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Coupling and decoupling processes in monsoonal surface layer using MONTBLEX-90 tower data

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सार — ऊपरी तल पर भौतिक प्रक्रियाओं के अध्ययन के लिए वाराणसी और जेाधपुर के मौंटब्लैक्स-90 के आँकड़ों का प्रयेाग किया गया है। परिणाम यह दशति हैं कि, वर्षा के दौरान 5.13 x 10^{-1} J-s kg^{-1} परिणाम के क्रम की औसत भंवर विस्कासित पर ऊष्मा, संविग बल और आर्द्रता के प्रक्षुब्ध अन्तरण हुए हैं। निरपेक्ष स्थायी मामले में, भंवर विस्कासिता पर ऊष्मा, संविग बल और आर्द्रता के प्रक्षुब्ध अन्तरण हुए हैं। निरपेक्ष स्थायी मामले में, भंवर विस्कासिता 4.94 x 10^{-4} J-s kg^{-1} के बराबर अथवा फलक्सों के विक्षुब्ध अंतरण के शमन के लिए शेष भूमंडलीय सीमांत तल पर वियुग्म ऊपरी तल से कम हेा सकती है। ये परिणाम 8 मी. और 15 मी. मौसम टॉवर प्रेक्षणों और भूतल मृदा तापमान पर आधारित हैं। जिसके लिए ''बायन'' (1990) और ''के'' सिद्धांत के विश्लेषणात्मक हल का उपयेाग किया गया है। यह पाया गया है कि ऊपरी तल केवल क्लास 'ए' के स्थायित्व के मामले में वियुग्मित हेाता है, क्योंकि स्थूल रिचर्डसन संख्या शून्य से अधिक है और संगत स्थायितत्व प्राचल सकारात्मक है।

ABSTRACT. MONTBLEX-90 data of Varanasi and Jodhpur have been used to study the physical processes in the surface layer. The results show that turbulent transfer of heat, momentum and moisture commence at an average eddy viscosity of an order of magnitude 5.13×10^{-1} J-s kg^{-1} during rainy day. In absolutely stable case, eddy viscosity may be equal to 4.94×10^{-4} J-s kg^{-1} or less to decouple surface layer from rest of the planetary boundary layer for extinction of the turbulent transfer of fluxes. These results were based on 8m and 15m meteorological tower observations and surface soil temperature using analytical solution of Byun (1990) and K theory. It was found that the surface layer is decoupled only in case of stability of Class - A because bulk Richardson number is greater than zero and corresponding stability parameter is positive.

Key words — Monsoon Trough, Boundary Layer Experiment (MONTBLEX), Stability parameter, Momentum, Eddy viscosity.

1. Introduction

The past few decades are remarkable for boundary layer meteorologists. Field experiments have revealed considerable insight into surface layer turbulence and associated exchange processes, which have enhanced our understanding of free and forced convection (Clarke 1970, Garratt and Hicks 1990, Kaimal and Wyngaard 1990, Lettau 1990, Linsheng and Lijuan 1993 & Stull and Eloranta 1984). During monsoon

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Emeritus Scientist: B-1/52, Paschim Vihar, New Delhi season, particularly in July, rain bearing weather systems produce well distributed rainfall over the country. However, moisture in the surface layer is not uniform over the monsoon trough region. Upward transfer of momentum, heat and moisture are modified in the dry and the moist surface layer through the dominant mechanism of forced convection.

In most of the numerical models, the surface fluxes in stable condition are considered negligible relative to those in neutral and unstable conditions and these are zero beyond some specified degree of stability on the basis of Richardson number. In stably stratified surface layer, turbulence is driven by wind shear but suppressed by buoyancy. Field experiments show that Planetary Boundary Layer (PBL) is not steady, its mean wind and mean physical processes evolve continuously and its turbulence seems to be in local equilibrium (Wyngaard 1990). Eddy viscosity plays a vital role in transferring fluxes from lowest few hundred metres thickness of atmosphere on ground to mixed layer. Therefore, vertical distribution of boundary layer parameter is necessarily required to understand physical processes. Kinematic eddy viscosity is one of the important parameters, which significantly controls instabilities in the boundary layer. This is a general practice to decouple surface layer from atmosphere above choosing very small eddy viscosity (O'Brien 1970). Gradient Richardson number falls below its critical value (0.21), when surface layer is forced by synoptic scale systems during summer monsoon. Local equilibrium is disturbed due to the external forcings. Therefore, local mixing is intermittent rather than a continuous process in stably stratified layers. The wind shear and thermal characteristics are crucial to initiate upward transport to well known fluxes in the surface layer. Momentum, heat and moisture fluxes are the vital physical processes in the surface layer which explain stable, unstable and neutral conditions. Behaviour and severity of these fluxes vary according to weather situations. Over moist surface, more of the solar energy is used for evaporation, leaving less to cause heating. Thus, buoyancy will be relatively low because of higher humidity.

Many papers have been written on parameterization of turbulent diffusion in the PBL and its determination for episodic mixing of fluxes, but no study has been made to determine stability condition on the basis of eddy viscosities in various weather situations over monsoon trough region. The objective of this paper is to study 'non-neutral' surface layer using Monin-Obukhov Similarity Theory and compute eddy viscosities over monsoon trough in India based on MONTBLEX-90 tower data at Varanasi and Jodhpur. Gradient method of turbulent transfer of heat, momentum and moisture is used to estimate fluxes to investigate role of physical parameters in this layer before and after precipitation so that stability conditions can be considered on the basis of order of the magnitude of single parameter namely, eddy viscosity. This would help to modify flux equations in a simplistic way to minimise computational steps.

2. Methodology

Using Monin-Obukhov Similarity Theory, kinematic eddy viscosity can be written in stable and unstable condition as :

$$K_M = k u_* z / \phi m(z/L) \tag{1}$$

where, k = Von-Karman constant, u^* = Frictional velocity, z = Reference height, and $\phi m\,(z/L)$ = Stability parameter, which can be computed by Businger *et al.* (1971) and Mohanty *et al.* (1992).

The basic equations, which relate eddy viscosity with heat, momentum, and moisture fluxes (Yamamoto *et al.* 1973) are given below :

$$Q = -\rho C_p K_M \frac{\delta\theta}{\delta z} \tag{2}$$

$$\tau = \rho K_M \frac{\delta V}{\delta z} \tag{3}$$

$$M = -\rho K_M \frac{\delta q}{\delta z} \tag{4}$$

where, Q = Sensible heat flux, τ = Momentum flux, M = Moisture flux, ρ = Density of air, C_p = Specific heat at constant pressure, θ = Average potential temperature, V = Average wind speed, q = Average specific humidity at height z (1, 2, 4, 8, 15 and 30m) of MONTBLEX tower.

3. Data and synoptic situation

MONTBLEX-90 data of Jodhpur and Varanasi at 1800 hr (IST) on 2 July 1990, have been taken for the study. At Jodhpur, rain started from 2105 hr (IST) and lasted for 30 minutes while at Varanasi, there was rain and thunder before the observation time from

1505 to 1715 hr (IST). There was a cyclonic circulation over Haryana and adjoining Punjab and northwest Rajasthan and another cyclonic circulation lay over northwest Bay and adjoining Gangetic West Bengal and Orissa. Under the influence of these weather systems, monsoon was vigorous in Uttar Pradesh and active in Rajasthan. We have also considered another data set of Jodhpur at 0000 hr (IST) on 3 July 1990. Rain occurred from 0145 to 0630 hr (IST) under the influence of the Bay circulation which entered into the land on the same day. In addition to this, another low pressure area had formed over southwest Uttar Pradesh and neighbourhood causing rain at Jodhpur. Thus, wetness of surface layer varied in space and time over the trough zone. In addition, a few more data sets have been analysed during the period 9-24 July 1990 of Jodhpur to draw firm conclusions in respect of coupling and decoupling of different levels in the surface layer.

4. MONTBLEX instrumentation and reliability of data

An exhaustive effort has been made by Indian scientists to obtain systematic observations in the monsoon trough region. This effort became successful in 1990 under Monsoon Trough Boundary Layer Experiment (MONTBLEX). Four towers of height 30m each have been erected for surface layer observation. The complete tower instrumentation system used for the experiment may be broadly classified into three components, *viz*., the tower platform, sensors and signal conditioning units and data acquisition system.

4.1. *The tower platform*

The tower is so designed that booms can be fitted at 6 levels (1, 2, 4, 8, 15, 30m) with horizontal arms attached to these booms at a distance of about 1.3 m from the body of the tower. On these horizontal arms instrument posts are placed for mounting the sensors. The booms are designed so that these can be rotated about vertical and horizontal axes to facilitate the orientation of sensors towards the prevailing wind ensuring horizontality of the instrument post.

4.2. *Sensors and signal conditioning unit*

The sensors, mounted on the instrument posts of the booms, are connected to their respective electronic translators (signal conditioning units) which are installed in a weather-proof instrument container at the foot of the tower. The translators process data electronically from each sensor and convert it to the dynamic range of the data acquisition system. The main set of sensors used and meteorological parameters measured are given below:

(*i*) *Cup anemometer*

The 3-cup anemometer measures horizontal wind speed at all six levels of tower. The electronic conditioning unit is designed to accommodate wind speed in the range 0 - 50 ms^{-1}. The lowest starting threshold of wind speed is 0.5 ms^{-1} with an accuracy of 1.5 - 2% full scale and a distance constant of less than 1m.

(*ii*) *Wind vane*

This consists of a vane that rotates in the range of 0-360 degrees on a vertical shaft to orient itself in the equilibrium to the mean direction of wind. This instrument has an accuracy of ± 3 degrees ensuring a threshold wind speed of 0.5 ms^{-1} and a distance constant of 5m.

(*iii*) *Platinum Resistance Thermometer Devices (RTDs)*

,The thermometers are made of platinum wires of about 12.5 micron diameter and are usually encapsulated in ceramic. These thermometers work on the principle of change of resistance of the wire with temperature. A precision bridge is used for converting the change of resistance to a linearly varying DC voltage which is, in turn, proportional to fluctuating temperature. These RTDs measure air temperature with an accuracy of 0.2% of full scale range of 0-50°C. These sensors are mounted on tower booms with self-aspirated radiation shield.

(*iv*) *Humicaps*

These sensors measure relative humidity (RH) at different levels of the tower. The measurement of humidity based on the principle of change of capacitance of sensor with change in RH. The accuracy of the instrument is ± 2% in the range of RH 10- 90%.

In addition to these, there are other instruments used to measure solar radiation, soil temperature, absolute humidity and all the three components of wind. Details are given in Kumar *et al.* (1995).

4.3. *Data acquisition system*

Data acquired by various sensors are made available for logging and evaluation of quality through this communication link. This system is very efficient for storing and recording of data. There are two logging systems for recording of data which are known a slow (1 Hz) and fast (8 Hz) response data recording system. In slow response system, recorder used is based on Campbell's data logger while in case of fast response IBM - Compatible PC based recorder is used. These recorders work on the principle of pulse- code modulated (PCM) telemetry system.

The PCM telemetry system consists of a transmitter, a transmission link and a receiver. Details are described in Kumar *et al.* (1990 a, b). In order to verify the quality and validate the tower data from the field experiment MONTBLEX-90, the acquired data were processed performing the following seven checks :

(*i*) Visual inspections of time series data,

(*ii*) Comparison of data from different sensors measuring the same physical variable,

(*iii*) 10/15 minute average of time series data,

(*iv*) Mean wind profile and calculation of roughness length,

(*v*) Diurnal variation of various parameters,

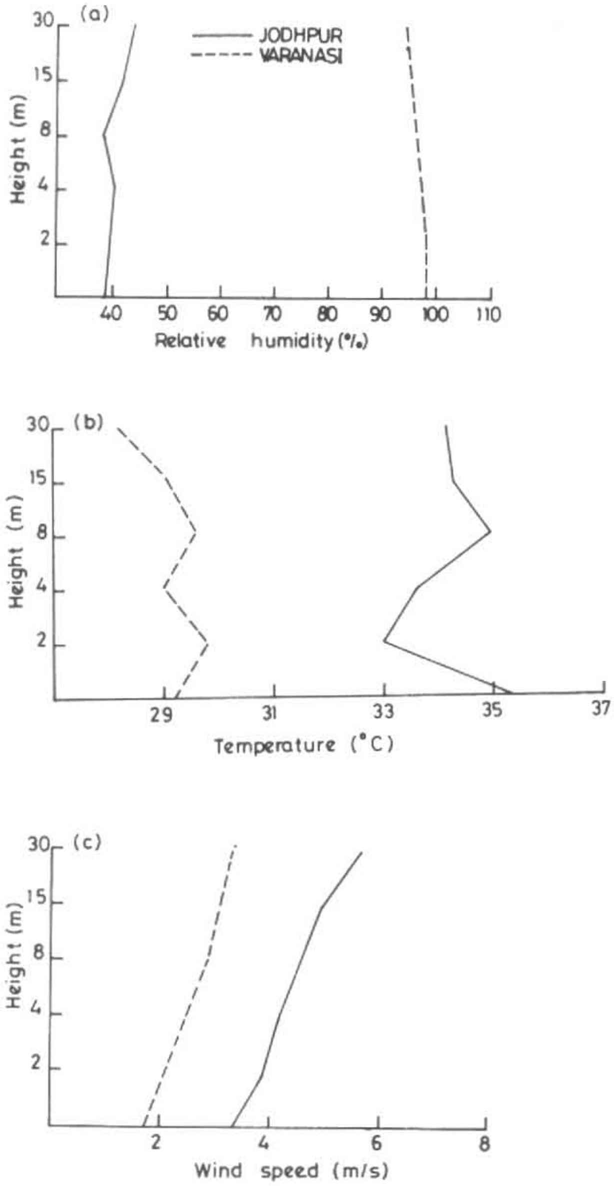
(*vi*) Probability density of data from various sensors and

(*vii*) Power spectral density.

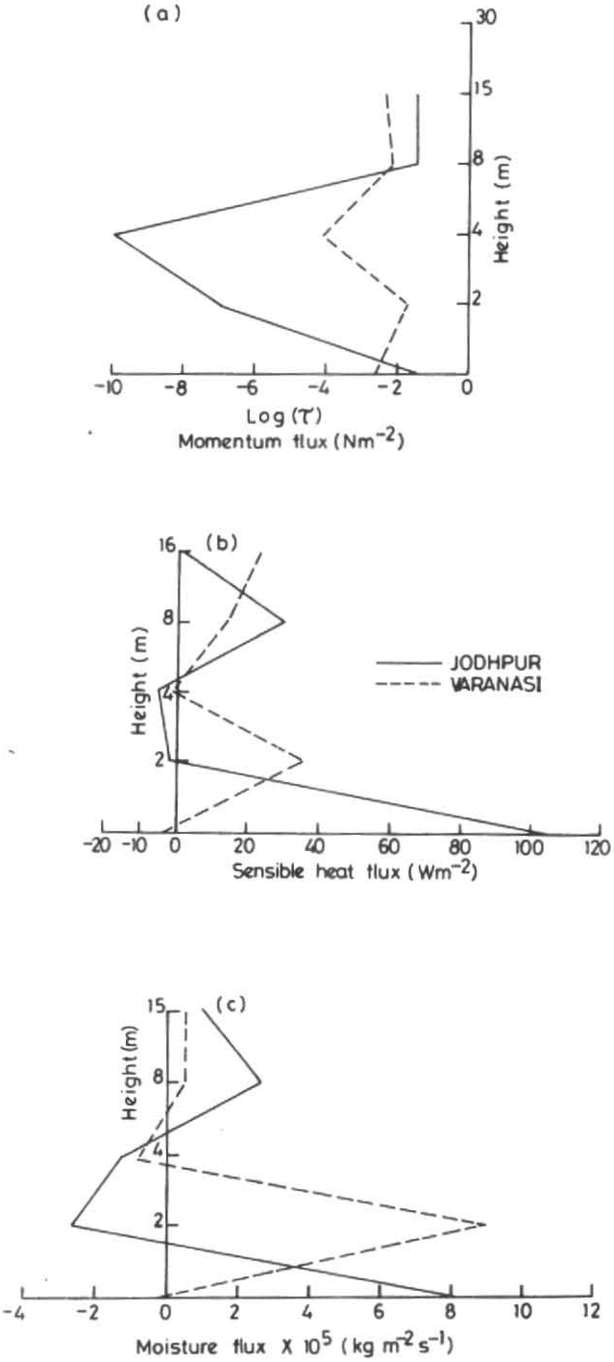
Details are given in Kumar and Prabhu (1991). These quality analyses have established that the instrumentation system has recorded various physical parameters in the surface layer quite accurately and has provided the strong potential for further detailed analysis to understand various aspects of boundary layer processes.

5. Results and discussion

The vertical distribution of meteorological elements at Varanasi and Jodhpur on 2 July 1990 at 1800 hr (IST) are shown in Figs. 1 (a-c). Fig. 1(a) shows average relative humidity profile of Jodhpur and Varanasi. Jodhpur is situated in dry convective zone and Varanasi in transition region between western dry and eastern deep moist convective zone (Goel and Srivastava 1990). The average relative humidity was 96% at Varanasi and 40% at Jodhpur. Also the temperature at Varanasi was less than that at Jodhpur at all the levels (Fig. 1b). Average temperature for 30m thickness of surface layer was 29.15°C at Varanasi and 34.29°C at Jodhpur. If the temperature profile at 2m height is compared, one finds surface inversion at Varanasi, while there was no inversion at Jodhpur. Similar is the case for Jodhpur at 4m height while at



Figs. 1 (a-c). Vertical distribution of (a) relative humidity, (b) temperature and (c) wind speed over Jodhpur & Varanasi



Figs. 2 (a-c). Inter-relationship among (a) momentum, (b) sensible heat and (c) moisture flux over Jodhpur and Varanasi

8m level there is surface inversion at both the stations, with a continuous fall upwards. Wind speed at Jodhpur is higher than that of Varanasi maintaining logarithmic wind profile [Fig. 1(c)]. The average wind speed was 4.41 m/s at Jodhpur and 2.61 m/s at Varanasi.

The inter-relationship among momentum, heat and moisture fluxes; on 2 July 1990 at 1800 hr (IST) is shown in Figs. 2 (a-c). Similarly kinematic eddy viscosity and stability parameters are shown in Figs. 3 & 4 respectively. The heat and moisture fluxes are

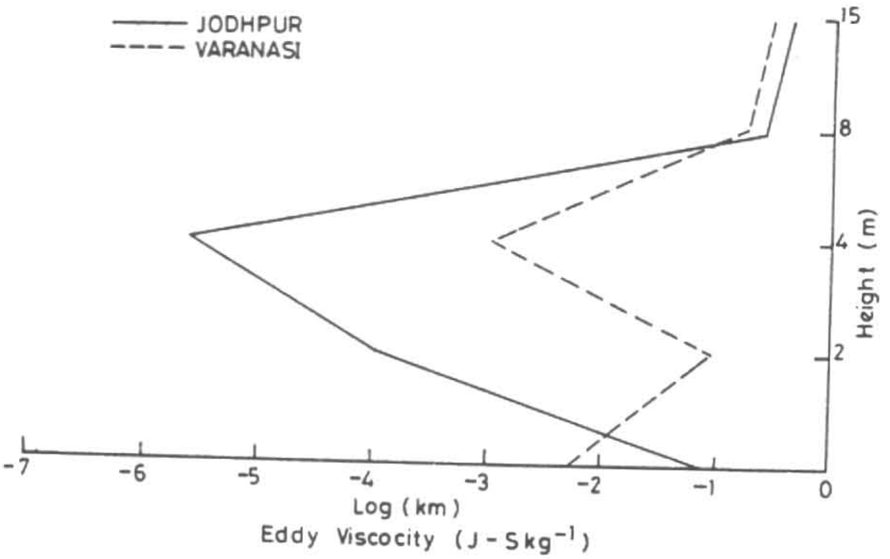


Fig. 3. Kinematic eddy viscosity over Jodhpur and Varanasi

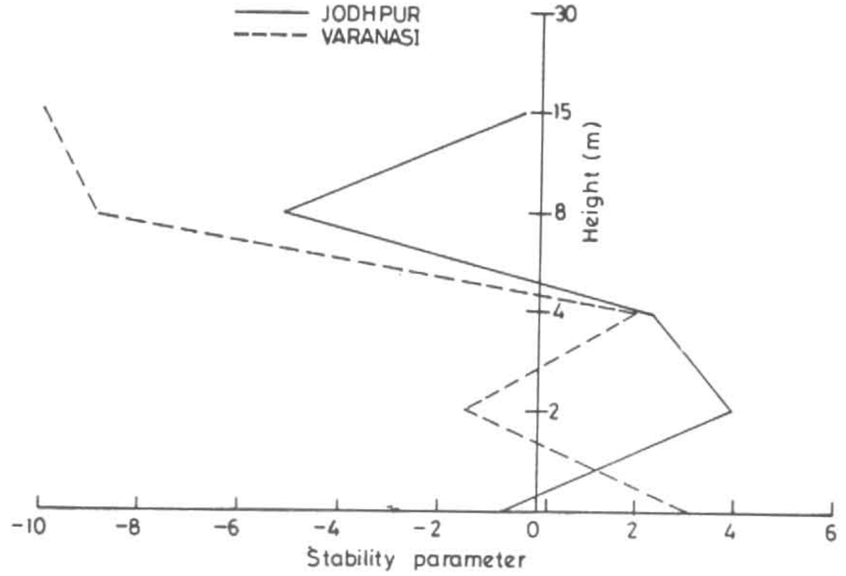


Fig. 4. Stability parameter over Jodhpur and Varanasi

in the upward direction on 1, 8, and 15m levels at Jodhpur; while these are also in the upward direction on 2, 8 and 15 m heights at Varanasi [Figs 2 (b) & (c)]. In these cases, the values of momentum flux are 3.96×10^{-2}, 1.92×10^{-2} and 1.83×10^{-2} Nm^{-2} at Jodhpur and 1.7×10^{-2}, 6.3×10^{-3} and 4.3×10^{-3} Nm^{-2} at Varanasi. Stable conditions are noted at Jodhpur because there is downward flux of heat and moisture at 2m height and the order of magnitude of momentum flux is 1.0×10^{-8} Nm^{-2}. Similarly, at 4m level, the momentum flux is 8.0×10^{-5} Nm^{-2} at Varanasi and 1.0×10^{-10} Nm^{-2} at Jodhpur. At this level, heat and moisture fluxes are of negative sign which show stable condition. At 8 and 15m levels, the surface layer is unstable at both the stations, with momentum flux being of the order of 10^{-3} Nm^{-2} at Varanasi and 10^{-2} Nm^{-2} at Jodhpur. At 2m level kinematic eddy viscosities are 7.2×10^{-2} J-s kg^{-1}, 4.9×10^{-5} J-s kg^{-1} and stability parameter as -1.8 and 4.0 (Fig. 3 and 4) at Varanasi and Jodhpur respectively.

TABLE 1

Station: Jodhpur, Date : 3 July 1990 at 0000 hr (IST)

Physical parameter	Height				
	1m	2m	4m	8m	15m
Eddy viscosity (J-s kg^{-1})	1.82×10^{-10}	3.20×10^{-6}	2.38×10^{-1}	3.66×10^{-1}	1.58
Momentum flux (N m^{-2})	3.43×10^{-10}	4.27×10^{-7}	2.33×10^{-2}	1.61×10^{-2}	6.75×10^{-2}
Moisture flux (kg m^{-2} s^{-1})	-5.0×10^{-8}	-1.0×10^{-6}	1.07×10^{-4}	6.7×10^{-5}	1.48×10^{-4}
Heat flux (W m^{-2})	–0.002	–0.009	66.7	38.5	71.3
Stability (Z/L)	1.56	1.39	–3.9	–9.9	–2.98
Temperature (°C)	25.42	26.01	26.51	25.60	25.00
Wind speed (m s^{-1})	1.01	1.17	1.38	1.70	1.95
Mixing ratio (kg/kg)	0.0181	0.0184	0.0187	0.0173	0.0162

The gradient Richardson number is -0.35 at Varanasi and 0.73 at Jodhpur, while the eddy viscosities are 7.4×10^{-4} and 1.34×10^{-6} J-s kg^{-1} at respective stations at 4m level. In this case, the Richardson number at Varanasi is 0.52 and at Jodhpur 0.9 showing positive stability parameters (Fig. 4). Similarly at 8 and 15m levels stability parameters are negative while the eddy viscosities are of the order 10^{-1} J-s kg^{-1} at both the stations. Results show that increasing and decreasing tendency of eddy viscosities correspond to increasing/decreasing instability at different levels (Mohanty *et al.* 1992). When stability parameter is positive, the level is decoupled from the layer above it and whenever the order of kinematic viscosity increases to 10^{-2} J-s kg^{-1} or greater than this, the level couples with the layers above it. Thus stability parameter being the function of Richardson number which is the most appropriate governing criterion for dynamical similarity motion in atmosphere (Batchelor 1953, Viswanadham 1979) and stability effects agree well with the field observations (Caughey et al. 1979 and Lenschow *et al.* 1988). It may, therefore, be summarized that the coupling in association with the turbulent mixing can be determined with the help of stability parameter and eddy viscosities.

TABLE 2

Station : Jodhpur

Date 1990	Time (IST)	Height (m)	R_b	z/L	Sensible heat flux (Wm^{-2})	Eddy viscosity (J-s kg^{-1})
9 July	0600	8	–0.77	–4.87	24.2	2.70×10^{-1}
		15	–1.54	–8.30	55.6	1.12
9 July	0900	8	0.64	3.50	–0.86	2.34×10^{-7}
		15	–0.11	–0.82	5.12	4.81×10^{-1}
24 July	1200	8	0.58	2.73	–0.06	1.13×10^{-8}
		15	–0.55	–1.96	17.4	8.86×10^{-1}
24 July	1500	8	–0.53	–5.74	8.2	1.43×10^{-1}
		15	–0.07	–0.30	20.3	1.18×10^{-1}

Table 1 shows the surface layer structure at Jodhpur on 3 July at 0000 hr (IST). The 4, 8 and 15 m levels are found to be unstable and the corresponding eddy viscosities are greater than or equal to an order of 10^{-1} J-s kg^{-1} and the order of momentum and moisture fluxes are 10^{-2} Nm^{-2} and 10^{-5} kg m^{-2} s^{-1} respectively. Stability parameters indicate that the surface layer is unstable. Hence, there is good upward mixing of heat, momentum and moisture fluxes in the atmosphere through eddies. At this juncture, it is remarkable to note that levels at 1 and 2m are stable, where eddy viscosities are very small (negligible) as compared to higher levels where stability parameters are positive. Momentum, moisture and heat fluxes are also very small as compared to other higher levels. The average wind speed at 1 metre is 1.01 ms^{-1} and at 30m height it is 2.48 ms^{-1}. Analysis of a few more data set of morning and day time during fair weather condition on 9 and 24 July 1990 showed that the orders of eddy viscosities increase in unstable conditions and decrease in stable conditions.

In order to identify the most prominent and determining parameter which articulates stability characteristics in the surface layer, physical processes at Varanasi and Jodhpur were compared on same date and time as well as at Jodhpur at different date and time. The temperature, wind and humidity structures differ significantly with each other on 2 July at 1800 hr (IST), with a surface inversion at different levels upto 8m height. At Varanasi, soil was moistened just before the observation time; while it was dry at Jodhpur. Consequently, surface temperature decreased due to evaporative cooling and the availability of moisture increased in the surface layer at Varanasi. It is well known that momentum flux is precursor to mixing process in PBL. But this is highly variable quantity depending on meteorological conditions (Sivaramakrishnan *et al.* 1992). Analysis shows that different levels at Jodhpur are unstable when momentum flux at a level is of the order of 10^{-2} Nm^{-2} or more. Similarly, at Varanasi unstable condition occurs when the momentum flux at that level exceeds 10^{-3} Nm^{-2}. For 30 m thickness of surface layer, values of average momentum flux are 1.5×10^{-2} Nm^{-2} and 5.9×10^{-3} Nm^{-2} at Jodhpur and Varanasi respectively. On the contrary, the order of momentum flux is maintained at Jodhpur on different date and time during unstable condition. Considering eddy viscosities, we find that identical orders of this parameter are maintained at all levels at different times at both the stations inspite of variable weather condition.

Various unstable levels were identified on the basis of stability parameter and gradient Richardson number. We found that eddy viscosity was of the order of 10^{-1} J-s kg^{-1} whenever stability parameter was negative. On some occasions, a few levels were found unstable, when eddy viscosities were of the order of 10^{-2} J-s kg^{-1} in the surface inversion layer. Similarly, there had been unstable condition at Jodhpur on 9 July (0600 hr IST) and 24 July (1200 hr IST) at 2m height, when eddy viscosity was of the order of 10^{-3} J-s kg^{-1}. So, turbulent mixing may begin in the surface inversion layer in the range of eddy viscosity from 10^{-2} to 10^{-3} J-s kg^{-1}. If the surface layer is treated as inversion-free, the turbulent mixing will commence at eddy viscosity of the order of 10^{-3} J-s kg^{-1}. This result is in agreement with Kantha and Clayson (1994).

Heat and moisture fluxes are highly sensitive to the wetness of soil and gradient of specific humidity in the surface layer. On 2 and 3 July 1990, synoptic situations were favourable for moisture feedback in the trough zone and surface moisture availability values are consistent with rain events. On 3 July at 0000 hr (IST), average mixing ratio was 17.3 gm/kg which was comparable to 2 July at Jodhpur. The average momentum, heat and moisture forcings at this place are stronger on 3 July above 4m height than those on 2 July. Physical quantities were smaller in case of Varanasi than at Jodhpur. On 2 July average heat flux is 13.3 Wm^{-2} and 24.76 Wm^{-2} at Varanasi and Jodhpur respectively for 30 m thickness of surface layer. Synthesizing the results based on the transfer of fluxes vis-a-vis weather phenomena prior and after the observation time, we find that exchange processes become weak just after the occurrence of rainfall and become pronounced prior to precipitation under the influence of synoptic weather system.

6. Classification of stability using single level data

Most of the observing stations in India Meteorological Department (IMD) record only a single level data in the surface layer. A method has been developed analytically for determining stability parameter and turbulent fluxes for profile extrapolation based on single level data (Byun 1990). For thin viscous layer, diffusion process is dominant to transfer fluxes. Stability parameter (z/L) is function of bulk Richardson number (R_b) in stable and unstable cases. Therefore, stability condition of the surface layer may be classified on the basis of bulk Richardson number to establish a link between z/L and eddy viscosity over monsoon trough for stable and unstable condition using the following simplified relations.

Class A : *when* $R_b > 0$

$$z/L = \frac{[z/(z-z_0)]\ \ln(z/z_0)}{(59.7\,R_b - 12.7)}$$

$$[-(12.7\,R_b - 1) - (1 + 8.919\,R_b)^{1/2}] \tag{5}$$

Class B : *when* $-\ 0.2097 < R_b \leq 0$

$$z/L = \left[-\left(T_b + \frac{Q_b}{T_b} \right) + \frac{1}{3\gamma_m} \right] [z/(z-z_0)]\ ln(z/z_0) \tag{6}$$

Class C : *when* $R_b \leq -\ 0.2097$

$$z/L = \left(\frac{z}{z-z_0} \right) \ln\left(\frac{z}{z_0} \right) \left[-2\,(Q_b^{1/2})\ Cos\left(\frac{\theta_b}{3} \right) + \frac{1}{3\gamma_m} \right] \tag{7}$$

where,

$$T_b = \left[(P_b^2 - Q_b^3)^{1/2} + P_b \right]^{1/3}, \; Q_b = \frac{1}{9}\left[\frac{1}{\gamma_m^2} + \frac{3\gamma_h}{\gamma_m} S_b^2 \right]$$

$$P_b = \frac{1}{54}\left[\frac{-2}{\gamma_m^3} + \frac{9}{\gamma_m}\left(\frac{-\gamma_h}{\gamma_m} + 3 \right) S_b^2 \right]$$

$$\theta_b = Cos^{-1}\left(\frac{P_b}{Q_b^{3/2}} \right), \; S_b = \frac{R_b}{P_r}$$

P_r = Turbulent Prandtl number = 0.74.

Soil temperature (10 cm depth) has been assumed as the surface temperature for the computation of R_b using the following formula:

$$R_b = \frac{g}{\theta_s} \frac{(\theta - \theta_s)(z - z_0)}{V^2} \tag{8}$$

where, θ_s = Surface temperature, V = Wind speed at height z, z_0 = Roughness length and remaining terms have their usual meaning as defined in Byun (1990) and Lo (1993) as γ_m = 15 and γ_h = 9. R_b was computed at 8m and 15m height of MONTBLEX tower on 9 and 24 July which is given in Table 2. If one compares bulk Richardson number, stability parameter *(z/L)* and corresponding eddy viscosity at these heights, one will find that surface layer is unstable when eddy viscosities are of the order of 10^{-1} J-s kg^{-1} or greater. Similar results were also found for Varanasi. In the case of stability Class A, Surface layer will decouple from rest of atmosphere above it. Because stability parameters are 3.50 and 2.73 at 8m height on 9 and 24 July at 0900 and 1200 hr (IST) respectively and eddy viscosity being of the order of 10^{-7} J-s kg^{-1} or less. Similarly, at 15m height, there is turbulent transfer of sensible heat flux because of $z/L < 0$ and eddy viscosity being of the order of 10^{-1} J-s kg^{-1} (Table 2). It is believed that turbulent mixing of fluxes from surface layer couples the atmosphere. So these stability classes may be used at forecasting stations to understand stability condition of surface layer using one level data. The above results indicate that the upward transfer of heat, momentum and moisture fluxes occur when the stability class is B or C.

7. Conclusions

The above study brings out the following results :

(*i*) During the monsoon season, particularly in July, the surface layer may be stably stratified under the influence of synoptic weather systems. Coupling and decoupling in the surface layer do occur episodically.

(*ii*) The effect of eddy viscosities are significant for mixing when it is greater than 10^{-3} J-s kg^{-1}.

(*iii*) The average eddy viscosity 5.13×10^{-1}J-s kg^{-1} may be used for computation of fluxes during the season in the surface layer when there is no inversion.

(*iv*) In the presence of inversion, one can use eddy viscosity of the order of 10^{-2} to 10^{-3} J-s kg^{-1} for turbulent mixing due to heat, momentum and moisture fluxes.

(*v*) In stable surface layer, average value of 4.95×10^{-4} J-s kg^{-1} or less may be used for complete extinction of turbulence when the level decouples from the layer above it over the monsoon trough region.

(*vi*) Surface moisture does not have any effect on the magnitude of eddy viscosity.

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