*Journal of Agrometeorology 3(1&2) : 133-141 (June-December 2001)*

# Roughness length and drag coefficient at Anand

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## ABSTRACT

LASPEX-97 tower data of Anand for IOP period of July and September months have been used to estimate the roughness length ($z_0$) and drag coefficient ($C_d$) under the different stability conditions. The average value of roughness length was 0.4cm in unstable condition while in near neutral condition it was 1.5 cm. Average drag coefficient was found to be 5-7x10$^{-3}$. The interdependence of wind speed, wind direction, frictional velocity, and drag coefficients has been assessed graphically and linear relationships have been determined.

*Key words:* Roughness length, Drag coefficients, Friction velocity

Accurate estimation of surface roughness parameters is crucial for determining the surface drag and for parameterization of turbulent transport of heat, momentum and moisture between the earth and the atmosphere. Earlier studies using certain similarity hypotheses (Dyer and Hicks, 1970; Businger *et al*, 1971) introduced explicitly a local surface roughness length $z_o$, which for many purposes is an adequate characterization of the roughness. Wieringa (1993) emphasized the importance of a correct knowledge of the surface roughness of the earth in the description, modeling and forecasting of the behaviors of the averaged winds and turbulence on all scales. The variation of fluxes of momentum, heat and moisture in the surface boundary layer and their distribution in the rest of the planetary boundary layer play a vital role in the energy transport mechanism of the land-surface-atmospheric transfer system.

The most widely used bulk aerodynamic formula for momentum transport requires specification of the values of a drag coefficient, which can be determined from the turbulence measurements made in a field experiment. A comprehensive review on the estimation of drag coefficient over ocean and land surfaces has been reported by Garratt (1977). Dependence of $C_d$ on wind speed, stability and nature of underlying surface has been emphasized. However, the information on the dependence of drag coefficient over land surfaces on wind speed and stability is still inadequate in many of the reviews (Goel and Srivastava, 1990). Hence the present study makes an attempt in this direction.

## MATERIALS AND METHODS

For the present analysis, data collected during Intensive Observational Period (IOP) (13$^{th}$ to 17$^{th}$ of every month) for two phases of monsoon, namely, active phase (July, 1997) and withdrawal phase (September, 1997) have been used. Temperature and wind speed at 4 levels (1,2,4 and 8 m), wind direction at 2 levels (1 and 4m) collected at 8m-tower site of Anand have been used. Details of soil properties and agroclimatic features of the sites are presented by Pandey *et al.* (2001).

### *Roughness length*

The roughness length was calculated for statically neutral situation using logarithmic wind profile law. The neutral stability cordition was delimined by -0.01 > Ri < 0.01 (Panofsky and Dutton 1984), where Ri is the Richardson number determined by

$$Ri = \frac{-g}{T} \frac{\partial\theta/\partial z}{(\partial u/\partial z)^2}$$

where g is the acceleration due to gravity, $\partial\theta/\partial z$ and $(\partial u/\partial z)^2$ are the vertical gradients of mean potential temperature and mean horizontal wind speed, and T is the absolute temperature (degree Kelvin).

Roughness length ($z_o$) was obtained using logarithmic wind profile law,

$$u/u_* = (1/k)\ \ln(z/z_o)$$

where k = von Karman's constant and $u_*$ is frictional velocity.

### *Drag coefficient ($C_d$)*

Bulk aerodynamic method is the most convenient and widely used method for determining the surface fluxes. In this method, the basic assumption is that the surface wind stress is in the direction of surface wind.

The surface momentum flux, is expressed as,

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

where $C_d$ is the momentum transfer or drag coefficient and u is the wind velocity.

## RESULTS AND DISCUSSIONS

### *Wind speed and friction velocity*

At Anand the wind speed and wind direction were found to vary with the season as well under different stability conditions. Under neutral condition the wind was confined between 1.5 to 4.5 $ms^{-1}$ (Fig.1) mostly from 240° -271° (SW) during active monsoon period (July) and less than 2$ms^{-1}$ during September from 180° to 300° direction. Under unstable condition, however, the situation was slightly different. The wind speed was higher and mostly concentrated in the 270°-290° sector during July and 240° to 290° sector during September (Fig.2).

Frictional velocity ($u_*$) was more or less constant under neutral condition (Fig.3). Large variation (0.1 to 0.4) in $u_*$ is observed during both the seasons (July and September) in statically unstable conditions (Fig.4).

### *Roughness length ($z_o$)*

Roughness lengths show different values depending upon the surface roughness and crop height. The variations of $z_o$ with wind speed are depicted in Figs. 5 and 6. With increase in wind speed $z_o$ decrease in all the cases. It may further be noted that the values of $z_o$ were lower under unstable condition and varied between 0 to 0.4 cm and under neutral condition it was 0 to 1.5cm. As the wind direction changed from 240°-270° to 356°-360°, its values increased even under neutral condition. During July there was 10-11 cm high sunhemp crop near the tower and it is observed that during this period $z_o$ was lower. This might be to the fact that during the month

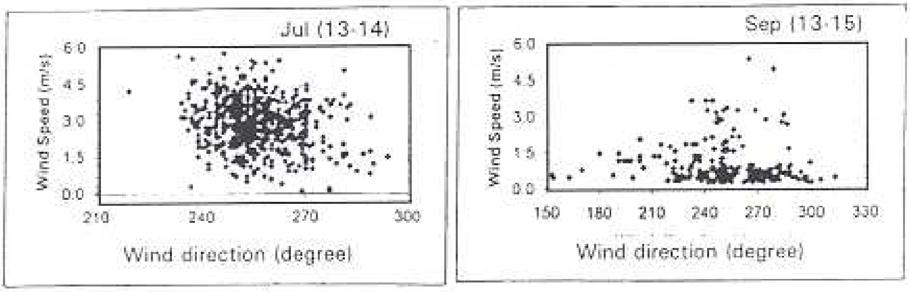


**Fig. 1 :** Wind speed during statically neutral condition for different sector

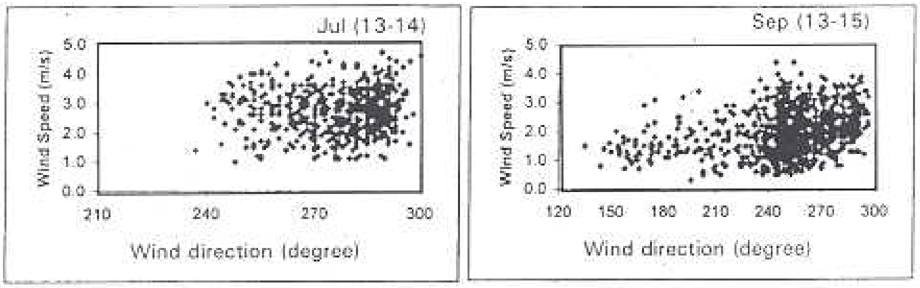


**Fig. 2 :** Wind speed during statically unstable condition for different sector

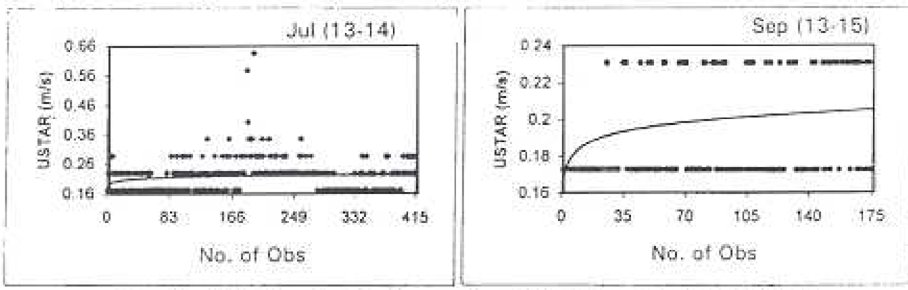


**Fig. 3 :** Frictional velocity under statically neutral condition

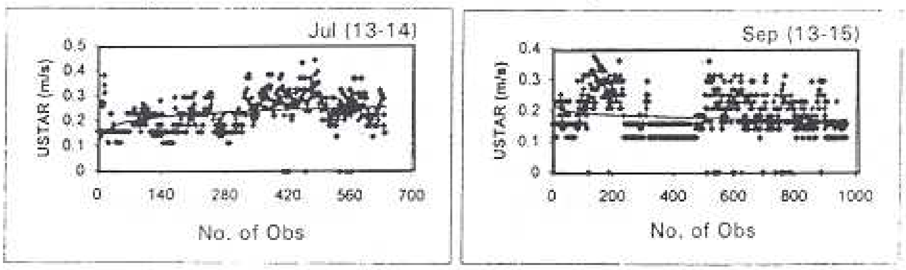


**Fig. 4 :** Frictional velocity under statically unstable condition

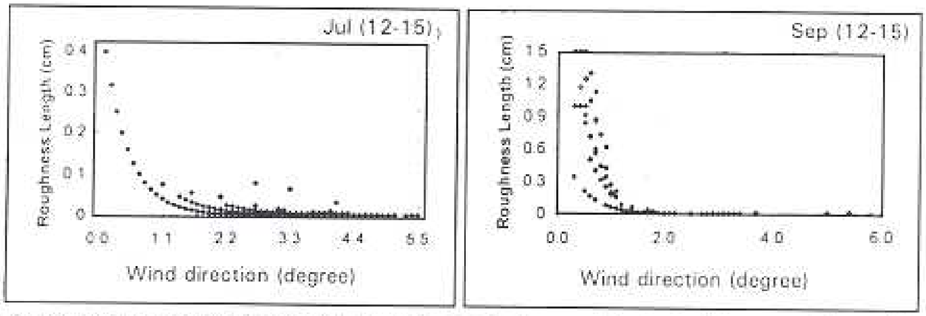


**Fig. 5 :** Dependance of roughness length on wind speed in statically neutral condition

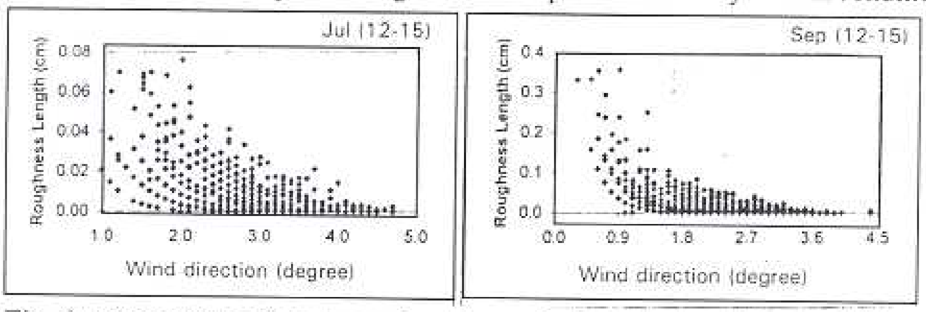


**Fig. 6 :** Dependance of roughness length on wind speed in unstable condition

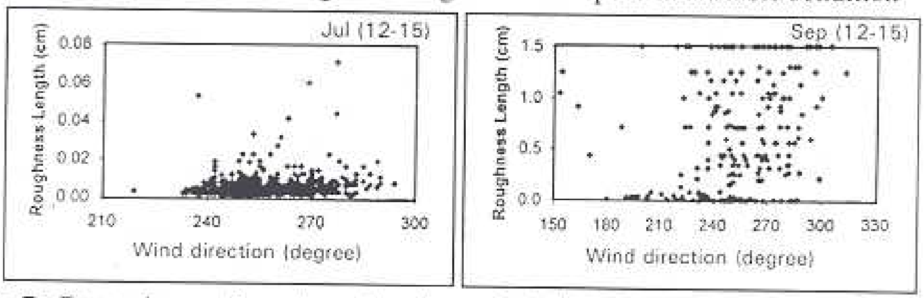


**Fig. 7 :** Dependance of roughness length on wind dir. in statically neutral condition

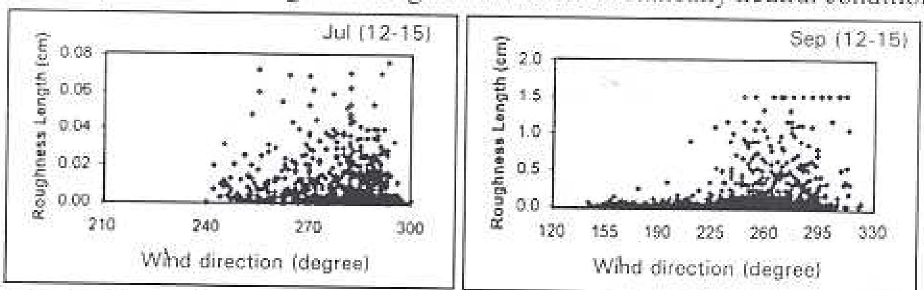


**Fig. 8 :** Dependance of roughness length on wind dir. in unstable condition

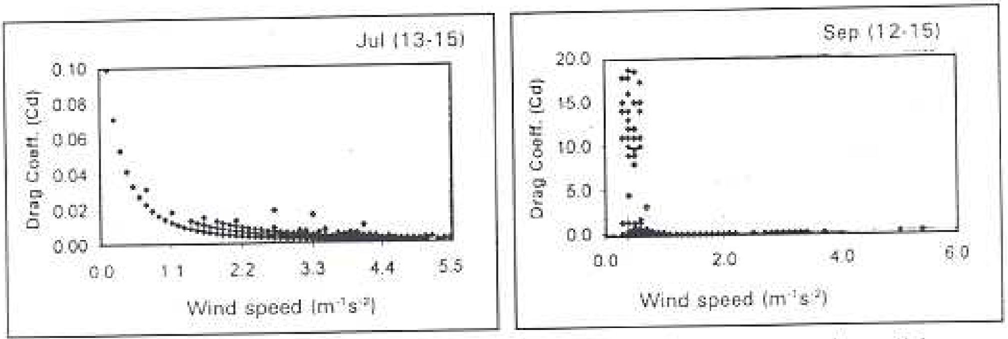


**Fig. 9 :** Dependance of drag coefficient on wind speed for near neutral condition

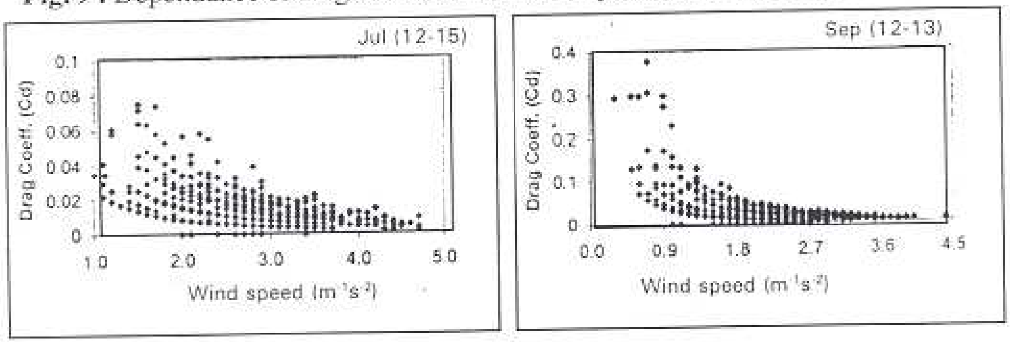


**Fig. 10 :** Dependance of drag coefficient on wind speed under unstable condition

of September the soil was totally saturated due to rains and so it became porous which was relatively rougher whereas during July, surface was smoothed by weathering and compaction; even it was short height crop, as mentioned earlier, during the month of July. The results are in agreement with that observed by (Rao, 1995; Sauer *et al.*, 1996; Wieringa, 1963).

Variation in $z_0$ with the variation in wind direction is shown in Figs. 7 and 8. During active monsoon period (July) the wind directions were confined between 230°-290° while during withdrawal phase of monsoon (September) the direction varied between 130° to 310°. During July in most of the cases the $z_0$ varied from 0 to 0.04 cm while during September it was higher (0 to 1.5 cm) under neutral as well as unstable conditions.

### *Drag coefficient ($C_d$)*

#### *Dependence on wind speed*

Figs. 9 and 10 depict the dependence of drag coefficient on wind speed under neutral condition and unstable condition. Under near neutral conditions (Fig. 9) drag is not only significant at low winds but varies nearly linearly with wind speed.

As an approximation, curve fit for the drag coefficient as function of wind speed from

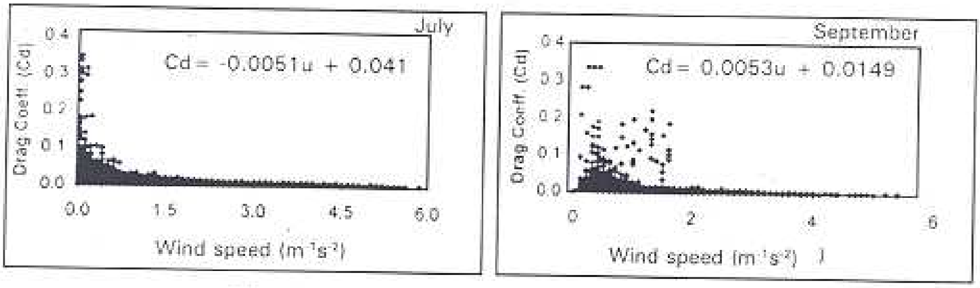


Fig. 11 : Variation of drag coefficient with wind

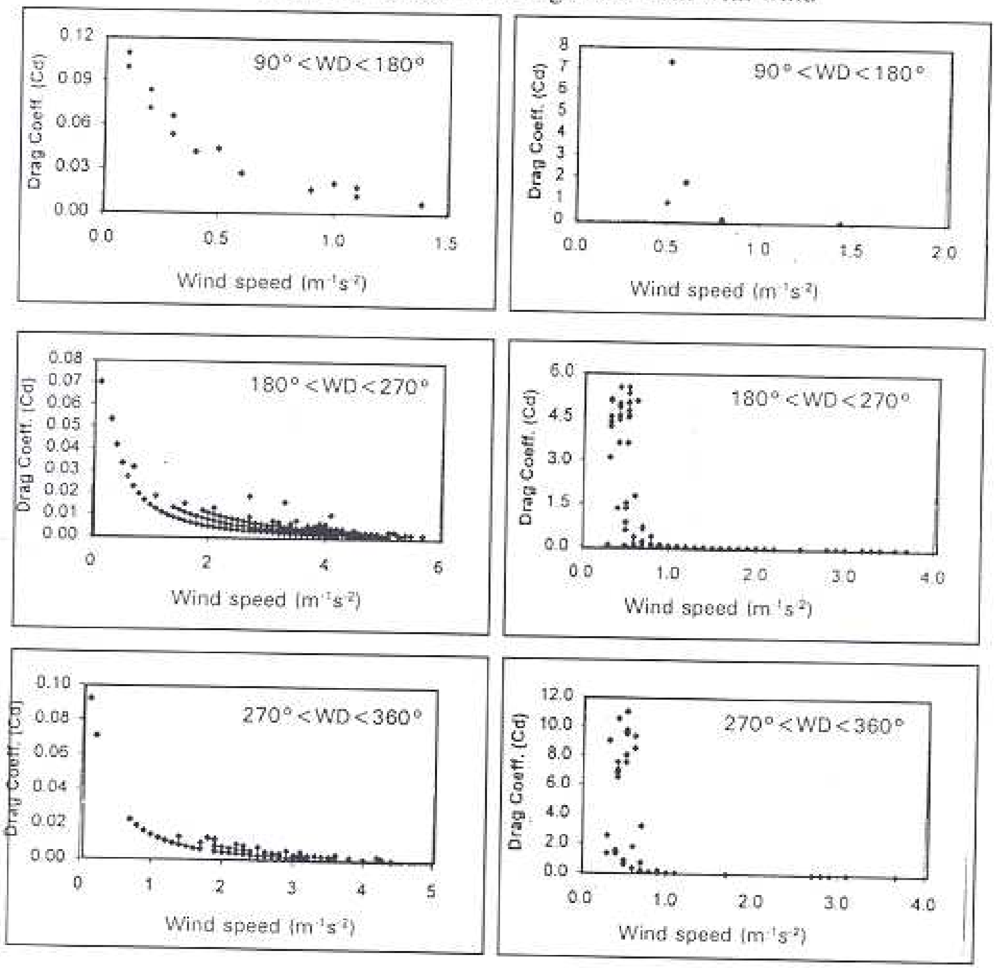


Fig. 12 : Dependence of drag coefficient for -0.005<Ri<0.03 for different wind sector (a) Jul (13-15) and (b) Sep (13-14)

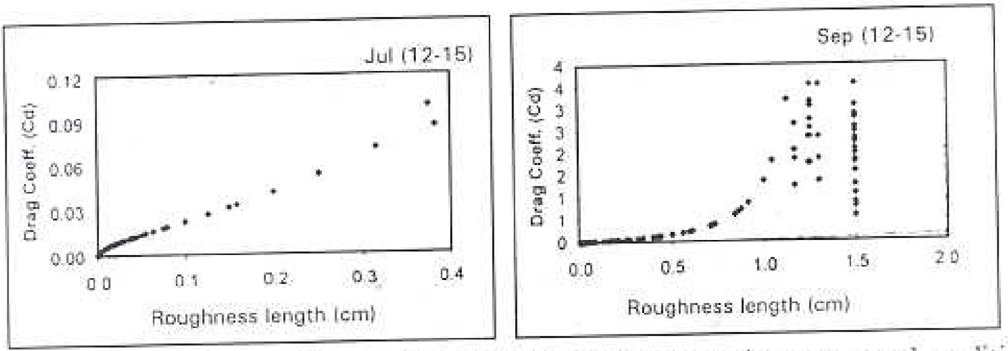


**Fig. 13 :** Dependance of drag coefficient on Roughness length for near neutral condition

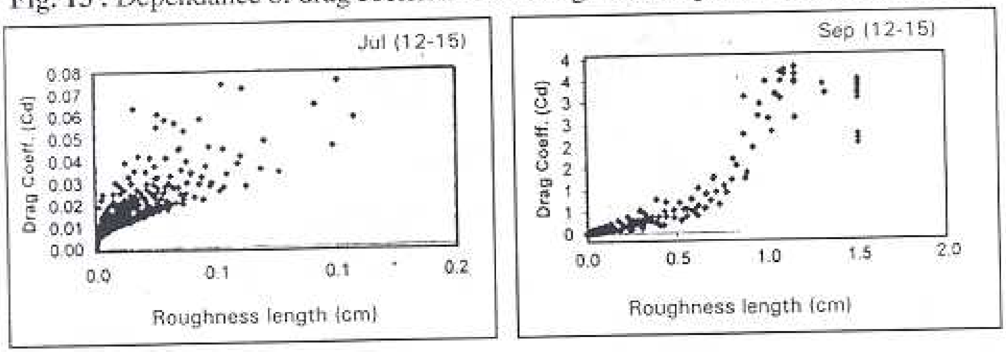


**Fig. 14 :** Dependance of drag coefficient on Roughness length under unstable condition

all directions and for all the conditions for July and September and described the linear equation (Fig. 11) as

$C_d$ = -0.0051 u + 0.041, for July

$C_d$ = -0.053 u + 0.0149, for September in comparison to Stull (1988)

$C_d$ = $(1.10+ 0.07\ u)10^{-3}$ for Neutral drag coefficient over plains and during night.

***Dependence on wind direction***

The low winds at Anand were found to be blowing from SW directions around the tower (Fig. 12). Since the roughness lengths at Anand vary with sectors as demonstrated in earlier section, the drag coefficients were plotted as a function of wind speed for three different sectors around the tower, namely 90°-180°, 180°-270° and 270°-360° for July and September under near neutral condition. $-0.001 < Ri < 0.001$. The drag coefficients assume very high value at low winds in the sectors 90° to 180°. Fewer values were observed between the sectors 90° and 180°. During withdrawal phase under unstable conditions, for the same range of wind speed drag coefficient showed significantly higher values than for July and it was higher between sectors 90°-180° and 270°-360°.

*Dependence on roughness length*

Figs. 13 and 14 depict the relationship of drag coefficient with roughness length in all the sectors. Drag coefficient increased nearly linear with surface roughness length but increased significantly in September.

## CONCLUSIONS

On the basis of above discussion we can say that all the surface layer parameters frictional velocity, roughness length and drag coefficient are largely dependent on the wind, surface roughness, nature of the terrain and the direction of the wind from where it blowing. The following conclusions may be inferred on the basis of the above discussion:

1. Frictional velocity ranged from 0.2-0.3 for both the periods.

2. The drag coefficient exhibits a decreasing tendency with increasing wind speed in the region of 1-5 $ms^{-1}$.

3. The average value of Cd is found to be of the order of $5\text{-}7 \times 10^{-3}$, which is about 1.5 times larger than the average value of natural drag coefficient for Asian continent, prescribed, by Stull in 1988 ($3.9 \times 10^{-3}$).

The conclusions regarding the estimation of land surface parameters are confined to only one site of LASPEX-97. Similar studies at other locations using LASPEX -97 data are desirable to establish the spatial and temporal variation of these parameters during summer and winter which will be useful in parameterization of surface layer in large scale numerical models.

## ACKNOWLEDGEMENT

The authors are highly grateful to the Department of Science and Technology, Govt. of India, New Delhi for financial support to carry out LASPEX-97.

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