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Turbulence studies at dry and moist convective regions of monsoon trough during different phases of monsoon

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सार—टॉवर से मंथर व द्रुत गति से प्राप्त आंकड़ों का उपयोग करते हुए आर्द्र संवहनी स्टेशन खड़गपुर (23.3°उत्तर, 87.2° पूर्व) और शुष्क संवहनी स्टेशन जोधपुर (26.3° उत्तर, 73° पूर्व) के बीच मानसून की तीन प्रावस्थाओं अर्थात् मानसून के आरम्भ मध्य व अन्त के समय प्रक्षोभ प्राचलों जैसे कि घर्षणात्मक वेग ($u*$) तापमान माप ($\theta*$), प्रक्षोभ तीव्रता, संवेदी उष्मा फलक्स (H), सतह संवेग फलक्स (τ) और भंवर विसरणशीलता पद्धति (K_m) का तुलनात्मक अध्ययन किया गया। प्रोफाइल पद्धति (अपरोक्ष पद्धति) के साथ भंवर सहसंबंध (परोक्ष पद्धति) द्वारा आकलित सवेद्य उष्मा फलक्स की दैनिक विभिन्नता की प्रवृत्ति समान है तथापि अप्रत्यक्ष पद्धति से आकलित फलक्स में अतिशयता पाई गई है।

ABSTRACT. Utilising the slow and fast data from the towers, a comparative study of turbulence parameters *i.e.* frictional velocity (u_*), temperature scale (θ_*), turbulence intensities, sensible heat flux (H), surface momentum flux (τ) and eddy diffusivity (K_m) during the three phases of monsoons *i.e.* onset, mid-monsoon and end-monsoon between the moist convective station Kharagpur (23.3°N, 87.2°E) and dry convective station Jodhpur (26.3°N, 73°E) was made. Trends were similar in the diurnal variation of sensible heat flux computed by eddy correlation (direct method) with profile method (indirect method), however, indirect method overestimated the flux.

Key words — Eddy diffusivity, Frictional velocity, Temperature scale, Sensible heat flux, Momentum flux, Turbulence intensity, Eddy correlation method, Profile method.

1. Introduction

Extensive studies have been made on the surface boundary layer (SBL) turbulence characteristics in the extra-tropical regions (Businger *et al.* 1971, Dyer & Hick 1970, Carl *et al.* 1973, Korrell *et al.* 1982). Though less attention has been paid to the structure of SBI under tropical conditions, some studies are reported on the turbulence characteristics (Mohanty *et al.* 1992).

Singhal *et al.* 1993, Chakrabarty and Padmanabhamurty 1995, Kusuma *et al.* (1995 & 1996). The boundary layer parameterizations presently being used in the tropical countries are based on experiments conducted in the extratropical conditions which may not be valid for the Indian region. For instance, Padmanabhamurty (1981) from a preliminary analysis of seven levels tower micrometeorological data during December 1978 at Visakhapatnam found the values of K_m. to be much higher than the extratropical values quoted in literature. In the present paper it is therefore proposed to study the turbulence parameters and fluxes in the SBL using tower data (both slow and fast) during the Pilot experiment phase of Monsoon Trough Boundary Layer Experiments (MONTBLEX) in 1990.

2. Description of data set

In the present study, slow as well as fast response data from the towers collected at Kharagpur (KGP) and Jodhpur (JDP) for three representative days in different phases of monsoon (Onset, Mid and End-mosoon) during MONTBLEX 1990 were utilized. The entire MONT-BLEX raw data set for four months was processed (Rudrakumar and Prabhu 1991, Rudrakumar *et al.* 1991b) for further analysis.
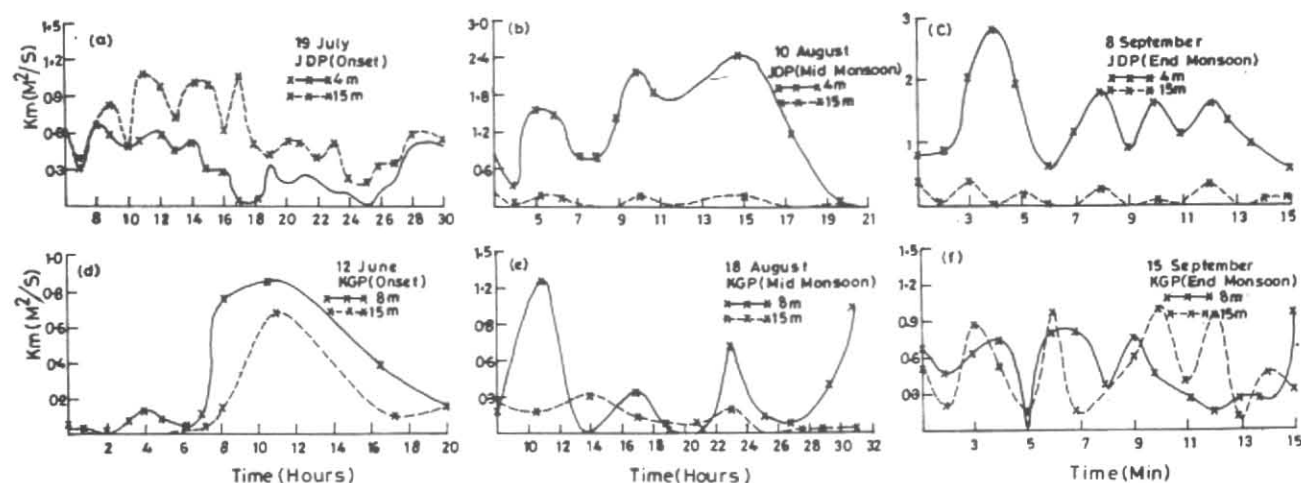
Figs. 1(a-f). Diurnal variation of K_m at (a-c) Jodhpur and (d-f) Kharagpur during onset of monsoon, mid-monsoon and end-monsoon
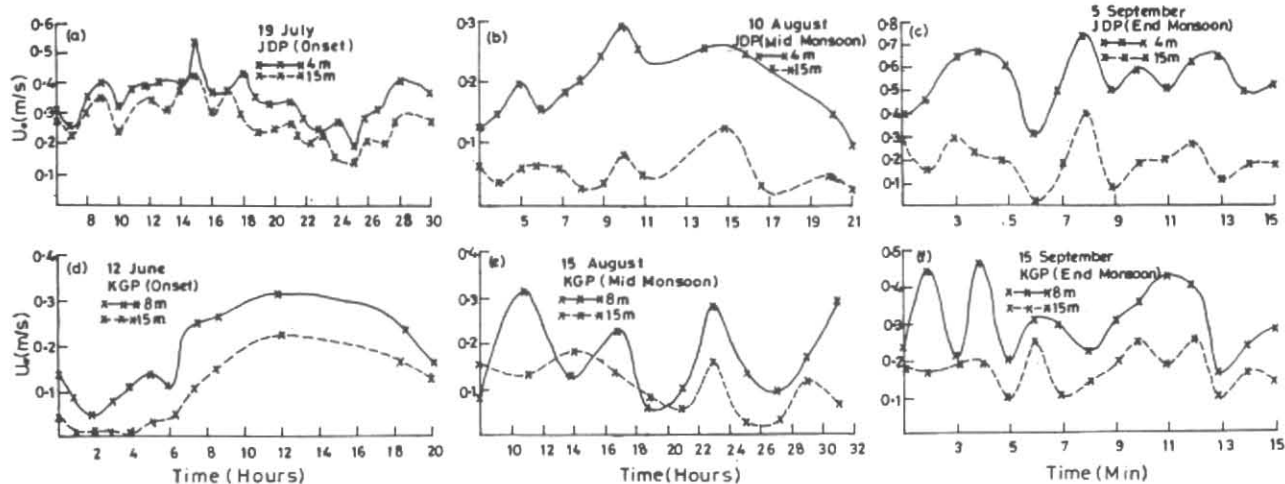
Figs.2(a-f). Diurnal variation of u_*, at (a-c) Jodhpur and (d-f) Kharagpur during onset of monsoon, mid-monsoon and end-monsoon

The Sonic anemometer was placed at 4m height at Jodhpur and 8m height at Kharagpur. Gill anemometer was placed at 15m height at both the stations. Cup anemometers were placed at all the six heights of the tower 1,2,4,8,15, and 30m at both places. The slow data was sampled once every minute whereas the fast response was recorded for 16 minutes sampling period at hourly or three hourly intervals at the rate of 8 Hz (Rudrakumar *et al.* 1991a).

At Jodhpur, the dates chosen for analysis are 19 July, 10 August and 8 September 1990 for the onset mid-monsoon and end-monsoon phases. The dates corresponding to the above monsoon phases selected for analysis at Kharag-

pur are 12 June, 18 August and 15 September. For details about the synoptic conditions prevailing during these periods, reference may be made to the weather summary by Rudrakumar *et al.* (1991a), Srivastav (1995) and Kusuma *et al.* (1995).

3. **Analysis of data**

3.1. *Computation of mean gradients*

The mean gradients of wind and temperature were determined using the observations from the slow response sensors. In the present study, gradients are determined using finite difference approximations. The wind shear at

4m & 8m were found from measurements at 1m & 8m levels and at 1m & 15m levels respectively. For wind shear at 15m, 1m and 30m levels were used.

3.2. *Determination of surface layer parameters*

To determine the surface scaling parameters, the eddy correlation method was used. This method involves the direct determination of covariances using data from fast response sensors, avoiding assumptions about relationships between vertical fluxes and gradients. Observations from the Sonic anemometer and Gill anemometer for both the stations have been used for the determination K_m , $u*$, $\theta*$, τ and H. In order to obtain all significant high frequency contributions, the ratio of the path length of the instrument to the height above the ground should be less than 0.08 which is satisfied in the case of the Gill as well as Sonic anemometer (Brook 1974). Time series were generated for all the variables in each run and the fluctuations were computed by subtracting the mean from the instantaneous values. The covariances of the fluctuations have been determined by averaging the products of the appropriate fluctuations.

4.   Methodology

4.1. *Momentum eddy diffusivity (K_m)*

Eddy viscosity relationships

$$\overline{u'w'} = -K_m \left(\frac{\partial U}{\partial z} \right) \tag{1}$$

where K_m is eddy diffusivity of momentum, u' and w' are fluctuations and U is the mean wind.

4.2. *Frictional Velocity ($u*$)*

Frictional velocity, $u*$ has been evaluated using the eddy correlation method from the expression

$$u* = (\tau/\rho)^{\frac{1}{2}} - [(\overline{u'w'})^2 + (\overline{v'w'})^2]^{\frac{1}{4}} \tag{2}$$

where $\overline{u'w'}$ and $\overline{v'w'}$ are the turbulent fluxes of momentum in the direction of u and v components of wind velocity, ρ is the density of air and τ is the surface shear stress, respectively.

4.3. *Temperature scale ($\theta*$)*

Temperature scale ($\theta*$) has been determined through the following relation

$$\theta* = - \frac{\overline{w'\theta'}}{u*} \tag{3}$$

where $\overline{w'\theta'}$ is the turbulent flux of heat in the vertical direction.

4.4. *Sensible heat flux (H)*

Surface turbulent sensible heat flux (H), was obtained from

$$H_0 = \rho \, C_p \, \overline{W'T'} \tag{4}$$

where C_p is the specific heat at constant pressure.

4.5. *Turbulence studies*

In neutral stratified boundary layer, surface layer observations from different sites indicate (Arya, 1988)

$$\frac{\sigma_u}{u*} \cong 2.5 \tag{5}$$

$$\frac{\sigma_v}{u*} \cong 1.9 \tag{6}$$

$$\frac{\sigma_w}{u*} \cong 1.3 \tag{7}$$

Above the surface layer

$$\frac{\sigma_u}{u*} = 2.5 \exp \left| \frac{-3 fz}{u*} \right| \tag{8}$$

$$\frac{\sigma_v}{u*} = 1.9 \exp \left| \frac{-3 fz}{u*} \right| \tag{9}$$

$$\frac{\sigma_w}{u*} = 1.3 \exp \left| \frac{-3 fz}{u*} \right| \tag{10}$$

5.   Results and discussion

Eddy diffusivity of momentum K_m , for JDP [Figs.1(a-c)] and KGP [Figs.1(d-f)] shows irregular diurnal variation during the onset, mid-monsoon and end-monsoon phases. During the onset phase it can be seen from Sonic (4m) and Gill (15m) anemometer data. K_m increases with height at JDP *i.e.* upward transport of momentum due to forced convection and thermals of warm air rising from the ground. Daytime strong winds with maximum speed of 4 to 6 ms^{-1} found during this period, presumably caused vigorous mixing in SBL. But this trend is reversed and K_m decreases with height during monsoon season, resulting in downward transport of momentum from higher layers towards ground. This may be due to cooler air brought by precipitation from cloud on to the warmer ground during the monsoon phase and is indicative of the arrival of the monsoon. At KGP, it can be seen from Sonic (8m) and Gill (15m) anemometer data K_m , decreases with height, suggesting a downward transport of momentum both at the onset as well as mid-monsoon phases because of persistence of moist air throughout the monsoon period.
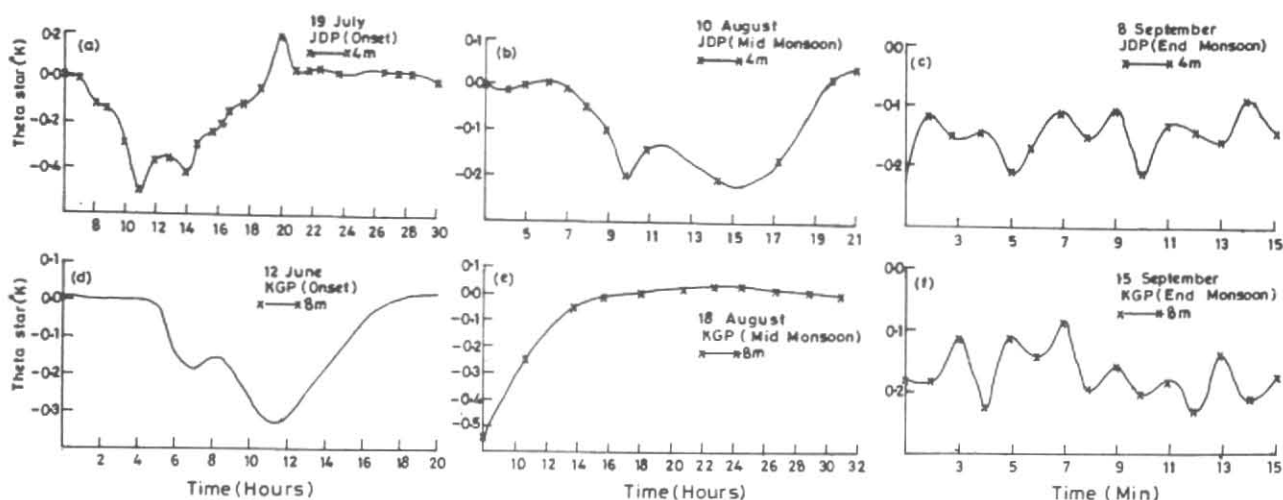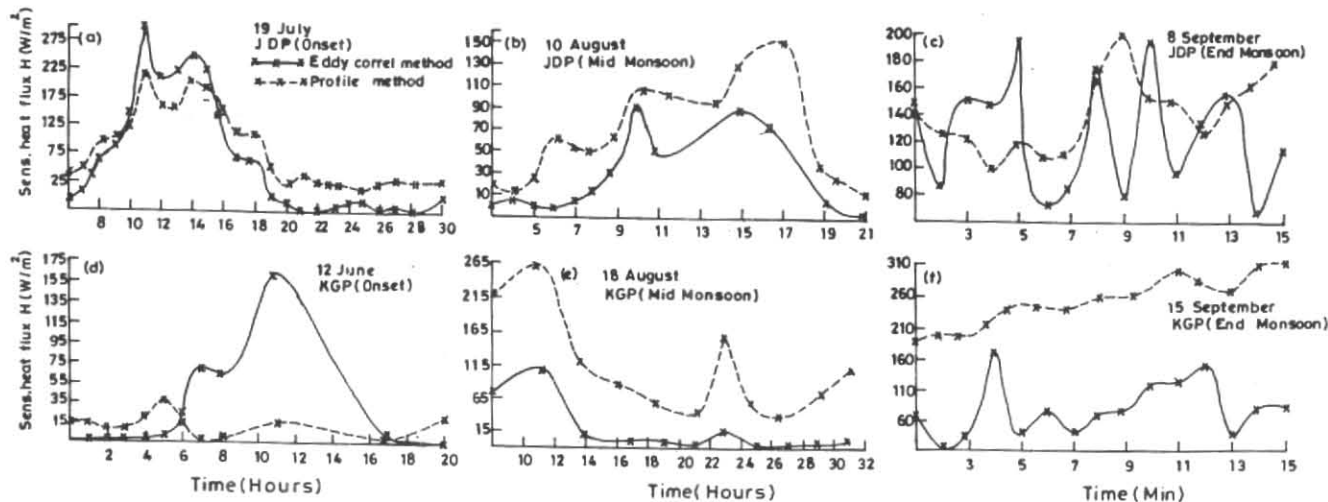
Figs.3(a-f). Diurnal vairation of θ. at (a-c) Jodhpur and (d-f) Kharagpur during onset of monsoon, mid-monsoon and end-monsoon
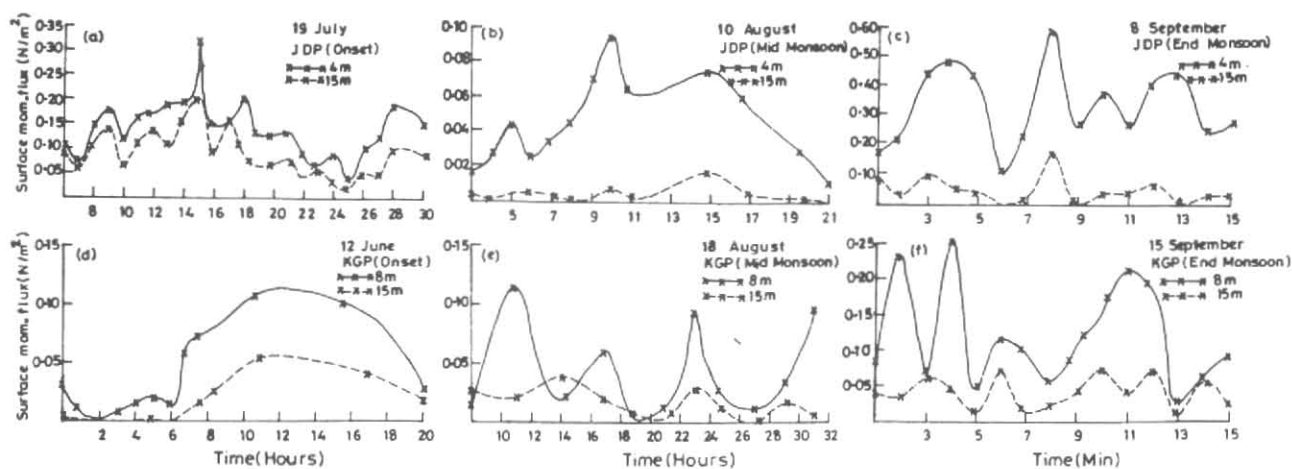
Figs.4(a-f). Diurnal variation of Momentum flux τ at (a-c) Jodhpur and (d-f) Kharagpur during onset of monsoon, mid-monsoon and end-monsoon

For the same reason, during the monsoon period, at both the stations K_m decreases with height, but K_m variations are less for JDP compared to KGP. As sufficient data for the end-monsoon period for both the stations was not available to study the diurnal variation. Only one data set has been taken for the computation at 1430 IST on September 1990. The behaviour of K_m by eddy correlation method during the end-monsoon phase for JDP and KGP from 1430 to 1445 hours IST is shown in [Figs.1(c&f)]. The eddy diffusivity coefficient K_m fluctuated erratically during end-monsoon phase for both the stations, however fluctuations are more at KGP compared to JDP. Increase of K_m with height at KGP is indicative of withdrawal of monsoon. However, K_m

decreased with height at JDP. This difference between JDP and KGP is due to different convective activities in these regions. During all the periods investigated, at the 4m and 8m level, K_m has much higher values than those reported in extra-tropical countries (Haltiner and Maritin 1957). The values are in accordance with those reported by Padmanab- hamurty (1981) at Visakhapatnam, India. The present re- sults suggest downward transport of momentum at KGP during onset and mid-monsoon phases whereas an upward transport of momentum at JDP during the onset period and a downward transport of momentum during the active mon- soon period in the year 1990.

Figs.5(a-f). Diurnal variation of Sensible heat flux H at (a-c) Jodhpur and (d-f) Kharagpur during onset of monsoon, mid-monsoon and end-monsoon

The surface layer parameter, frictional velocity u_* is computed using the fast response data. The diurnal variation of u_* during onset, mid-monsoon and end-monsoon phases are shown in Figs.2(a- c) for JDP and Figs.2(d-f) for KGP. At both the stations, u_* decreased with height and the variation of u_* between the two levels is more than 10%. This shows that the shearing stress is more at the lower level and fluxes in the SBL are not constant with height. It also points out that either the height of SBL is very shallow up to the height of the lower level of observation or the deviations of u_* and fluxes with height may be larger than 10% within the SBL as is commonly reported at extratropical regions. Generally u_* increased with wind speed for the three periods investigated and for both the stations u_* shows large variability and relatively higher values for the JDP compared to KGP. This shows that JDP is a region of thermally high convective activity compared to KGP. Under unstable conditions, u_* does not show any definite trend with height for KGP. In the monsoon period, u_* shows less variability for JDP compared to KGP. During the end-monsoon phase variation is more for both the stations. This could be due to short averaging time. However, the trend is similar in the three periods.

The temporal variation of turbulent temperature scale θ_*, during all periods at 4m for JDP [Figs.3 (a- c)] and at 8m for KGP [Figs.3(d-f)] shows that variability is more for JDP compared to KGP. Under unstable/daytime conditions θ_* is more negative, suggesting maximum upward transport of heat from the surface before noon during the onset period and counter gradient of heat flow during night at both the stations. But during monsoon, at KGP at 8m, the upward transport of heat peaks at 0800 hr and gradually decreases till the next day morning. During end-monsoon period up-

ward transport of heat is observed in the afternoon (1430-1445 hrs) for JDP and KGP. During the onset phase, at JDP at 4m θ_* shows large variability with a highest negative value (-.51) at 1100 hr and changing sign and peaking at 2000 hr (.2). On the other hand, during monsoon phase θ_* shows less variability with a sign reversal at 2000 hr. Largest negative θ_* (-.22) occurred at 1500 hr and highest positive θ_* (.04) at 2100 hr. During the end monsoon phase θ_* is again having large variability with highest negative θ_* (-.26) at 1430 hr with no reversal of sign till the end of the period. In the case of KGP θ_* varied smoothly at 8m height during the monsoon phase compared to onset phase. During the monsoon phase θ_* has largest negative value (- 0.55) at 0800 hr and highest positive value (0.02) at 2100 hr with reversal of sign at 1900 hr. During onset phase highest negative value of (-0.32) θ_* occurred at 1100 hr and sign reversed at 2000 hr with positive θ_* at 0000 hr and 2000 hr. During the end-monsoon phase there is no reversal of sign but highest negative θ_* (-0.23) occurred at 1433 hr and lowest negative θ_* (- 0.09) at 1436 hr.

The diurnal variation of surface momentum flux has no regular trend for JDP [Figs.4(a-c)] or KGP [Figs.4(d-f)] during all the periods. The prominent feature during all the periods for JDP and KGP is the large variation observed in τ especially under unstable/daytime conditions. This variability could be due to the short averaging time (15 minutes) used and suggests the possible influence of convective circulations (Haugen et al. 1971). The results show a consistent decrease with height. Under unstable conditions the difference in stress between the two levels is more. This could be attributed to besides short averaging time, different instruments used at the two levels. The diurnal trend show

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TABLE 1
Standard deviation of wind normalized by friction velocity (Sonic & Gill) in the surface boundary layer

Surface layer					
Sonic			Gill		
σ_u/u_*	σ_v/u_*	σ_w/u_*	σ_u/u_*	σ_v/u_*	σ_w/u_*
Period - Onset and Station - Jodhpur					
1.3-3.5	1.8-2.9	1.1-1.5	1.5-2.4	1.5-2.5	1.2-2.3
Period - monsoon and Station - Jodhpur					
1.6-6.4	1.0-6.4	1.3-1.7	3.0-16.0	3.2-19.0	1.0-4.7
Period - end monsoon and Station - Jodhpur					
1.8-3.5	1.6-3.7	1.0-1.6	1.9-7.0	2.3-8.2	0.8-2.1
Period - onset and Station - Kharagpur					
1.6-3.0	1.6-2.7	1.2-1.7	2.2-8.0	2.6-9.8	1.0-7.0
Period - monsoon and Station - Kharagpur					
2.2-5.3	1.3-4.5	1.0-1.8	2.1.-9.0	1.5-8.0	0.6-2.8
Period - end monsoon and Station - Kharagpur					
1.0-2.5	1.5-2.5	0.9-1.5	1.8-2.8	1.0-2.5	0.9-1.6

TABLE 2
Standard deviation of wind normalized by friction velocity (Sonic & Gill) above the surface boundary layer

| Above surface boundary layer					
Sonic			Gill		
σ_u/u_*	σ_v/u_*	σ_w/u_*	σ_u/u_*	σ_v/u_*	σ_w/u_*
Period - Onset and Station - Jodhpur					
2.2-2.3	1.7-1.8	1.1-1.2	2.1-2.2	1.6-1.7	1.1-1.2
Period - monsoon and Station - Jodhpur					
1.2-2.2	1.0-1.7	0.7-1.2	0.1-1.7	0.1-1.3	0.1-0.9
Period - end monsoon and Station - Jodhpur					
2.3-2.4	1.7-1.8	1.1-1.2	1.8-2.3	1.5-1.7	1.0-1.2
Period - onset and Station - Kharagpur					
1.1-2.3	0.8-1.7	0.8-1.2	0.5-2.0	0.1-1.7	0.1-1.2
Period - monsoon and Station - Kharagpur					
1.8-2.3	1.3-1.7	0.9-1.2	1.0-2.3	0.7-1.6	0.5-1.2
Period - end monsoon and Station - Kharagpur					
1.6-2.2	1.2-1.6	0.9-1.1	1.5-2.0	1.1-1.5	0.8-1.0

τ is almost the same at both the heights for all the periods for both the stations. At JDP, the surface momentum flux is significantly large during onset, when it is found to be 0.34 Nm^{-2} because of dry stronger winds prevailing during that period, whereas at the time of mid-monsoon momentum flux is found to be much lower in magnitude. At KGP, the momentum flux is found to be around 0.12 Nm^{-2} and there is no significant difference between onset and mid-monsoon. This could be because of persistent monsoonal air over KGP till the end of the monsoon period. Air mass over JDP, which is on the other end of monsoon trough, depends on the position of the monsoon trough and air over JDP could be monsoonal or dry continental because of the difference of the air masses. During the end monsoon period momentum flux is higher of the order of 0.6 Nm^{-2} at JDP but it is still less at KGP because of prevalence of moist air.

Sensible heat flux (H) is computed by eddy correlation (direct method) and profile method (indirect method). The heat fluxes at 4m for JDP [Figs.5(a-c)] and at 8m for KGP [Figs.5(d-f)] showed temporal variation during all the periods investigated. During the onset period, H is large at JDP and attained a maximum (300 Wm^{-2}) at 1100 hr with sharp decrease after 1400 hr. During the mid-monsoon period intensity of H is less and never exceeded 95 Wm^{-2} which occurred at 1000 hr. The decrease in sensible heat flux is substantially accounted by the absence of solar input to the ground after sunset. During day time, H values are overall

higher in the onset phase than the monsoon phase. This could be due to some advection from surrounding areas. Sensible heat flux during the end-monsoon phase shows more variability and peaks (195 Wm^{-2}) at 1434 hr with no reversal of sign during the period 1430 - 1445 hrs. At KGP [Figs.5(d-f)], maximum sensible heat flux during onset and mid-monsoon phase occurring before noon. The sensible heat flux at 8m (Sonic) for the onset and mid-monsoon periods attained a maximum (165 Wm^{-2}) and (113 Wm^{-2}) at 1100 hr and reverses sign during transition periods. No abrupt and significant changes of sensible fluxes were noticed during the two periods. The sensible heat flux estimated from turbulence parameters may not reflect the effect of the heat capacity of the surface during the monsoon period. That is why heat flux is larger during onset and end monsoon period. In the evenings continuous fall of sensible heat flux is noticed. Peak values of H occurred at before noon for both stations which is attributed to the maximum outgoing long wave radiation during forenoon. At KGP, during the end- monsoon period. H again showed a more variability and maximum H (170 Wm^{-2}) occurred at 1433 hr and minimum H (14 Wm^{-2}) occurred at 1431 hr. The results with eddy correlation as well as profile method showed similar trend. Hence, for both the stations and for the periods investigated, it is concluded that profile method (indirect), most of the time, over estimates sensible heat flux in comparison with eddy correlation method (direct).
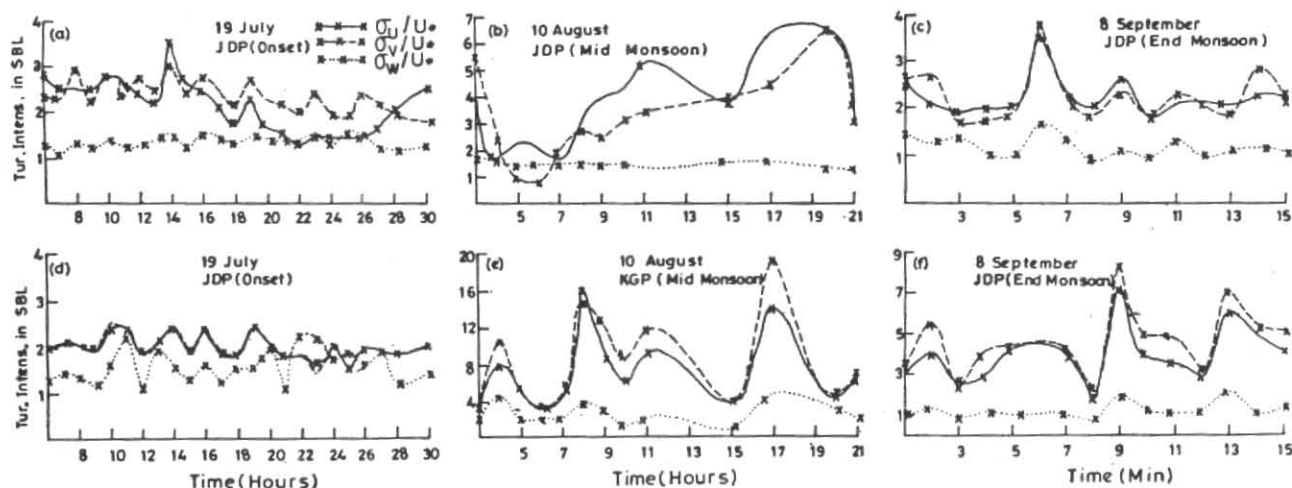
Figs. 6(a-f). Diurnal variation of $\sigma_u/u*$, $\sigma_v/u*$ and $\sigma_w/u*$, for Jodhpur above SBL (a-c) at 4m and (d-f) at 15m during onset of monsoon, mid- monsoon and end-monsoon
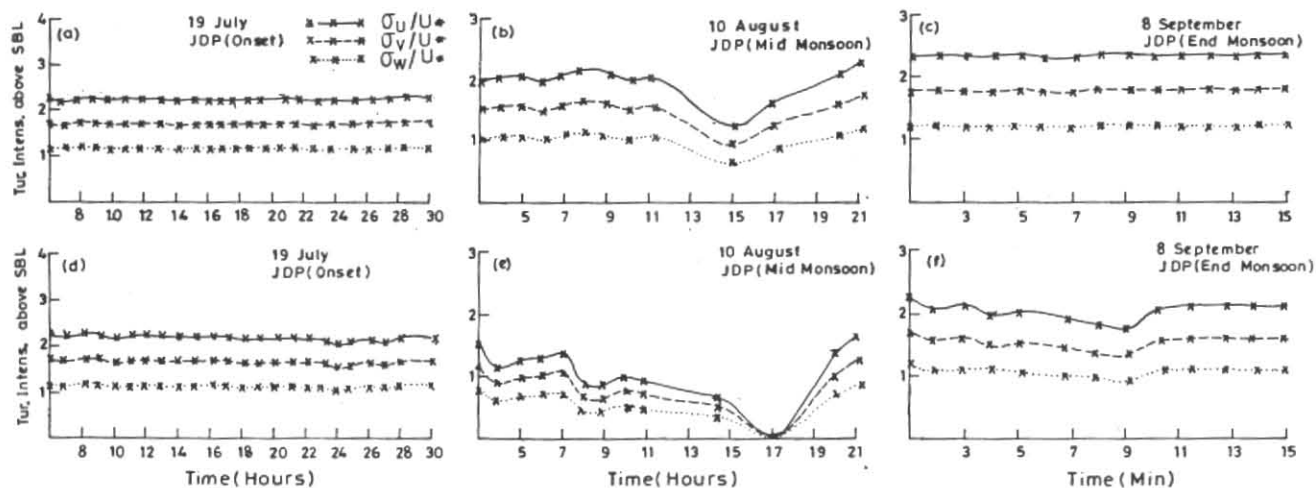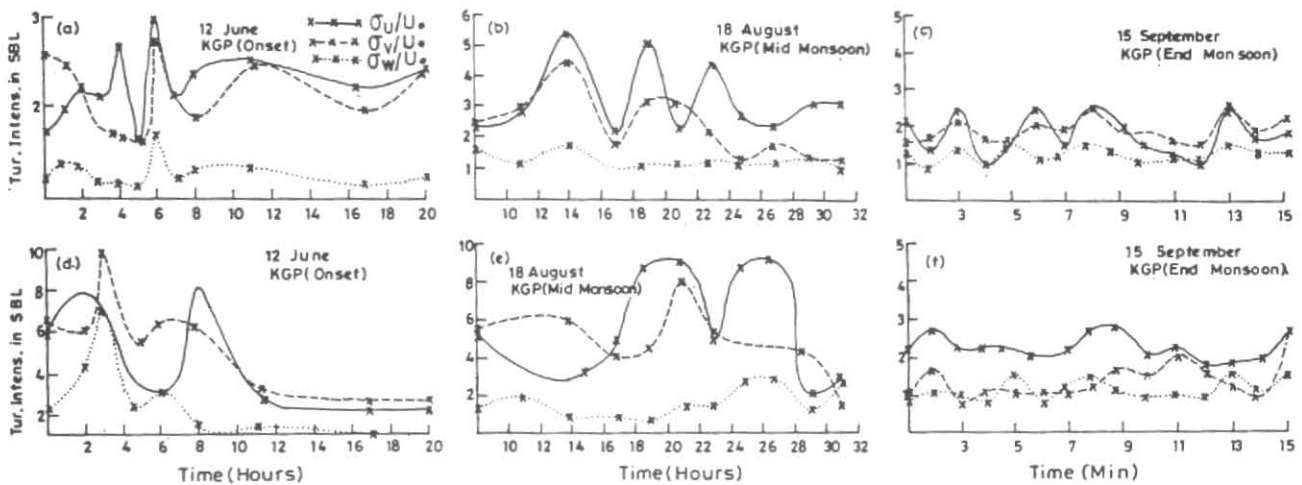

Figs. 7(a-f). Diurnal variation of $\sigma_u/u*$, $\sigma_v/u*$, and $\sigma_w/u*$, for Jodhpur above SBL (a-c) (wind componant normalized by $u*$, at 4m) and (d-f) (wind componants normalized by $u*$, at 15m) during onset of monsoon, mid-monsoon and end-monsoon

The three σ components of turbulence represent turbulent mixing in the atmospheric boundary layer and are useful in the estimation of convective activities in and above the surface boundary layer JDP and KGP tower data of fast response sensors were examined by deriving statistical parameters like (standard deviations) σ_u, σ_v and σ_w of the three velocity components u, v and w and normalized by the friction velocity $u*$ within and above the surface layer. The range of $\sigma_u/u*$, $\sigma_v/u*$ and $\sigma_w/u*$, during all the three periods at JDP and KGP are given in Table 1 for SBL and in Table 2 for above the SBL.

The diurnal variation of $\sigma_u/u*$, $\sigma_v/u*$ and $\sigma_w/u*$ at JDP during onset, mid-monsoon and end-monsoon phases are

shown in Figs. 6(a-f) in the SBL and in Figs. 7(a-f) above the SBL. During the onset phase [Figs.6(a-c)] it can be seen from Sonic (4m) anemometer data that the turbulence intensities $\sigma_u/u*$, $\sigma_v/u*$, are large during daytime compared to nighttime. The difference in the daytime and nighttime values is less for the vertical component. The normalized quantity $\sigma_w/u*$, during all the three phases are in the range of (1.1-1.5), (1.3-1.7) and (1.1-1.6) which are in general agreement with the values given by Agarwal *et al.* (1995). During mid-monsoon season turbulence intensities are quite large compared to onset and end-monsoon phases at JDP (Table 1). During end-monsoon phase, most of the time a similar trend is observed for $\sigma_u/u*$, $\sigma_v/u*$ and $\sigma_w/u*$.

Figs.8(a-f). Diurnal variation of $\sigma_u/u*$, $\sigma_v/u*$ and $\sigma_w/u*$, for Kharagpur in the SBL (a-c) at 8m and (d-f) at 15m during onset of monsoon, mid-monsoon and end-monsoon
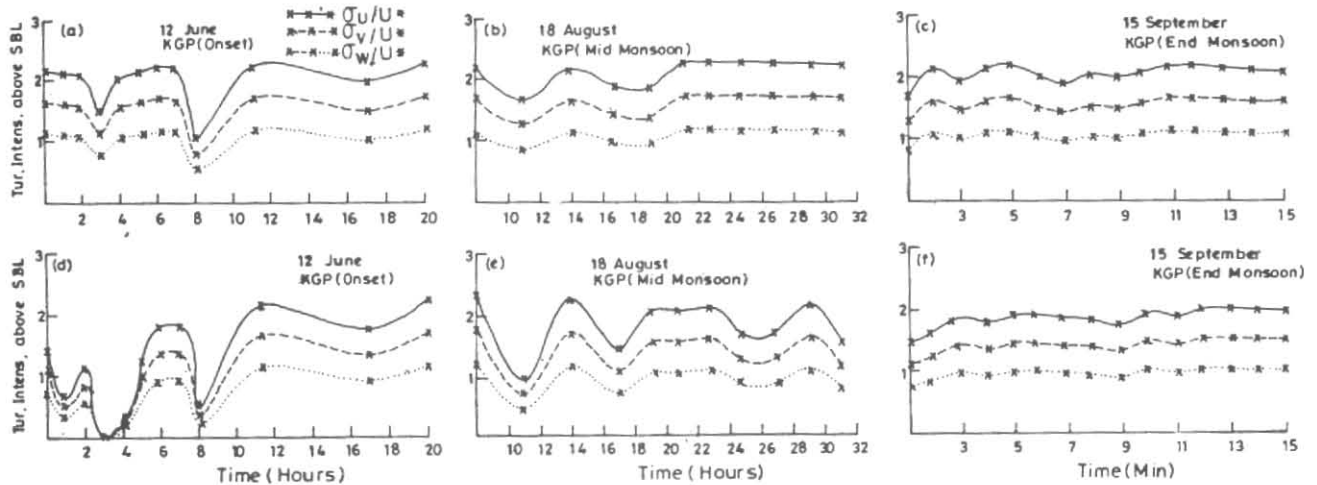
Figs.9(a-f). Diurnal variation of $\sigma_u/u*$, $\sigma_v/u*$, and $\sigma_w/u*$ for Kharagpur above SBL (a-c) (wind components normalized by $u*$, at 8m) and (d-f) (wind components normalized by $u*$, at 15m) during onset of monsoon, mid-monsoon and end-monsoon

During the onset phase at 15m (Fig.6d), $\sigma_u/u*$, $\sigma_v/u*$, and $\sigma_w/u*$, are in the range of (1.5-2.4), (1.5-2.5) and (1.2-2.3). Turbulence intensities are large during mid-monsoon and end-monsoon phases when standard deviations of wind velocity components are normalized by friction velocity $u*$, at 15m [Figs.6(e&f)] compared to 4m [Figs.6(b&c)]. The increase in the turbulence intensities are due to decrease in the magnitude of $u*$, values at 15m compared to 4m.

During onset and end-monsoon phases above the SBL at JDP. $\sigma_u/u*$, $\sigma_v/u*$ and $\sigma_w/u*$, are nearly constant like 2.3, 1.8 and 1.2 when velocity components normalized by either $u*$, at 4m [Figs.7(a&c) or 15m [Figs.7(d&f).]. During

mid-monsoon phase. $\sigma_u/u*$, $\sigma_v/u*$ and $\sigma_w/u*$ are in the range of (1.2-2.2), (1.0-1.7) and (0.7-1.2) when velocity components normalized by $u*$, at 4m (Fig.7b) and (0.1-1.7), (0.0-1.3) and (0.1-0.9) at 15m (Fig.7e).

The diurnal variation of $\sigma_u/u*$, $\sigma_v/u*$, and $\sigma_w/u*$, at KGP during onset, mid-monsoon and end-monsoon phases are shown in Figs.8(a-f) in the SBL and Figs.9(a-f) above the SBL. The normalized quantities $\sigma_u/u*$, $\sigma_v/u*$, and $\sigma_w/u*$, are higher during all the three periods for KGP at 15m compared to 8m, but turbulence intensities are quite large during mid-monsoon phase compared to other two phases at 8m. The diurnal variation of $\sigma_u/u*$,

$\sigma_v/u*$ and $\sigma_w/u*$ shows similar trend above SBL in all three periods. During the end-monsoon phase, above the SBL, not much difference is found in the values of $\sigma_u/u*$, $\sigma_v/u*$, and $\sigma_w/u*$, for the daytime/unstable and night-time/stable conditions.

During mid-monsoon season turbulence intensities are quite large compared to other two phases at both stations. Turbulence intensities are higher at JDP in comparison with KGP. During onset phase, normalized quantities are large at nighttime because of prevalence of low winds at KGP. In our study too the magnitude of parameters like $\sigma_u/u*$, $\sigma_v/u*$, and $\sigma_w/u*$ are in general agreement with those reported by other workers (Agarwal *et al.* 1995) except the monsoon season at JDP.

During all periods, at JDP, above the surface layer, there is not much difference in the range of $\sigma_u/u*$, $\sigma_v/u*$, and $\sigma_w/u*$.; the values are more or less constant when standard deviations are normalized by friction velocity computed by Sonic anemometer compared to Gill anemometer. However, differences are found with KGP data.

6. Conclusions

Variation of Eddy Diffusivity (K_m), Frictional velocity ($u*$), Temperature scale ($\theta*$), Surface momentum flux (τ). Sensible Heat flux (H) and Turbulence intensities at JDP and KGP were studied using fast as well as slow response data. During the onset, mid-monsoon and end- monsoon phases. $u*$ and momentum flux do not show any definite variation with height under unstable conditions at both the stations and both decrease with height. Eddy diffusivity coefficient, K_m shows irregular diurnal variation during the onset, mid-monsoon and end-monsoon phases at both the stations. Eddy diffusivity coefficient K_m fluctuated erratically during the end-monsoon phases at both the stations. During the three periods, at 4m and 8m levels, K_m values are much higher than those reported for extra-tropical countries. The turbulent temperature scale $\theta*$ shows more variability for JDP compared to KGP. The sensible Heat flux computed by the profile method is quantitatively over estimated compared to the flux directly determined by the eddy correlation method. And turbulence intensities are quite large at JDP and KGP during mid-monsoon phase compared to other two phases.

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