity. The sonic anemometer temperature output, T_s', measures the real temperature fluctuations T', when the humidity and the normal velocity fluctuations are zero as shown by the equation

$$\overline{w'T_s'} = \overline{w'T'} + e\,\overline{T}\,\overline{w'q'} - 2\,\overline{T}\,\overline{u}\,\overline{u'w'}/c^2 \quad ...1$$

Here, w' represents the vertical velocity fluctuations, q' the specific humidity fluctuations and u' the normal velocity fluctuations. ε is a constant representing the ratio of the molecular weight of water vapour to that of dry air. The other symbols have their usual definitions.

The energy balance equation is given by

$$R_N = \rho c_p \overline{w'T'} + \rho\lambda\overline{w'q'} + G \quad .....2$$

R_N is the net radiation, G is the heat flux into the ground, taken positive in the direction away from the surface, ρ is the density of dry air at temperature T, and c_p and λ are the specific heat of dry air at constant pressure and the latent heat of vapourization respectively. The second and third terms in the above equation represent the sensible and latent heat fluxes, respectively, which are taken positive when directed away from the surface. Substituting for $\overline{w'q'}$ from the above equation into eq.(1) we get:

$$\overline{w'T'} = \frac{\overline{w'T'_s} - \varepsilon\,\overline{T}\,\overline{R_N} + \varepsilon\,\overline{T}\,G - 2\,\rho\lambda\,\overline{T}\,\overline{u}\,\overline{u'w'}/c^2}{\rho\lambda(1 - \varepsilon\,\overline{T}\,c_p/\lambda)} \quad ...(3)$$

Eliminating $w'T'$ between equations (1) and (2) we get :

$$\overline{w'q'} = \frac{\rho c_p\,\overline{w'T'_s} - R_N + G + 2\,\rho c_p\,\overline{T}\,\overline{u}\,\overline{u'w'}/c^2}{\varepsilon\rho c_p\,\overline{T} - \rho\lambda)} \quad (4)$$

This equation gives the moisture flux in terms of the heat flux as measured by the sonic anemometer.

Let

$$\delta = \mathrm{Sin}\,[\,\pi\,(12 - t)/12]$$

where t is the time in hours. The quantity within square brackets denotes the hour angle.

We define the Bowen-ratio as

$$\beta = \frac{c_p\,\overline{w'T'}}{\lambda\,\overline{w'q'}}$$

Equation (2) can be rewritten as

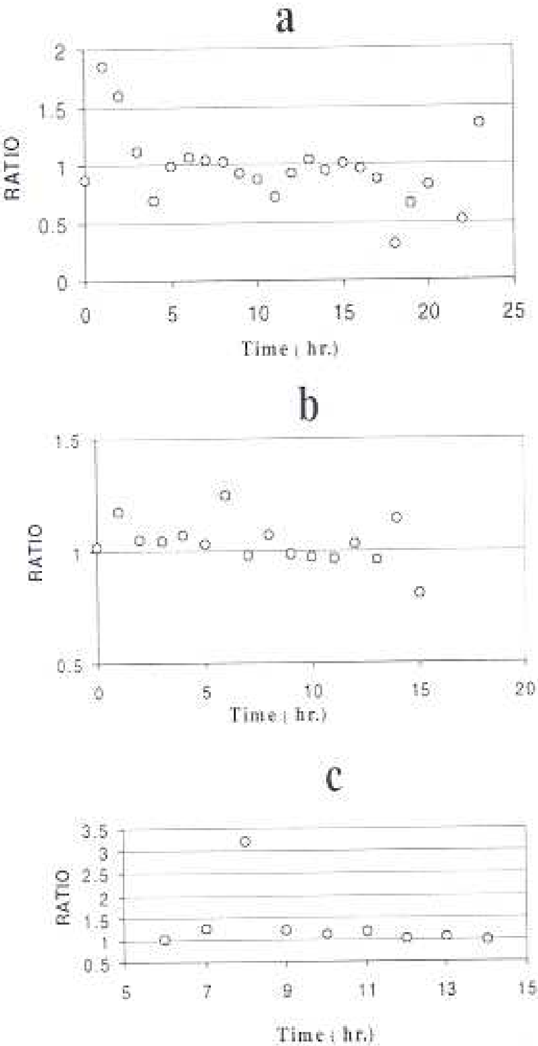


Fig. 1 : Ratio of the observed to calculated relative humidities at Anand on 17.5.97

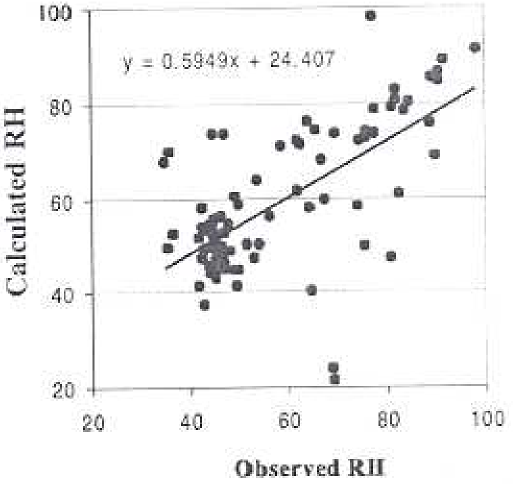


Fig. 2 : Calculated vs Observed relative humidities

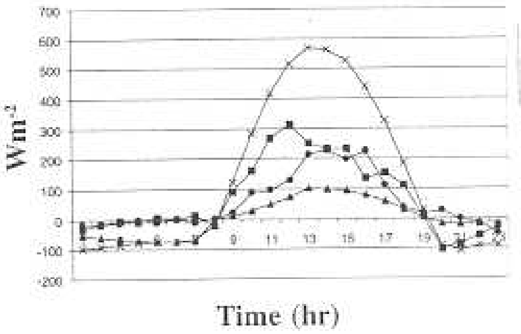


Fig. 3 : The components of the surface energy balance at Anand on 15.5.97

$$G = R_N - \rho\lambda\,\overline{w'q'}(1+\beta).$$

It may be seen from this equation that the soil heat flux G is a function of R_N and the moisture flux, which is a function of the hour angle. At night the temperature increases with depth in the soil, causing the soil heat flux to be negative. The moisture flux is very small, making G proportional largely to the net radiation. After sunrise, the

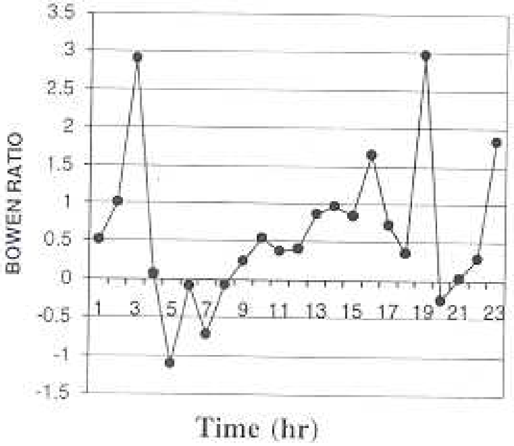


Fig. 4 : Time variation of the Bowen ratio at Anand on 15.5.97

surface heating gradually reverses the temperature gradient in the soil and the moisture flux, together with the net radiation, start increasing. After noon, the moisture flux remains almost constant till around 15.00 hrs., and then starts decreasing, but at a much slower rate compared to the net radiation. The soil heat flux is therefore, influenced mostly by the net radiation term. These observations were used to define certain expressions for G in terms of the net radiation and a function of the hour angle, for different time zonesas follows

$G = 0.53\ R_N\ (1+\delta)$ for $t \leqslant 6.0$

$G = 0.18\ R_N / (1+\delta)$ for $6.0 < t < 12.0$

$G = 0.18\ R_N$ for $t \geqslant 12.0$

It is also seen that the soil heat flux is influenced by the Bowen ratio, which has a high variability during the course of the day, both in magnitude and sign. The Bowen ratio displays different characteristics for positive and negative values of the net radiation. The negative values of net radiation occur just before sunset and continue till some time after sunrise and during this period, the Bowen ratio displays high values and fluctuations. The amount of water vapor present in the atmosphere, is proportional to the difference between the heat flux which is measured by the sonic anemometer and the true heat flux, as suggested in equation (1). This proportionality changes with the Bowen ratio, thus requiring the definition of a factor to take this into account. Now we define this factor (f) as

if $R_N < 0$, then for

$\beta > 1$ $f = 0.8\ \beta\ G / R_N$;

$0 < \beta <$ $f = (R_N - G) / (\varrho\lambda\ w'q')$;

$-1.1 < \beta < 0$ $f = 1.8$;

$\beta < -1.1$ $f = 1.35$

if $R_N > 0$, then for

$\beta < 0$ $f = 1.18$

$\beta < 0$ $f = \frac{\rho[cp\ \overline{w'T'} + \lambda\ \overline{w'q'}]}{R_N}$

The relative humidity (RH) is computed from the following expression

$$RH = \frac{c_p[\overline{w'T_s'} - \overline{w'T'}]}{\lambda\ \overline{w'q'}}\ \frac{1}{q_s}\ \frac{dq_s}{dT}\ .\ T\ f\ C_1 \qquad ...(5)$$

C_1 is a constant whose value is $\lambda * 10^3$, where λ is the psychrometric constant whose value is

$c_p / \lambda \cong 4 * 10^{4}\ (g_{water} / g_{air})\ K^{-1}$.

From Clausius - Clapeyron equation we have

$$\frac{dq_s}{dT} = \frac{\varepsilon\lambda}{RT^2} q_s$$

Where,

R is the gas constant = 287.04 J $K^{-1}kg.^{-1}$, q_s is the saturation mixing ratio.

RESULTS AND DISCUSSION

Figs. 1(a) to 1(c) show the ratio of the observed relative humidities to the computed relative humidities, at hourly intervals, on different days. It may be seen that barring some short intervals, when the stability regimes change, the ratios are close to one. The first of these intervals occur around zero hours, the second occurs around sunrise time and the third occurs soon after sunset, when the incoming short wave radiation is cut off and surface cools due to the emission of long wave radiation. In the process, the stability regime changes from an unstable convective regime during afternoon, to a stable regime with the formation of the surface inversion. In between, thestability regime passes through the neutral stage, which is characterized by large covariances between the temperature and the vertical velocity fluctuations. Soon after sunrise, the stability regime passes from stable to the unstable regime due to surface heating by the incoming short wave solar radiation, giving rise to similar large covariances. Around zero hours, the moisture flux becomes very small and since this parameter occurs in the denominator of the expression for computing RH (equation 5), a small error in the value of the moisture flux is greatly magnified in the value of RH. Fig. 2 shows the scatter diagram between the calculated and observed relative humidities. The agreement between the two values is very good for relative humidities around 60%, deteriorating at higher and lower values.

Fig. 3 shows the values of the different terms in the energy balance equation, during a 24-hour period on 15th. May 1997. All the terms, except the net radiation term R_N were computed by the above method. The net radiation was observed. Fig. 4 shows the variation of the Bowen ratio over a 24-hour period, on the same date. Here also, large values are seen during the intervals when the stability regimes change. The present study shows that the sonic anemometer can provide fairly accurate values of relative humidity, moisture and sensible heat fluxes in addition to other surface boundary layer parameters.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the encouragement given by the Director of the Institute and the funding of the Land Surface Processes Experiment (LASPEX), by the Department of Science and Technology, Government of India.

REFERENCES

Shotanus, P. F., Nieuwstadt T. M. and DeBrown H. A. R. 1983. Temperature measurements with a sonic anemometer and its application to heat and moisture fluxes. *Bound. Layer Meteorol.*, 26 : 81-93.