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Diurnal variations in soil temperature, momentum and sensible heat fluxes at Anand during LASPEX-97

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ABSTRACT

LASPEX-97 tower data of Anand for IOP period of May, July, September and December months have been used to estimate the frictional velocity, momentum flux and sensible heat flux by bulk aerodynamic method. The fast response Metek sonic anemometer was also used to calculate these parameters by eddy correlation method. A comparison of these two showed that the friction velocity and momentum flux observed by aerodynamic techniques were underestimated during most of the time to that of eddy correlation method. Sensible heat flux was by bulk aerodynamic method except in May. Variations of soil temperature under cropped and bare soil are presented.

Key words : Land surface processes, Friction velocity, Momentum flux, Sensible heat flux, Eddy correlation technique

Land air-interface plays an important role in determining the net energy available at or near the surface that drives the atmosphere. The micrometeorological weather conditions at the surface layer strongly depend upon the various components of energy and water balance (Stull, 1988). In the surface layer the fluxes of heat, momentum and water vapor are affected by the surface roughness and are directly transmitted through the mechanism of turbulent mixing. These fluxes constitute important input parameters for modeling the various physical processes that affect the dispersal of pollutants released into the atmosphere (Rao, 1996). The surface fluxes are of crucial importance in determining the mean profiles of the surface layer and atmospheric boundary. They are also used in the short and medium range weather forecast models.

Several approaches are in practice for the determination of the fluxes. The flux profile, gradient, eddy correlation, and Bowen's ratio methods are the most common. The bulk aerodynamic method was widely used in the past (Mohanty *et al.*, 1995). In this, the turbulent transport of momentum, heat and moisture are treated as proportional to the differences of mean meteorological parameters such as wind speed, temperature and moisture between the underlying surface and a reference level. In the present study the mean variation of different land surface parameters are discussed.

MATERIALS AND METHODS

For the present analysis, data collected during intensive observational period (IOP) (13th to 17th of every month) for May (pre-monsoon), July (active monsoon), September (withdrawal of the monsoon) and December (winter) have been used. The data of soil temperatures at surface, 5,10,20,40 and 100 cm depths for both bare and cropped surface, wind speed, air temperatures at 4 levels (1,2,4 and 8 m height) collected from 10 m-tower site of Anand have been used. Sensible heat, momentum fluxes and frictional velocity were directly obtained from Metek sonic anemometer data (eddy correlation method). The data were averaged on a time scale of an hour and the 5-day mean value of IOP was taken.

Bulk aerodynamic method

The surface shear stress (τ) frictional velocity (u_*) and heat flux (H_0) for the neutral condition are given by

$$\tau_0 = \varrho Km(\partial u/\partial z);$$

$$u_* = (\tau/\varrho)^{1/2};$$

$$H_0 = -\varrho C_p Kh(\partial \varnothing/\partial z)$$

Where, Km, Kh are the exchange coefficients of momentum and heat respectively.

For non-neutral conditions these parameters are multiplied by a stability factor (SF) that is chosen according to emprirically derived formula given by (Oke, 1987; Dyre, 1974) depending upon Richardson number (Ri).

$$SF = 1, \text{ if } -0.02 \leq Ri \leq 0.02 \quad \text{(Neutral condition)}$$

$$SF = (1 - 5Ri)^2 \text{ if } 0.02 \leq Ri \leq 0.1 \quad \text{(Stable condition)}$$

$$SF = (1 - 15\,Ri)^{3/4} \text{ if } -0.1 \leq Ri \leq 0.02 \quad \text{(Unstable condition)}$$

This method is good if z_2/z_1 = 2 to 4 otherwise it gives errors of more than 30% in the estimate of surface fluxes (Arya, 1988).

Eddy correlation technique

The most reliable and direct measurements of turbulent exchanges of momentum and heat in the atmosphere are usually made with sophisticated fast response turbulence instrumentation (Metek sonic anemometer). Here all the fluctuations of velocity and temperature that contribute to the desired momentum and heat fluxes are carefully sensed and recorded and their covariances were determined by averaging the products of the appropriate fluctuations (Oke; 1987) over any desired averaging time. In particular, the vertical fluxes of momentum and heat over a homogenous surface are given by

$$\tau = -\varrho \overline{u'\,w'}$$

$$H = -\varrho C_{pd}(1 + 0.81q)\, u_*\, \theta_*$$

$$u_* = (\overline{u'w'}^2 + \overline{v'w'}^2)1/4$$

Here,

θ_* = $-\overline{w'\theta'}/u_*$

ϱ = density of air

C_{pd} = specific heat of dry air at constant pressure

q = specific humidity

$\overline{u'w'}$ = covariance between u' and w'

$\overline{v'w'}$ = covariance between v' and w'

$\overline{w'\theta'}$ = covariance between w' and θ'

u_* = friction velocity

Variation of land surface parameters such as soil temperature, surface wind, momentum flux, roughness and sensible heat

Table 1 : Magnitudes of soil temperatures at different depths at Anand (24 hr IOP average)

Depth(s) in cm	Soil temperature in (°C)							
	May		July		September		December	
	Bare	Grass	Sanhemp	G'nut	Bare	G'nut	Bare	Wheat
Surface	37.6	36.3	29.9	32.0	29.9	30.0	23.0	21.6
5	37.0	35.7	29.5	31.3	29.1	30.0	23.0	22.8
10	36.0	35.3	29.8	31.1	29.2	29.0	23.2	23.0
20	35.0	34.8	29.8	30.9	30.7	28.0	24.0	21.0
40	34.0	34.7	31.1	30.9	29.9	31.0	25.0	24.3
100	32.6	32.2	30.9	30.2	30.5	30.5	26.4	24.7

flux representing the microclimate near the ground were worked out.

RESULTS AND DISCUSSION

Soil temperature

Fig. 1 depicts the profiles of soil temperatures up to one meter depth during May, July, September and December months representing summer, active monsoon, withdrawal of monsoon phase and winter season. They varied with depth, season as well as type of surface. There was also a lag in the time at which the maximum temperature was recorded in the successive layers compared to surface maxima and this lag increased with the increase in soil depth. The maximum diurnal variation of 22-57 °C was observed during May under bare soil condition. Under short grass cover, it ranged from 21 to 56.5 °C at the surface and both maximum and minimum surface temperatures were reduced by 0.5 to 1.0 °C. Soil temperature at 5cm depth was 2 °C lower throughout the day under the uniform grass covered field. With crop growth, the temperature difference between the two surfaces also increased. During July surface temperature under groundnut was 42.7° at peak hrs and 27 °C during morning hours whereas, it ranged between 23°C - 41°C under sun hemp crop cover. Similar trend was observed in the variation of subsurface temperatures. The maximum variation was noticed up to 20 cm depths with no diurnal variation at 1m. During monsoon season (July) the variation in soil temperature was less than that of May due to frequent occurrence of rain. During September further reduction in soil temperature was observed at all the depths. However, during December a slightly different result was observed. A 0.4 °C difference was noticed (Table 1) between 40 and 100 cm depths under wheat in contrast to a 1.4 °C difference under bare soil condition. This is attributed to effect of moist soil under irrigated wheat.

Wind speed

Fig. 2 shows diurnal variation in wind speed. During day time i.e. between 0900-1800

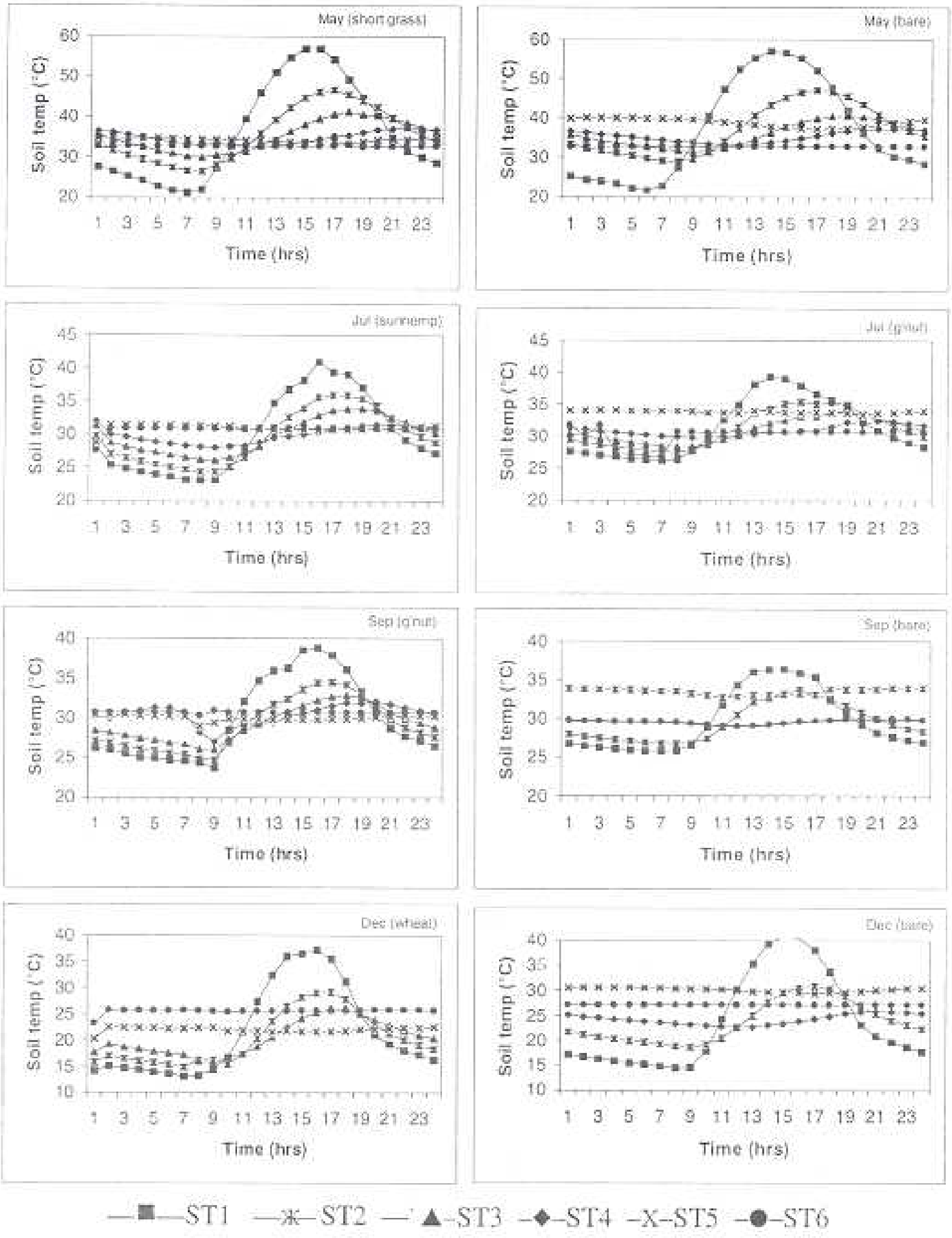

Fig. 1 : Diurnal variation of soil temperatures under different conditions

hrs winds started to increase in all the months and again decreased from 1800 hrs. Maximum wind speed was observed during July.

Frictional velocity

During each month, frictional velocity computed from fast response data, i.e., from eddy correlation method was about 1.4 times greater (Fig. 3) than that obtained from bulk aerodynamic method. Frictional velocity was higher during active monsoon phase (0.1 to 0.32 ms^{-1}), with extreme values corresponding to relatively higher surface winds of the order of 2.2 to 2.7 ms^{-1} indicating that the atmosphere near the surface layer remained unstable during daytime. As instability increased, the difference between these two methods is also seen to increase.

Surface momentum flux

Fig. 4 depicts diurnal variation in momentum flux computed using the two methods. The fluxes were first obtained directly from the Metek sonic anemometer (eddy correlation technique) and then indirectly by the bulk aerodynamic method for different stability conditions.

Though there was similarity in the nature of the variation of these fluxes irrespective of their method of evaluation, the most striking feature is that the fluxes determined indirectly by bulk aerodynamic method were consistently lower. Higher eddy fluxes (July) correspond to the winds in the surface layer during this period, which were relatively stronger (1.2-2.7 ms^{-1}) than those of the pre

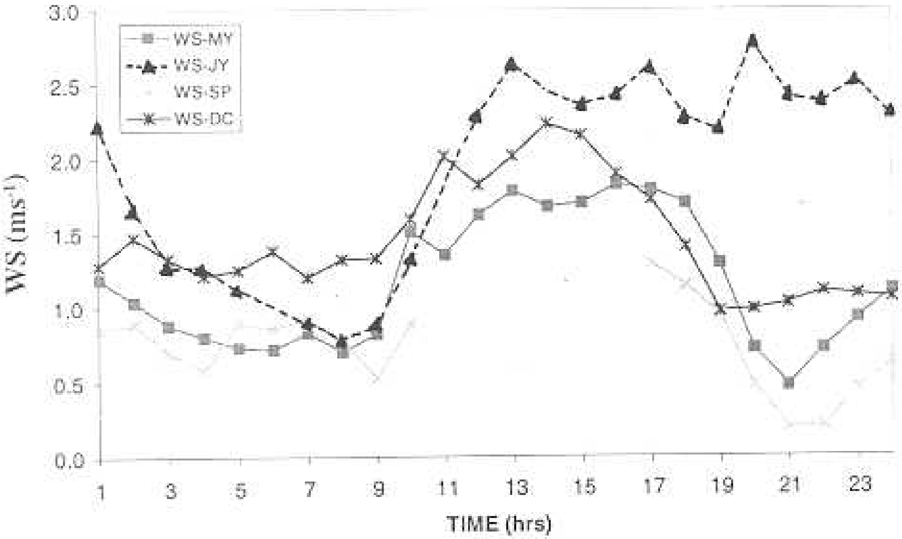

Fig. 2 : Seasonal diurnal variation of wind speed.

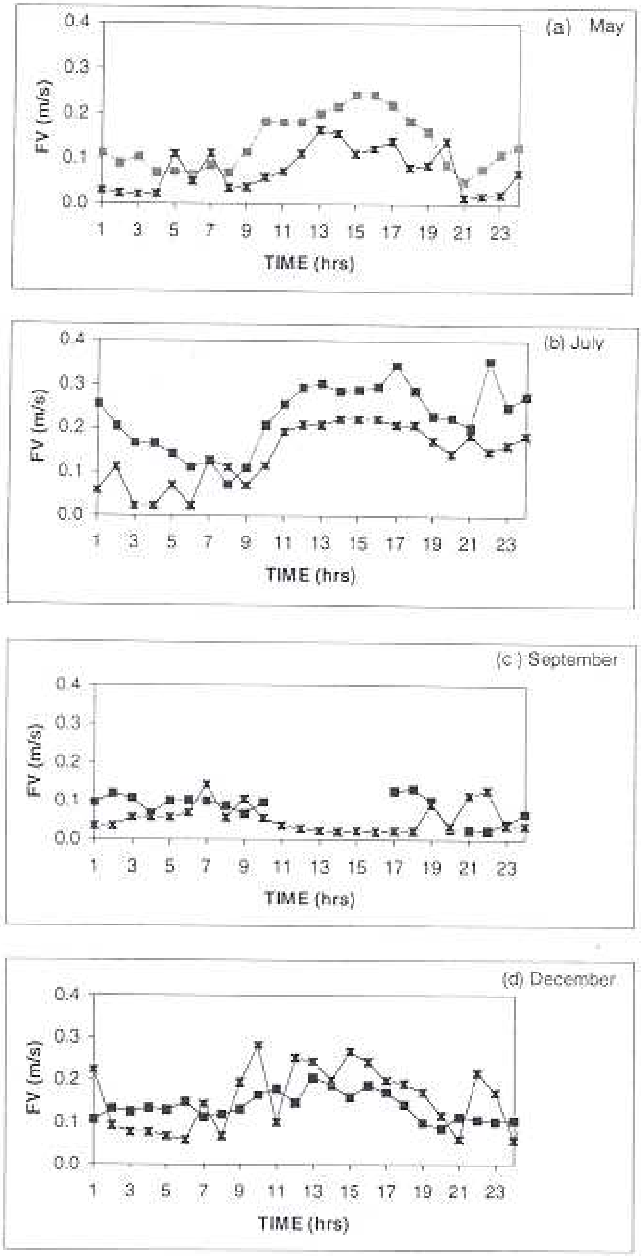

Fig.3 : Variation in friction velocity computed by eddy correlation (■) and aerodynamic (*) method

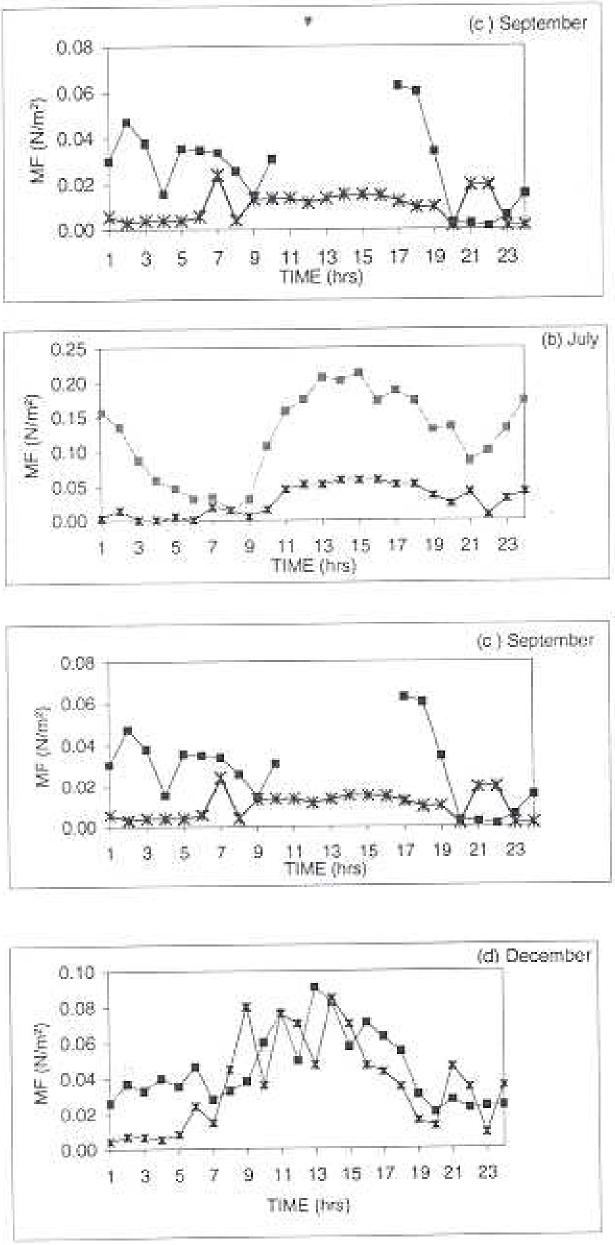

Fig.4 : Variation in momentum flux computed by eddy correlation (■) and aerodynamic (*) method

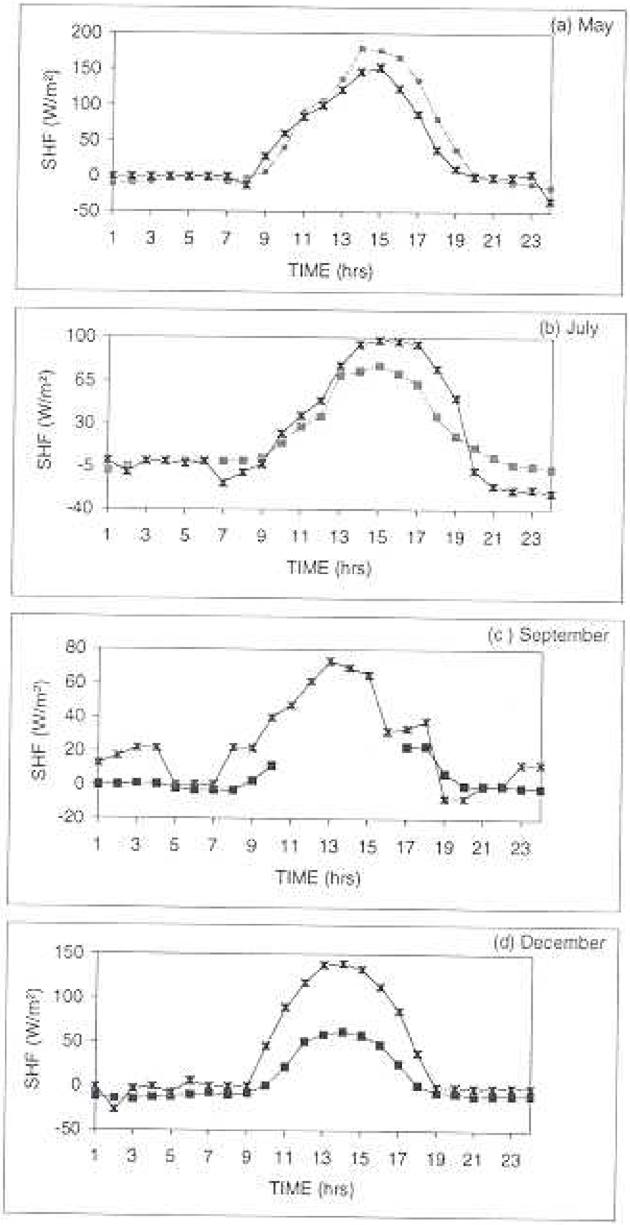

Fig.5 : Variation in sensible heat flux computed by eddy correlation (■) and aerodynamic (*) method

monsoon (0.6-1.8 ms^{-1}) and post monsoon phases (1.6 ms^{-1}). The daytime maximum and nighttime minimum momentum fluxes varied from 0.095 to 0.016 Nm^{-2}, 0.21 to 0.015 Nm^{-2}, 0.06 to 0.002 Nm^{-2} and 0.09 to 0.02 Nm^{-2} by eddy correlation method and 0.046-0.013, 0.058-0.006, 0.013-0.004 and 0.07-0.015 Nm^{-2} by bulk aerodynamic method during May, July, September and December months, respectively. During December not much variation was observed in the values obtained by these two methods.

Sensible heat flux

It is observed that the sensible heat flux obtained from the aerodynamic method was underestimated (by 15-20%) during summer (May) but overestimated during rest of the months, compared to directly measured eddy correlation method. The nighttime minimum sensible heat during May was -20Wm^{-2} with a maximum during daytime (175Wm^{-2}). But the average value (24-hours average during IOP) was observed to be lower during monsoon season (50-70 Wm^{-2}). Large variation was observed between two methods in winter season during daytime, unlike the momentum flux.

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