# Characteristics of momentum and sensible heat flux during the monsoon conditions over LASPEX-97 region

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### ABSTRACT

The data on wind and temperature collected during Land Surface Processes Experiment (LASPEX-97) for the month of July and September 1997 were used to study the fluxes of sensible heat and momentum. The analysis suggested that the sensible heat flux was maximum of the order of 100 Wm $^{\rm 2}$  between 1300-1500 hrs (IST) at all stations of LASPEX-97. Maximum momentum flux was observed at about 1600 hrs (IST). Drag (C $_{\rm D}$ ) and heat exchange (C $_{\rm H}$ ) coefficient decreased with increasing stability (z/L). C $_{\rm D}$  and C $_{\rm H}$  showed higher magnitude in September than those in July, C $_{\rm H}$  was 2-3 times greater than C $_{\rm D}$ .

Key words: Sensible heat flux, Momentum flux, Net radiation, Exchange coefficients.

Over the past decade, it has become apparent that the numerical weather prediction and general circulation models require a more accurate representation of the complex interactions occurring at the land surface in terms of the exchanges of surface fluxes of heat, momentum and moisture. These fluxes can be estimated using bulk aerodynamic method in which exchange coefficients are used. Exchange coefficients vary with different atmospheric parameters over land such as roughness length, wind speed, stability etc. The information on these coefficients are essential to modify the surface conditions which are to be incorporated in the numerical weather prediction and climate forecasting models to provide better simulations.

Garratt (1977) has reported a comprehensive review on  $C_{\rm D}$  over land as well as sea surface. The variation of  $C_{\rm D}$  and  $C_{\rm H}$  with wind speed and stability are described

elsewhere Stull (1988). Using the Monsoon Trough Boundary Layer Experiment (MONTBLEX) data, some attempts were made to provide the information on the fluxes and C, by various worker (Patil and Parasnis, 2001; Kusuma, 1996; Mohanty et.al., 1995) and on C, (Patil and Parasnis, 2001; Kusuma et.al., 1996). The Land Surface Processes Experiment (LASPEX-97) provided on-site observations where soil properties, agriculture practice and climatic conditions change drastically from station to station. The purpose here is to investigate the characteristics of the surface fluxes of sensible heat and momentum with respect to different soil and vegetation properties.

### MATERIALS AND METHODS

LASPEX-97 was carried out in the state of Gujarat in the Mahi and Sabarmati river basin where large climate variability as well as soil properties persist. Qualitative details of the experiment can be found in this issue (Shekh et.al., 2001).

### Data analysis

The data collected at the site was supplied to the users at 1 minute interval. For the analysis in the present work, it was further averaged for 1 hour. According to the Monin-Obukhov similarity theory (Businger et. al., 1971; Yaglom, 1977; McBean, 1979), the vertical profiles of wind and temperature for turbulent flow in the surface layer can be described by the following equations:

$$u\left(z\right) = \frac{u_{*}}{k} \left[ \ln \left( \frac{z}{z_{0}} \right) \cdot \Psi_{u} \left( \frac{z}{L} \right) + \Psi_{w} \left( \frac{z_{0}}{L} \right) \right] \qquad --- (1)$$

$$\Delta \theta = \theta (z_i) - \theta (z_i)$$

$$= \frac{\theta_{*}}{k} \left[ \ln \left( \frac{z_{1}}{z_{*}} \right) - \Psi_{k} \left( \frac{z_{1}}{L} \right) + \Psi_{k} \left( \frac{z_{1}}{L} \right) \right] \qquad ---(2)$$

where u, is the friction velocity defined by

$$u^2 = \tau/\rho$$

where  $\tau$  is wind stress and  $\theta$  is density of air;  $z_o$  is the surface roughness length; k=0.4 is the von Karman constant;  $\theta_o$  is the flux temperature scale;  $\psi_M$ , and  $\psi_H$  are the stability function for momentum and sensible heat flux respectively;

$$L = u.T/kg\theta.$$

is the Obukhov length;

$$T = [\theta(z_i) + \theta(z_i)]/2;$$

and g is the acceleration due to gravity. The momentum flux  $(\tau)$  and sensible heat flux (H) were estimated by the following equations

$$\tau = \rho u_*^2 \qquad --- (3)$$

$$H = -\rho C_p u_* \theta_* \qquad --- (4)$$

Different form of stability functions have been derived and used in the literature. According to recent review of Hogstrom (1988), the early formulations obtained by Paulson (1970), Dyer and Hick (1970) and Hicks (1976) are still good approximations for an unstable surface layer and were used in the analysis for the case of unstable stratification (0,<0 or L < 0). These formulations are:

$$\Psi_{\text{M}} = 2 \ln \left( \frac{1+x}{2} \right) + \ln \left( \frac{1+x^2}{2} \right) - 2 \tan^{-1}(x) + \frac{\pi}{2}$$
 (5)

$$\Psi_{\rm H} = 2 \ln \left( \frac{1 + x^2}{2} \right) \qquad ---(6)$$

where

$$X = \left(\frac{1 - 16z}{L}\right)^{14} = \left(\frac{16z kg \theta}{Tu^2}\right)^{14}$$

For the case of stable or very stable stratification ( $\theta_* > 0$  or L>0), the following stability functions suggested by Holtslag and DeBruin (1988) and Beljaars and Holtslag (1991) were used.

$$-\Psi_{\text{\tiny M}} = a\frac{z}{L} + b\left(\frac{z}{L} - \frac{c}{d}\right) exp\left(-d\frac{z}{L}\right) + \frac{bc}{d} --- (7)$$

$$-\Psi_{H} = \left( + \frac{2 \text{ az}}{3 \text{ L}} \right)^{3z} + b \left( \frac{z}{\text{L}} - \frac{c}{d} \right) \exp \left( -d \frac{z}{\text{L}} \right)$$

$$+\frac{bc}{d} - 1$$
 --- (8)

where a = 1, b = 0.667, c = 5 and d = 0.35. For estimating u, and  $\theta$ , from equation (1) and (2), iterative procedure was followed. This is the profile method (Nieuwstadt, 1978; McBean, 1979). Thus the fluxes estimated by (3) and (4) were used to compute the  $C_{\rm B}$  and  $C_{\rm H}$  using following relations.

$$\tau = \rho C_D u^2 \qquad --- (9)$$

$$H = -\rho C_u \Delta \theta u \qquad --- (10)$$

where u is the  $[u(z_1)+u(z_1)]/2$ .  $\Delta\theta$  is the potential temperature difference between  $z_1$  and  $z_2$  level. In the computation, averaged (hourly) wind and temperature data were used at  $z_1=1$  m and  $z_2=8$  m levels.

### RESULTS AND DISCUSSION

Estimation of sensible heat and momentum flux were made for the days of Intensive Observational Period (IOP) of the month July and September, IOP was selected from dates 13-18 of each month. The fluxes were averaged on hourly basis over a period of no of days in IOP in a representative month. In this averaging process, we eliminated those values which showed greater spike with respect to the majority of data points. The data used in the study pertains to monsoon season (July) and its withdrawal (September) periods, The sky conditions were cloudy in the region with variable cloud amounts. Cloud conditions for the month of July and September of 1997 are given in Table 1.

## Diurnal variation of sensible heat and momentum flux

Fig. 1 shows the diurnal variation of sensible heat flux for the months of July and September over all the stations of LASPEX-97. Maximum sensible heat flux observed at all the stations (except at Arnej in July) was about 100 Wm<sup>2</sup>. The variation of fluxes at Sanand in September could not be estimated

because of the failure of data recording of some parameters. At Arnej, in July, sensible heat flux remained constant throughout the daytime without displaying routine diurnal cycle. This may be because of water logging at the tower site and the soil was totally moist. However in September, observations showed their natural diurnal cycle. Sensible heat flux maxima were observed at 1300-1500 hrs IST. Maximum momentum flux was observed at 1600 hr IST (Fig. 2) that was 2-3 hours after the peak of sensible heat flux occurred.

The highest value of momentum flux observed at Khandha in July was 0.37 m<sup>2</sup>s<sup>-2</sup>. The stability parameter (z/L) was under near neutral conditions during most of the time except at dawn hrs. Momentum flux was lower in September besides z/L shows higher range of instability during daytime. Wind direction in July was southwest, and in the field, tall crops like sugar cane, pigeon pea were grown. In September, wind direction changed to northwest, where short crops were grown. Thus the influence of vegetation/roughness length was the dominating factors over stability in rising momentum flux at Khandha. Over the LASPEX site, low momentum flux was observed at Anand and Derol in which during daytime, surface layer showed moderate convective instability and stable to near neutral conditions during nighttime. Thus the higher magnitude of fluxes were associated with stronger instability and vice-versa. A comparison of fluxes with different types of soil showed that, higher magnitudes of fluxes were observed over clay soils; where as they were at lower magnitude at the site where the soil type was loamy sand.

Fig. 3 depicts the observed maxima in net radiation. Net radiation maxima were comparable for both the months at Arnej and

Table 1: Cloud amount at the LASPEX-97 region during IOP for July and September 1997

Date	Anand	Derol	Sanand	Khandha	Arnej
			TOLY		
12-7-1997	No observation	No observation	No observation	Cloudy, 3/8 (Rain in	No observation
13-7-1997	Overcast,	Cloudy	Overcast	passed night) Overcast, Drizzle (Rain	No observation
4-7-1997	Cloudy, 4/8	Cloudy	Cloudy, 4/8	in passed night) Overcast, Rain	No observation
5-7-1997	Cloudy, 5/8	Cloudy	Cloudy, 4/8	Cloudy, 6/8, Rain	No observation
16-7-1997	Cloudy, 7/8	Cloudy	Cloudy, 3/8	Overcast	No observation
7-7-1997	Cloudy, 6/8,	Cloudy, Drizzling	Overcast	Cloudy, 6/8	No observation
	Drizzle in noon hrs. Rain in night	in evening hrs	000000000000000000000000000000000000000		
18-7-1997	Overcast, Rain in evening hrs.	Cloudy (Rain occurred in	Overcast	Overcast, Rain	No observation
		1000	SEPTEMBER		
12-9-1997	Overcast, Rain	No observation	Cloudy, 6/8, Rain	Cloudy, Rain	No observation
3-9-1997	Cloudy to	Cloudy, 6/8	in noon hrs. Cloudy, 6/8, Rain	Cloudy, 6/8	No observation
	overcast, Rain		in evening hrs.		
14-9-1997	Cloudy	Cloudy, 7/8	Cloudy, 6/8, Rain	Cloudy, 6/8	No observation
15-9-1997	Cloudy to overcast	Cloudy, 7/8	Cloudy, 6/8	Cloudy, 6/8	No observation
16-9-1997	Overcast, Rain in	Cloudy, 7/8	Overcast, Rain in	Cloudy, 6/8	No observation
17-9-1997	Overcast (Rain in	Cloudy, 6/8	noon hrs Overcast (Rain	Cloudy, 5/8	No observation
18-9-1997	rassed mgm) night) No observation	No observation	occurred passed No observation	Cloudy 4/8	No observation

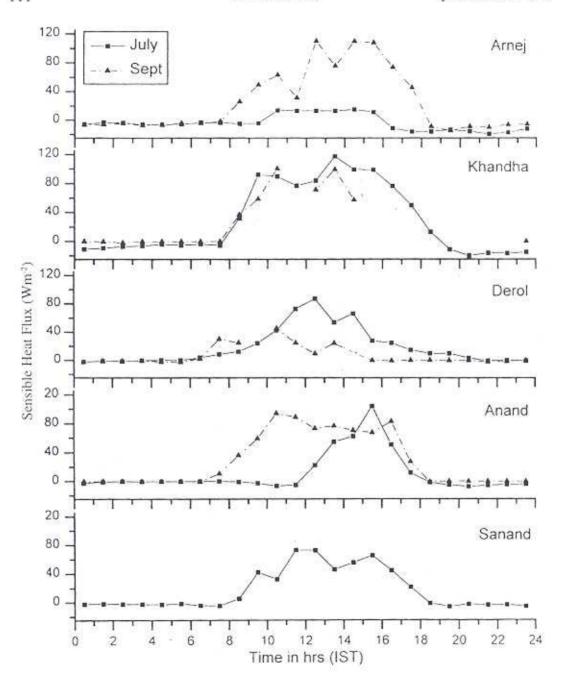


Fig. 1: Diurnal variation of sensible heat flux in July and September 1997

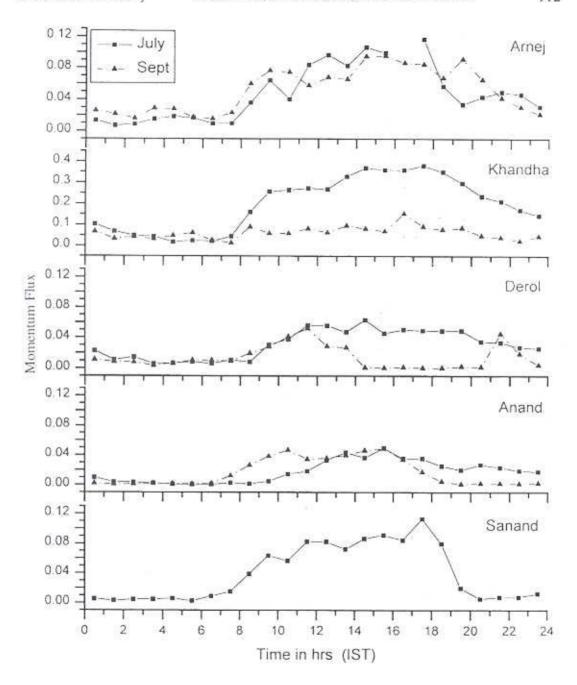


Fig. 2: Diurnal variation of momentum flux (m2 s-2) in July and September 1997

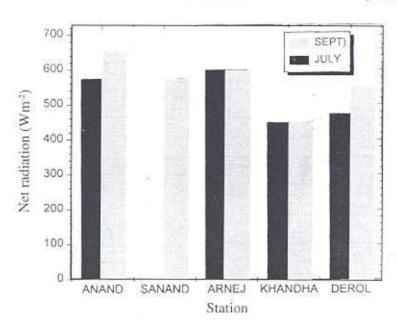


Fig. 3: Net radiation observed at peak hours in July and September 1997.

Khandha where the soil type was clay. It was higher in September than that in July at other two stations. At Sanand, radiation data are erroneous due to failure in calibration of radiation sensors for July and hence are not shown. The spatial differences in the fluxes of sensible heat, momentum and net radiation could be due to different soil and vegetation properties as well as surface pattern.

## Variation of drag and heat exchange coefficient with stability

The fluxes were estimated by profile method in which stability was given by the Momin-Obukhov length (L). A nondimensional factor z/L was used as a stability parameter. Fig.4 and 5 show the variation of  $C_{\rm D}$  and  $C_{\rm H}$  respectively with z/L.  $C_{\rm H}$  was 2-3 times larger than  $C_{\rm D}$ . Both coefficients ( $C_{\rm D}$  and  $C_{\rm H}$ ) showed decreasing trend with increasing stability in most of the

cases. At Khandha, in September, they were scattered but one could see higher magnitude in unstable conditions (-ve z/L) than in stable condition.

Under neutral conditions (z/L  $\simeq$  0), C<sub>0</sub> and Cu showed higher magnitude in September than those in July. Overall, larger coefficients were observed at Arnej and Khandha. The variation of these coefficients with wind speed (Figure not shown) did not show systematic trend. Over LASPEX site, under neutral conditions, Cp varied between 0.0035 (Anand and Derol) to 0.010 (Khandha and Arnei) whereas C<sub>H</sub> varied from 0.011 (Anand and Derol) to 0.021 (Khandha and Arnej). During MONTBLEX, over Jodhpur, which is nearer to the LASPEX site, Cp and CH were studied by various workers (Patil and Parasnis, 2001; Kusuma, 1996; Kusuma et.al., 1996; Mohanty et.al., 1995) using different

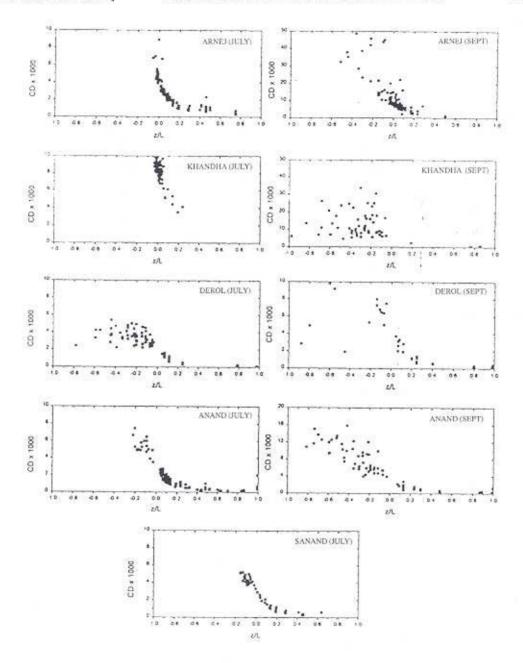


Fig. 4: Variation of C<sub>D</sub> with z/L over LASPEX-97 sites.

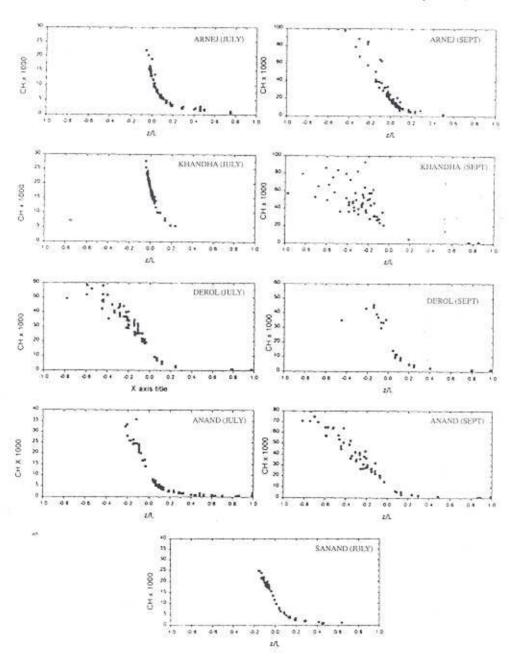


Fig. 5: Variation of  $C_H$  with z/L over LASPEX-97 sites.

techniques. The observed magnitudes of C<sub>D</sub> and C<sub>H</sub> are in agreement with the values reported by Patil and Parasnis (2001); Kusuma (1996) and Mohanty et.al. (1995). Observed variations in these values from station to station over LASPEX site is due to the greater variability in vegetation pattern as well as soil properties.

### SUMMARY

The study of variations of fluxes and exchange coefficients using LASPEX-97 observations suggested the followings:

- (i) The fluxes of sensible heat and momentum showed diurnal variations. The net radiation was higher in September as compared to that in July. In general, higher momentum flux was observed at the stations where soil type was clay; while at the stations where soil was loamy sand, the momentum flux was low.
- (ii) Under neutral stability, C<sub>D</sub> varied between (3.5 8.5) x 10<sup>-3</sup> in July and (5.0 10.0) x 10<sup>-3</sup> in September, while C<sub>H</sub> varied from (11.0 18.0) x 10<sup>-3</sup> in July and (14.0 21.0) x 10<sup>-3</sup> in September, C<sub>D</sub> and C<sub>H</sub> showed decreasing trend with increase in stability. Magnitude of C<sub>H</sub> was relatively higher (about 2-3 times) than C<sub>D</sub> under neutral conditions. Their variation with wind speed was not systematic. These results are attributed to the soil and vegetation properties at the respective stations.

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