

Boundary layer fluxes over Anand using similarity theory

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ABSTRACT

The Land Surface Processes Experiment (LASPEX-97) was conducted in the semi-arid region of Anand in Gujarat state of India during 1997. The experiment used a tower having instruments at 1 m, 4 m, 16 m and 30 m levels, with fast as well as slow response sensors. The tower data at Anand was utilised to computing fluxes using Monin-Obukhov similarity theory for both the stable and the unstable conditions. The computations were made for representative days during May, July and December 1997. The fluxes computed were compared with the in-situ observations. The inferences were made for the appropriateness of the similarity theory for the boundary layer parametrisation over land regions for use in the numerical modelling.

Key words: Boundary layer, Monin-Obukhov similarity theory

The exchange of momentum, heat and moisture in the atmospheric boundary layer plays an important role in determination of the structure of PBL and its characteristic parameters. The knowledge of the distribution of fluxes of momentum, sensible heat and latent heat in the surface layer are essential in understanding semi-permanent features of summer monsoon low and depression which bring copious amounts of rainfall in the Indian sub-continent. Although theoretical solutions are difficult to obtain, the semi-empirical relations are formulated following Monin-Obukhov (M-O) similarity theory, which is extensively used. Computation of boundary layer fluxes and its variation with stability parameters like bulk Richardson number (R_{ib}) were studied using operational meteorological satellites (Simon *et. al.* 1986) especially near tropical Indian Ocean. The latent heat flux over oceanic regions was shown to be strongly dependent on atmospheric stability. Joshi and Simon (1994) compared the fluxes estimated

by satellite and those obtained by Monin-Obukhov similarity theory over oceanic regions. They show that the stability dependent corrections may be more than 100 Wm^{-2} . In present paper boundary layer tower data over Anand were utilised with M-O similarity theory, to compute the sensible heat and momentum fluxes. The variation of these fluxes with inclusion of stability parameter (R_{ib}) was also studied. Boundary layer fluxes were compared with observed instantaneous fluxes.

MATERIALS AND METHOD

In the present study Sonic-anemometer located at 9.5 meter level under the LASPEX-97 program is utilised for computation of fluxes of momentum and the heat by eddy correlation method. This fast response data is stored with 10 minutes average. However for fluxes comparison purpose hourly average data is used. With hourly averaging data becomes smooth without disturbing the

variation pattern. We have used the observed data at 1 and 16 m to compute the fluxes of momentum and sensible heat using similarity theory.

Flux computation

The similarity fluxes of momentum (F_m) and heat (F_h) are respectively expressed by the relation (Chang 1978)

$$F_m = \rho C_m (U_2 - U_1)^2 \quad \text{--- (1)}$$

$$F_h = \rho C_h C_p (U_2 - U_1) (\theta_2 - \theta_1) \quad \text{--- (2)}$$

Where the similarity exchange coefficients are expressed by

$$C_m = \frac{K^2}{[\ln(z_2/z_1)]^2 (1 + 4.7 R_{bh})^2} \quad \text{--- (3)}$$

$$C_h = \frac{K^2}{-0.74 [\ln(z_2/z_1)]^2 (1 + 4.7 R_{bh})^2} \quad \text{--- (4)}$$

for stable and neutral case ($R_{bh} \geq 0$);

$$C_m = \frac{K^2}{[\ln(Z_2/Z_1)]^2} \left[1 - \frac{9.4 R_{bh}}{(1 + C |R_{bh}|^{0.5})} \right] \quad \text{--- (5)}$$

$$C_h = \frac{K^2}{-0.74 [\ln(Z_2/Z_1)]^2} \left[1 - \frac{9.4 R_{bh}}{(1 + C |R_{bh}|^{0.5})} \right] \quad \text{--- (6)}$$

for unstable case $R_{bh} < 0$.

Here Z_1 and Z_2 denote respectively the height of the bottom and top of the constant flux layer. (U_1, U_2), (θ_1, θ_2) denote the wind and potential temperature at bottom and the top of surface layer. R_{bh} denotes the bulk Richardson number whose sign is used to denote the stability, K denotes the von Karman constant.

R_{bh} is given by

$$R_{bh} = \frac{g}{\theta} \frac{(\theta_2 - \theta_1)(Z_2 - Z_1)}{(U_2 - U_1)^2} \quad \text{--- (7)}$$

Expression for C follows the analysis of Louis (1979)

$$C = \frac{69.5 K^2}{(\ln[Z_2/Z_1])^2} \left(\frac{Z_2}{Z_1} \right)^{0.5} \quad \text{--- (8)}$$

For momentum fluxes and,

$$C = \frac{49.8 K^2}{(\ln[Z_2/Z_1])^2} \left(\frac{Z_2}{Z_1} \right)^{0.5} \quad \text{--- (9)}$$

for heat fluxes.

RESULTS AND DISCUSSION

Identification of constant flux surface layer

Sensible heat flux (Fig. 1) for three layers (1-16 m), (4-16 m) and (4-30 m) computed using similarity theory shows that fluxes from three different layers are different in magnitude particularly during convection period. This type of pattern has been noticed on all days (study period). The diurnal pattern is seen clearly in all the layers. The observed fluxes using (1-16 m) layer compared well with the fluxes computed by eddy correlation method. This type of variation in the fluxes within the surface layer indicates the presence of isolated layers in surface layer rather than a constant surface and that identification of constant flux surface layer has to be done very carefully.

Diurnal variation of momentum flux

Variation of momentum flux with time has been studied for representative days in the months of May, July and December and

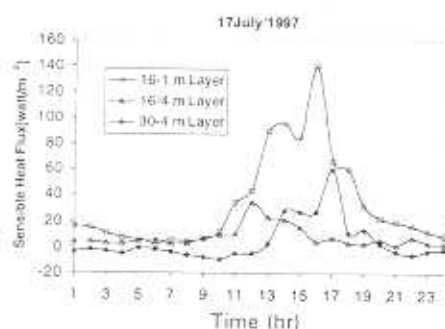


Fig. 1 : Comparison between sensible heat flux calculated for three different layers

shown in Figs.2 (a-c). The flux is maximum during noontime and minimum during early morning and late evening. Negative values indicate downward flux of momentum. In summer and monsoon period (May and July) the range of momentum flux is of the order of $10\text{--}175\text{ gm}^{-1}\text{s}^{-2}$ with a peak in May about $175\text{ gm}^{-1}\text{s}^{-2}$. In winter (December) the range is $0\text{--}50\text{ gm}^{-1}\text{s}^{-2}$. The momentum flux variation with stability factor is shown in Figs.3 (a-c) for May, July and December. In May and July momentum flux is higher under unstable atmosphere and less for stable or neutral atmosphere. The increase in the magnitude of momentum flux with instability is apparent. However after reaching a particular state of instability, the momentum flux again gets reduced. This reduction in magnitude is probably due to reduction in gradient of meteorological parameters like winds due to strong mixing in high convection situation.

Variation of sensible heat flux with stability

Variation of sensible heat flux with stability is shown in Figs.4 (a-c). Sensible heat is calculated using 1-16 m for different days

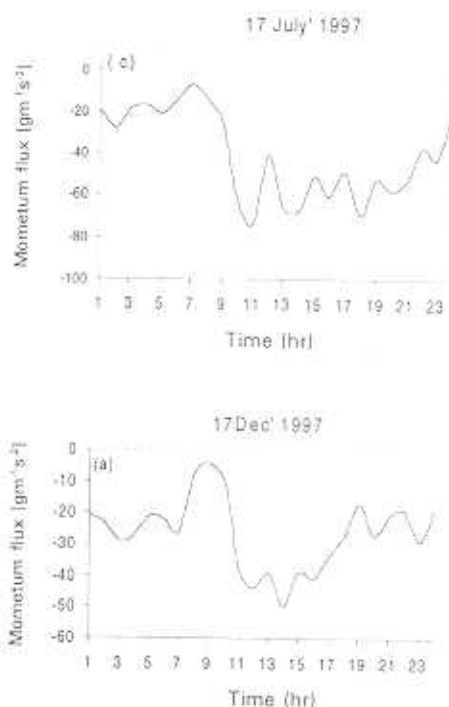


Fig. 2 : Momentum flux variation with time

in different months. Three profiles covering three months are shown in the figures. These figures show that the downward heat flux occurred for stable atmosphere [$R_m > 0$], upward flux is persistent for unstable atmosphere [$R_m < 0$] and negligible flux for

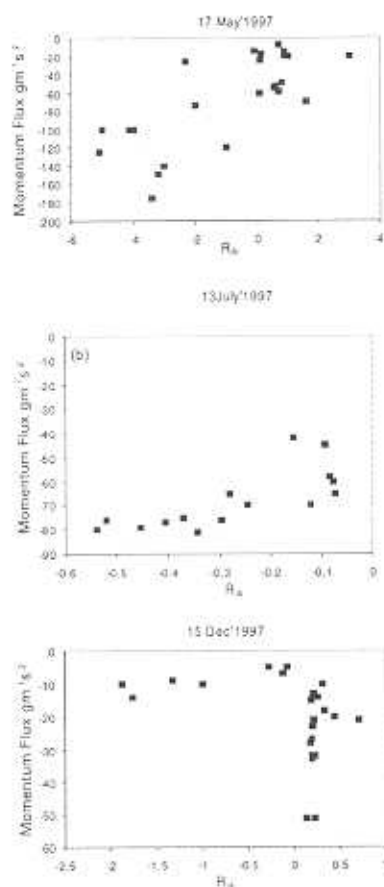


Fig. 3 : Momentum flux variation with bulk Richardson number

neutral atmosphere. Sensible heat flux is maximum under unstable atmosphere. The maximum value is around 200 Wm^{-2} during May, while maximum downward value is around 80 Wm^{-2} during December.

Comparison between the sensible heat flux given by eddy correlation method and similarity method

The sensible heat fluxes from both approaches are shown in the Figs.5 (a-c). Both

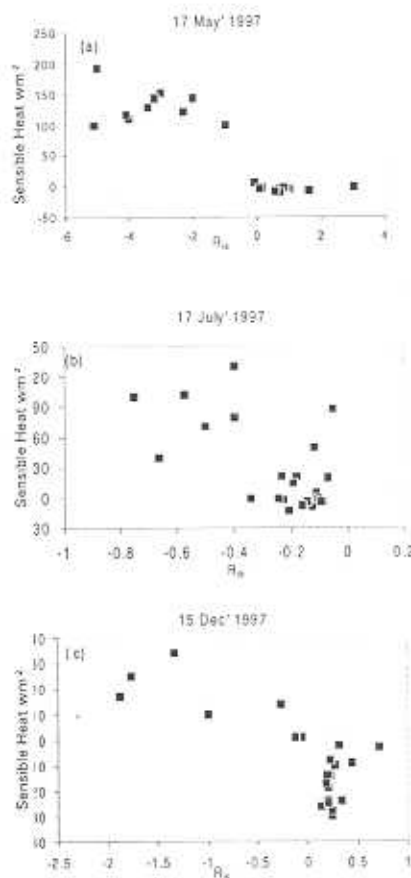


Fig. 4 : Sensible heat flux variation with bulk Richardson number (R_{bh})

approaches give the diurnal variation very well. As expected we find maximum upward flux around noontime and downward flux around early morning and late evening on clear sunny day. In pre monsoon and monsoon months (May and July) the sensible heat flux given by similarity method is in agreement with the eddy correlation method. Except on 17 May, the maximum values of sensible heat flux given by eddy correlation method are around 300 Wm^{-2} . Whereas the heat flux given

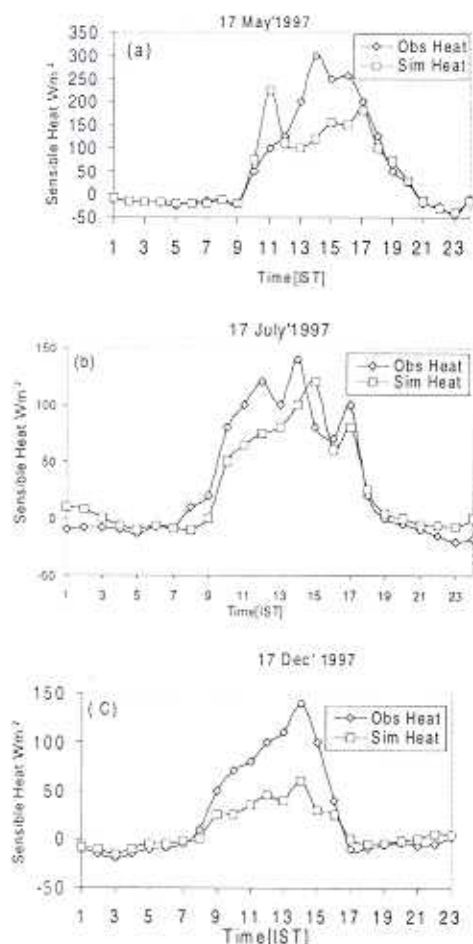


Fig. 5 : Comparison between sensible heat flux calculated using similarity method and eddy correlation (observed) method

by similarity theory is around 200 Wm^{-2} . During December the magnitude of sensible heat flux given by two approaches is quite different especially during noontime when atmosphere is unstable. Here also trend in the profile is same i.e. maximum around noontime. Maximum downward sensible heat flux is

around 75 Wm^{-2} in the month of December. Between 9-15 hours IST computed sensible heat flux at times is an underestimate deviating by 200 Wm^{-2} in summer (May) and by 100 Wm^{-2} during monsoon and winter months.

CONCLUSIONS

Downward transport of momentum flux is maximum during pre-monsoon period and around noon time with minimum or negligible values around early morning and late evening. The magnitude of momentum flux is found to decrease with increase in degree of instability in December and to increase with increase in degree of instability in the month of May and July. For sensible heat flux some differences in magnitude are observed between these two approaches. This may be due to following reasons:

- Eddy correlation method involves the data at only one level, but the present method takes into account the temperature structure of entire surface layer.
- Calculation of fluxes with similarity theory used dry potential temperature rather than virtual temperature, which may be one of the factors for differences in magnitude.

In view of differences observed between the similarity theory based fluxes and the observed fluxes, the parameterisation schemes (particularly using M-O similarity) used in numerical models needs modification.

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REFERENCES

- Chang, L.W. 1978. Determination of surface flux of sensible heat, Latent heat and momentum utilizing the bulk Richardson number. *Papers Meteorol. Res.*, 1: 16-24
- Joshi, P.C. and Simon, B. 1994. Boundary layer modelling and satellite data analysis, global change studies, ISRO-GBP Report NO. 42-92: 403-410.
- Louis, J.F. 1979. A parametric model of vertical eddy fluxes in the atmosphere. *Bound. Layer Meteorol.*, 17: 187-202.
- Simon, B. and Desai, P.S. 1986. Equatorial Indian Ocean evaporation estimates from operational meteorological satellites and some inferences in context of monsoon onset and activity. *Bound. Layer Meteorol.*, 37:12-37.