

# Identification of a surface layer structure and analysis of humidity data in two weather situations at Jodhpur ( $26^{\circ}18'N$ , $73^{\circ}04'E$ ), India, during MONTBLEX 1990

N DAS<sup>1</sup>, M BOSE<sup>2</sup> and U K DE<sup>1,\*</sup>

<sup>1</sup>*Environmental Science Programme, Jadavpur University, Kolkata 700 032, India*

<sup>2</sup>*Atmospheric Science Research Group, Physics Department, Jadavpur University, Kolkata 700 032, India*

\*e-mail: deutpal@hotmail.com

The Monsoon Trough Boundary Layer Experiment held in 1990 was a multi-institutional effort to probe the atmospheric boundary layer over the monsoon trough over northern India. For this experiment, four micrometeorological towers were set up at four different locations along the normal position of the trough. One such tower of 30m height was located at Jodhpur ( $26^{\circ}18'N$ ,  $73^{\circ}04'E$ ), Rajasthan. The fast and slow response data available during the experiment have been used in the present study to determine a suitable layer-structure of the surface layer for evaluation of sensible heat flux using the multilayer hypothesis of Kramm (1989).

## 1. Introduction

The Atmospheric Boundary Layer (ABL) is directly influenced by the earth's surface, and responds to surface forcing with a time scale of about an hour or less. It plays an important role in the evolution of weather systems. ABL experiments started during the late sixties. The pioneering work in this field in India was the Monsoon Experiment (MONEX-79) where, a 10 m high mast was installed at a coastal station close to the Bay of Bengal to probe the boundary layer (Mohanty *et al* 1995). In the summer monsoon season (June – September) of 1990, the Monsoon Trough Boundary Layer Experiment, acronymed as MONTBLEX, was designed to carry out exclusive boundary layer observations over land surfaces along the monsoon trough. During this experiment, micrometeorological towers of 30 m height with slow and fast response sensors fixed at six nearly logarithmic levels were installed at four locations along the normal position of monsoon trough over northern India. These locations represent the dry convective to moist convective nature of the

atmosphere along the normal axis of the monsoon trough.

As a part of this experiment, one such tower was placed at the Central Arid Zone Research Institute (CAZRI), Jodhpur, which represents the dry convective end of the monsoon trough. The tower had six levels of instrumentation. Booms were placed at 1, 2, 4, 8, 15 and 30 m heights and mentioned here as 1st, 2nd, 3rd, 4th, 5th and 6th levels respectively. Wind velocity, wind direction and temperature of slow response data at all levels and fast response type data at some selective levels were collected. The details about instrumentation are available in the literature (Rudra Kumar *et al* 1995). A Lyman-Alpha humidity sensor, which measures the absolute humidity and Humicap sensors, which measure relative humidity have been used here. The validation of the available data was carried out at the Indian Institute of Science, Bangalore (Rudra Kumar and Prabhu 1991).

As the tower of 30 m remains within the lower part of ABL, i.e., surface layer, studies have been undertaken, with this tower data to understand the characteristics of the surface layer. The study of

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the surface layer is based on the Monin-Obukhov similarity theory (Stull 1994), which proposes that the layer has constant fluxes i.e., the gradients of the vertical flux of heat, mass and momentum can be neglected. But the observations generally show that there is a non-negligible amount of variation of fluxes even within the surface layer. To make a bridge between the theory and the observations Kramm introduced multilayer hypothesis (Kramm 1989). Choice of the layer is, however a challenging task. Pradhan *et al* 1994 chose the different layers using a special technique and it was established for Kharagpur region. But this technique was neither tested over Jodhpur region nor did it include humidity measurements. In the work of Chattopadhyay and De (2000), over Jodhpur region, a different approach was made for the different layers, but this was done without humidity observations. In the present work an attempt has been made to remedy the omission of humidity. A comparative study between two different types of layered hypothesis over Jodhpur region is also done.

The main objective is to develop a suitable methodology for evaluation of the sensible heat flux over Jodhpur region, such that each isolated layer may be taken to have a definite stability parameter, where the concept of constant heat flux should be supported. In the second part of the study inter-comparison between two humidity measuring sensors, namely Lyman-Alpha and Humicap is carried out and the correlation between the two is presented.

## 2. Climatological condition over Jodhpur

CAZRI is located on the outskirts of Jodhpur city in Rajasthan, which is close to the western end of the monsoon trough. Jodhpur lies in the dry zone of the Thar desert, on the Aravalli range, and has a combination of both hill and valley terrain. It is situated at the extreme dry convective end of the monsoon trough. Rainfall over here is normally very low. For the eastern part of the country pre-monsoon season extends from March to May, but for Jodhpur region, the month of June can be taken as the premonsoon season, as the monsoon, in general, arrives here in the second week of July.

## 3. Data and analysis

We use six days of premonsoon data and four days of monsoon data, available at Jodhpur. Simultaneous data of both fast as well as slow response sensors were made available to the authors only for that period. The 30 m micrometeorological tower

at Jodhpur had 6 levels of instrumentation. The temperature, wind velocity and wind direction data were collected from the slow response sensors placed at different heights. Those sensors were sampling at 1 Hz but in general, the data are available continuously from the data center as 1 minute average. However, it is observed that if 30 minutes averages of slow response data are taken, the diurnal variation of data shows the usual variational pattern with smoothing of continuous fluctuations in the background (Pradhan *et al* 1994). So, in the present study 30 minutes average of slow response data are utilised. Here, the data of June 24th to June 29th (Julian Day 175 to 180), 1990 represents the premonsoon period scenario and from July 17th – July 20th (Julian Day 198 to 201) represents the monsoon period. Fast response data were collected at a frequency of 8/9 Hz. When heat flux is evaluated using flux-profile methodology only, the slow response data for wind speed and temperature are utilised. However, in case of comparison of absolute and relative humidity data, those from fast response sensors are only being considered in the present study.

## 4. Methodology and procedure

The tower height being 30 m, it lies within the surface layer of ABL. The parameters derived in the course of the present work are essentially surface layer parameters. As the potential temperature gradient has both signs successively even within 30 m height in both fast and slow response data, one needs to introduce the concept of a number of isolated layers even within the surface layer so that each distinct layer can have a particular stability parameter and taking a suitable average, the concept of constant heat flux layer can be preserved.

Surface heat flux ( $H$ ) is evaluated here using the flux-profile technique and the two layer concept, using 30 minute average data. Two different methods are used: approach A and approach B. In approach A, for the premonsoon period, the first layer is taken to be between 2 m and 8 m, and the other between 8 m and 30 m heights. The corresponding layers are taken to be between 1 m and 15 m heights and between 15 m and 30 m heights for the monsoon period. This is done following Das *et al* (2001). In approach B, the lower level and the upper level are kept undisturbed, i.e., the lower level is taken at 1 m height and the upper level is at 30 m. Then the middle level is chosen in the following way. The slow response data at 4 m and 8 m levels among the six levels are ignored, as temperature gradient is very high between these two levels. The mean of the meteorological parameters of 2 m and 15 m heights is placed at geometric mean

height of these two levels, i.e., at 5.48 m height. So two layers are between 1 m and 5.48 m heights and between 5.48 m and 30 m heights. The parameters at 5.48 m height are generated by taking the mean of data at 2 m and 15 m heights (Pradhan *et al* 1994).

For both the approaches stated above, surface heat flux (H) is calculated for each of the two isolated layers separately. Then the surface heat flux for the total 30 m height is calculated using the square root of the height weightage (Pradhan *et al* 1994). We next describe the flux profile technique, by which the surface heat flux is calculated.

#### 4.1 Flux-profile technique for slow response data

Slow response data for all the six levels are available. For the use of flux-profile technique wind speed and temperature data are used. The non-dimensional wind shear and temperature stratification may be expressed as (Chattopadhyay and De 2000),

$$\phi_m(\xi) = \frac{kz}{u_*} \frac{\partial u}{\partial z}, \quad (1)$$

$$\phi_h(\xi) = \frac{kz}{\theta_*} \frac{\partial \theta}{\partial z}, \quad (2)$$

where,  $z$  = height,  $k$  = Von-Karman constant,  $u$  = wind speed,  $\theta$  = potential temperature,  $u_*$  = frictional velocity,  $\theta_*$  = frictional temperature,  $\phi_m(\xi)$  = non-dimensional wind shear  $\phi_h(\xi)$  = non-dimensional temperature stratification.

The flux-profile technique is based on the Monin-Obukhov similarity relations (Pradhan *et al* 1994) for  $\phi_m(\xi)$  and  $\phi_h(\xi)$ . The generally accepted forms of the similarity relations are as follows

$$\phi_m(\xi) = (1 - \gamma\xi)^{-a} \quad (3)$$

and

$$\phi_h(\xi) = (1 - \gamma\xi)^{-b}, \quad (4)$$

where  $\gamma$  is a free constant and it is taken as 5 for Jodhpur region (Chattopadhyay and De 2000) and  $a, b$  are constants to be decided. The widely accepted values for  $(a, b)$  are either  $(1/4, 1/2)$  or  $(1/3, 1/2)$ . It has been concluded in the literature that  $(1/4, 1/2)$  law holds good for Jodhpur region (Chattopadhyay and De 2000). In the stable condition, the corresponding expressions are,

$$\phi_m(\xi) = \phi_h(\xi) = (1 + \beta\xi), \quad (5)$$

where  $\beta$  is a constant and the value of  $\beta$  may be taken as 5 (Kramm 1989).

Integrating the profile relations (1) and (2), with the help of 'similarity relations', i.e., equations (3), (4), or (5), the following relations are generated.

$$u(z) = \frac{u_*}{k} \left( \ln \frac{z-d}{z_0} - \psi_m(\xi, \xi_0) \right), \quad (6)$$

$$\theta(z) = \frac{\theta_*}{k} \left( \ln \frac{z-d}{z_0} - \psi_h(\xi, \xi_0) \right), \quad (7)$$

where,  $z_0$  = roughness length,  $d$  = zero plane displacement,  $\xi_0 = z_0/L$ ,  $L$  = Monin-Obukhov length,  $\Psi_m(\xi, \xi_0)$  = surface layer stability correction term for momentum,  $\Psi_h(\xi, \xi_0)$  = surface layer stability correction term for heat.

Applying  $(1/4, 1/2)$  power law, the expressions are modified as

$$\begin{aligned} \psi_m(\xi, \xi_0) &= \frac{-5}{L}(z - z_0 - d) && \text{for } L > 0 \\ &= 0 && \text{for } L \rightarrow \infty \\ &= 2 \ln \frac{1+y}{1+y_0} + \ln \frac{1+y_2}{1+y_{02}} \\ &\quad - 2 \tan^{-1} \frac{y-y_0}{1+yy_0} && \text{for } L < 0 \end{aligned} \quad (8)$$

and

$$\begin{aligned} \psi_h(\xi, \xi_0) &= \frac{-5}{L}(z - z_0 - d) && \text{for } L > 0 \\ &= 0 && \text{for } L \rightarrow \infty \\ &= 2 \ln \frac{1+y_2}{1+y_{02}} && \text{for } L < 0. \end{aligned} \quad (9)$$

Here,

$$y = \phi_m^{-1}(\xi) = (1 - \gamma\xi)^{1/4}. \quad (10)$$

Obviously,  $y$  is the reciprocal of the dimensionless wind shear.

Following the methodology of Kramm and others (Kramm 1989; Businger 1973; Kramm and Herbert 1984) and taking ' $d$ ' as zero, as the terrain of Jodhpur is flat, one can obtain the converged values of  $u_*$ ,  $\theta_*$  and  $L$  for a layer formed out of two levels. Then, following the procedure of Pradhan *et al* (1994), a second iterative process is carried out so that the equations (1) and (3) or (2) and (4) are exactly satisfied. After these two successive iterative processes, stable values of  $u_*$ ,  $\theta_*$  and  $L$  are obtained. The stable parameters are evaluated for both the layers. From these parameters the surface heat flux can be evaluated for each layer from the following relation (Brook 1978),

$$H = -\rho C_p u_* \theta_* \quad (11)$$

where,  $\rho$  = density of air,  $C_p$  = specific heat at constant pressure for moist air.

For the heat flux of the entire 30 m layer, the various weightages for the depth of each isolated layer can be introduced. But here  $\sqrt{z}$  weightage for the averaging technique has been accepted for the Indian region (Pradhan *et al* 1994). Taking  $H_1$  and  $H_2$  to be the heat flux for the two layers at heights  $z_1$  and  $z_2$  and considering the  $\sqrt{z}$  weightage for the depth of each isolated layer, the heat flux of the entire 30 m layer can be written as,

$$H = \frac{H_1\sqrt{z_1} + H_2\sqrt{z_2}}{\sqrt{z_1} + \sqrt{z_2}}. \quad (12)$$

Approach B is basically identical with approach A as far as the evaluation of layer parameters is concerned. During the study, the surface heat flux, obtained by both approaches, is compared and they show almost similar diurnal variational pattern although the magnitudes of the parameters are different. Comparison is done graphically between the surface heat fluxes obtained from both the approaches. Separate graphs are drawn for pre-monsoon and monsoon periods to understand the difference between the surface heat fluxes obtained by the two approaches (figures 1a and 1b). Again another graph is plotted combining the above mentioned two periods, to compare the characteristics of premonsoon and monsoon phases (figure 1c).

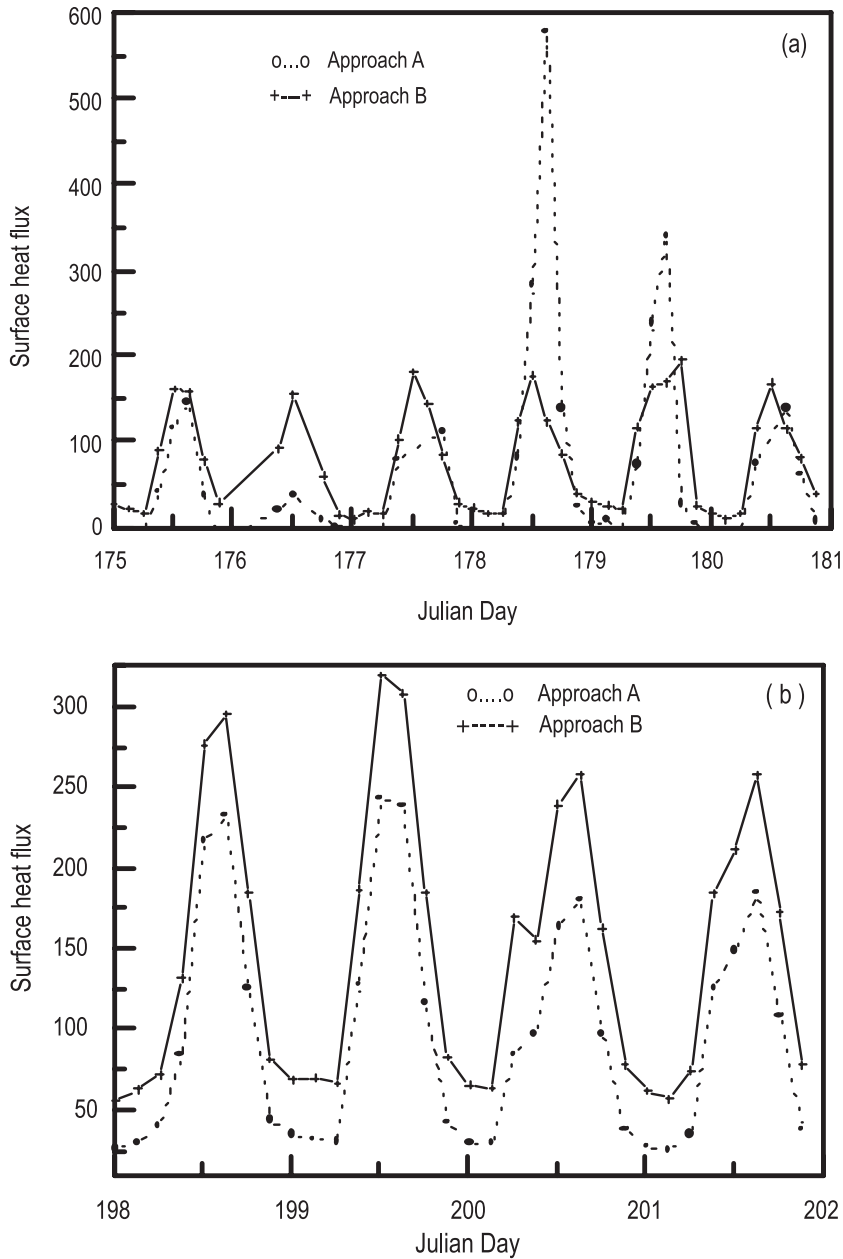


Figure 1. (Continued)

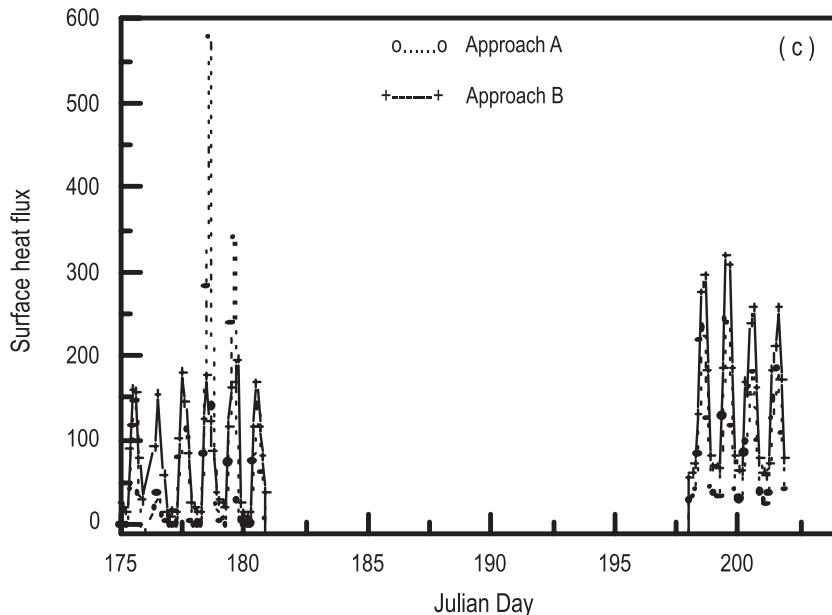


Figure 1. Comparison of variation of heat flux obtained from approach A and B using flux-profile method in the (a) pre-monsoon phase (b) monsoon phase (c) combination of premonsoon and monsoon phase.

#### 4.2 Intercomparison between different humidity measuring sensors

Here, surface layer parameter (humidity) is taken into account. First, the absolute humidity is considered, which is measured by Lyman-Alpha placed at 2 m height of the tower during the experiment. Then, the relative humidity is considered and this is measured by Humicap sensors placed at different heights of the tower. During the premonsoon phase (24th June to 29th June) Humicaps are placed at 1 m, 4 m and 30 m height and during the monsoon phase (17th July to 20th July) these are placed at 1 m and 30 m height only. The Humicap sensor, which was placed at 4 m height was absent during the monsoon phase of the period of our concern. All these are fast response sensors. During the course of the study the turbulence intensity of both absolute and relative humidity of all the available levels have been calculated. Then correlation between the turbulence intensity of absolute humidity data obtained from Lyman-Alpha sensor and relative humidity data obtained from Humicap sensor of different layers, individually, has been done. Here one correlation co-efficient for the whole day is taken into account. Again, the raw relative humidity data of Humicap sensor of all the layers obtained at different hours of the particular days of interest, are considered separately; and those are intercompared both graphically and in tabular form to get a clear idea about the correlation with the relative humidity at different levels. The theory inherent in the comparison between different kinds of humidity sensors is described below (Stull 1994).

Table 1. *R.m.s. error between surface heat fluxes calculated by eddy correlation method and flux-profile method using approach A and B, during premonsoon and monsoon phase.*

	For premonsoon period	For monsoon period
Approach A	0.897	0.614
Approach B	0.531	0.316

Let  $A$  be a variable and it can be split into mean and turbulent parts.

$$A = \bar{A} + a'. \quad (13)$$

Variance of  $A$  is,

$$\sigma_A^2 = \frac{1}{N} \sum^{N-1} (A_i - \bar{A})^2, \quad (14)$$

when  $N$  is the number of observations. The turbulent part or the perturbation or the gust part of a turbulent variable is given by,  $a' = A - \bar{A}$ . Substituting the  $a'$  in equation (14), variance can be written as,

$$\sigma_A^2 = \frac{1}{N} \sum^{N-1} a_i'^2 = \bar{a}_i'^2. \quad (15)$$

The non-dimensional turbulence intensity ( $I$ ) of a parameter is defined as standard deviation divided by the mean, i.e.,

$$I = \frac{\sigma_A}{\bar{A}}. \quad (16)$$

Table 2. Correlation co-efficient for turbulence intensity between Lyman-Alpha and Humicap data at different heights, during premonsoon and monsoon phase.

Premonsoon			Monsoon		
Date (in June)	Sensors placed at the height (in m)	Correlation co-efficient	Date (in July)	Sensors placed at the height (in m)	Correlation co-efficient
25th	1	0.645	17th	1	-0.281
25th	4	0.799	17th	30	0.098
25th	30	0.759	19th	1	-0.174
26th	1	0.085	19th	30	-0.113
26th	4	0.128	20th	1	-0.751
26th	30	0.317	20th	30	-0.925
27th	1	0.986			
27th	4	0.985			
27th	30	0.986			
28th	1	0.975			
28th	4	0.950			
28th	30	0.966			
29th	1	0.921			
29th	4	0.760			
29th	30	0.821			

The covariance between two variables  $A$  and  $B$  is defined as,

$$\text{Cover}(A, B) = \frac{1}{N} \sum^{N-1} (A_i - \bar{A})(B_i - \bar{B}). \quad (17)$$

Using Reynolds averaging methods, one can show that

$$\text{Cover}(A, B) = \frac{1}{N} \sum^{N-1} a'_i b'_i = \overline{a'_i b'_i}. \quad (18)$$

The normalised or linear correlation coefficient,  $r_{AB}$  is given by

$$r_{AB} = \frac{\overline{a'_i b'_i}}{\sigma_A \sigma_B}. \quad (19)$$

In the present study,  $I$  for both relative and absolute humidity is calculated. Then  $r_{AB}$  between turbulence intensity of absolute humidity and turbulence intensity of relative humidity for all the available layers have been calculated.

Correlation index is also evaluated simultaneously. The value of correlation index (Goon et al 1993) is nothing but the ratio between the standard deviation of the predicted value, i.e., fitted curve with the standard deviation of the raw data set. The value of correlation index for linear curve

as well as for polynomial of different orders (up to 9th order) has been estimated separately. Though for further study, only the value for best fitted curve is considered. Correlation index is calculated among the raw relative humidity data of different possible heights. This way, one value of correlation index for each hour of a day is available with synoptic conditions.

## 5. Results and discussions

### 5.1 Intercomparison between the parameters obtained from differently layered hypothesis

From the figures 1(a) and 1(b) one finds that both the methods give identical diurnal variational pattern of heat flux though the amplitudes are different. In a previous work (Das et al 2001), it has been noted that, there were two significant days when deep convection was present in the premonsoon period (i.e., in the month of June) for Jodhpur region. For these two days, when a system was present (i.e., 27th June and 28th June), eddy correlation method unusually indicates high magnitude of surface heat flux (Das et al 2001). In the present study, for these two particular days, both the methods cannot provide satisfactory results,

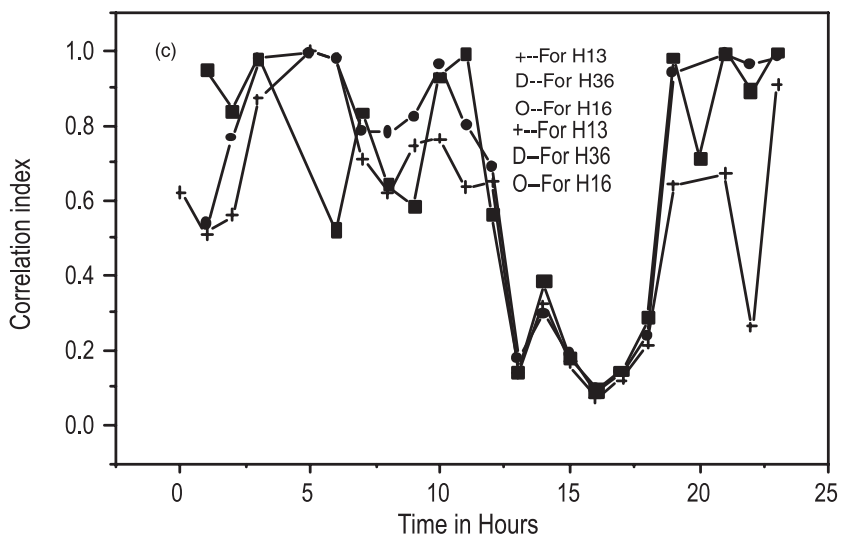
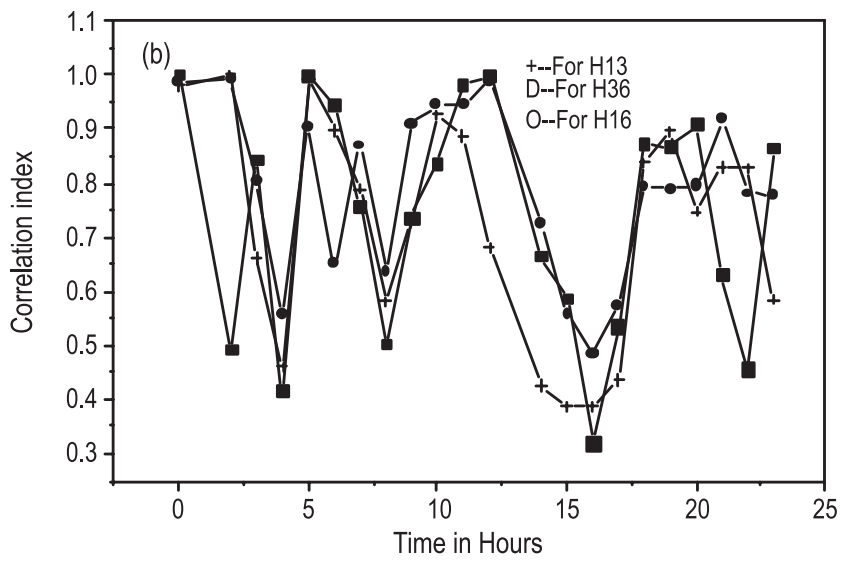
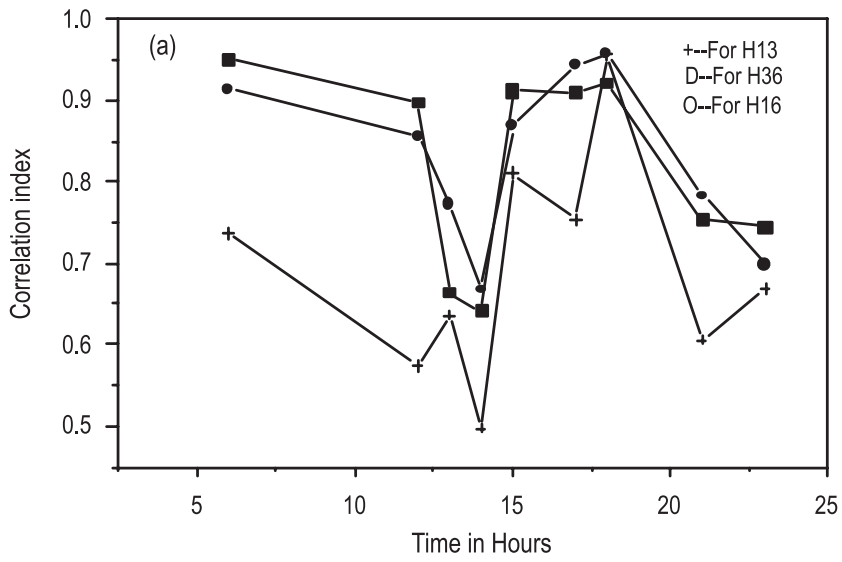


Figure 2. (Continued)

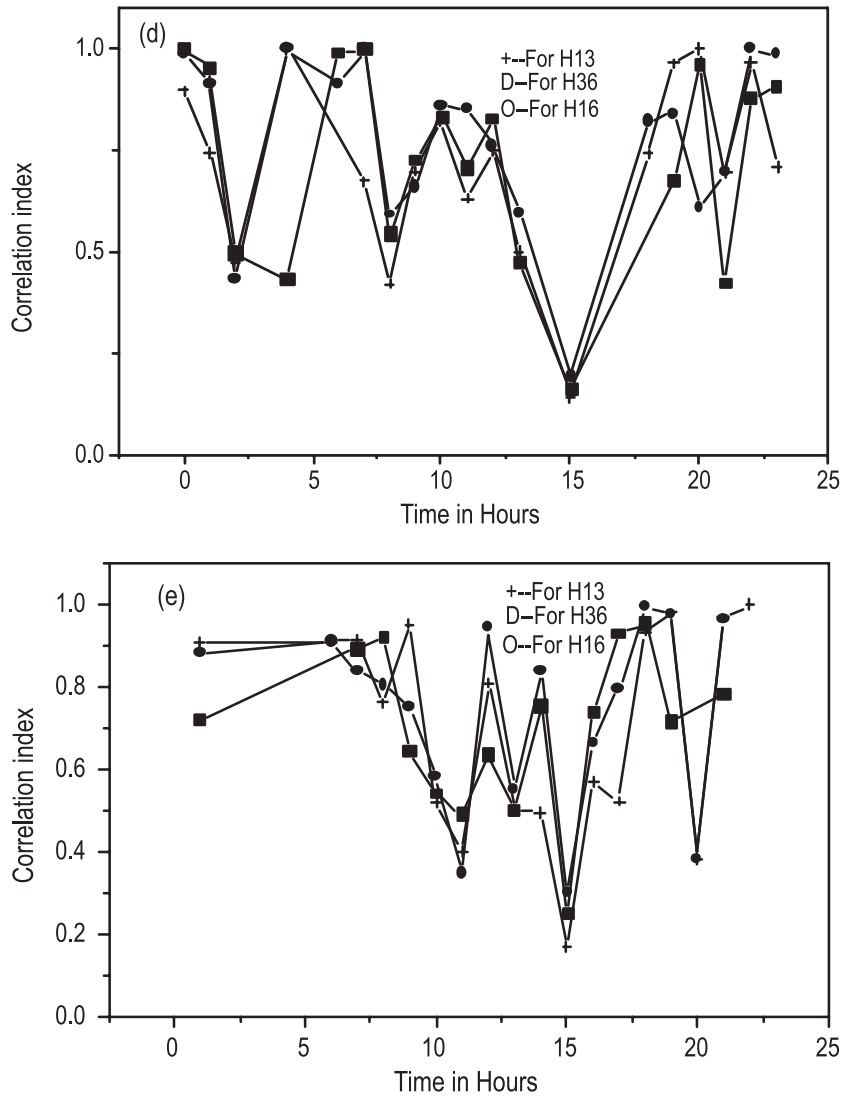


Figure 2. Comparison of correlation index for relative humidity at different heights (a) 25th June (b) 26th June (c) 27th June, (d) 28th June and (e) 29th June.

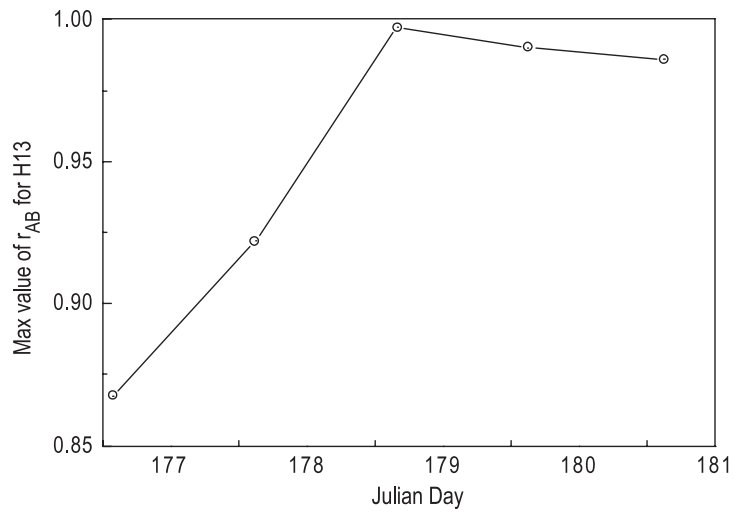


Figure 3. Variation of maximum value of correlation co-efficient between humicap data placed at 1 m and 4 m height in the premonsoon phase.

Table 3. Maximum value of correlation co-efficient between relative humidity at 1 m and 4 m height during premonsoon phase.

Time (in Julian)	Maximum value of correlation co-efficient
176.5883	0.867
177.6250	0.922
178.6667	0.997
179.6250	0.990
180.6250	0.985

in comparison to eddy correlation output: though from figures 1(a) and 1(b), it is evident that for these two days both the approaches exhibit peaks in the surface heat flux magnitude. Again, one

can accept that the eddy correlation method is an ideal one (Chattopadhyay and De 2000), for calculation of surface layer parameters. In that context, it has been shown that the flux-profile method is in the same status with eddy correlation method, but the only deficit is in the amplitude, i.e., flux-profile method always lags in amplitude compared to the eddy correlation method, which supports the fact that flux-profile method is less sensitive than the eddy correlation method. However from figures 1(a) and 1(b), we consider approach B to be more suitable in the monsoon situation as this approach gives higher magnitude of heat flux. When considering the sensitivity, approach B is more reliable than approach A, for the monsoon period. For the premonsoon phase approach B is, in general, more sensitive but for the two deep convective days (27th and 28th June) approach A

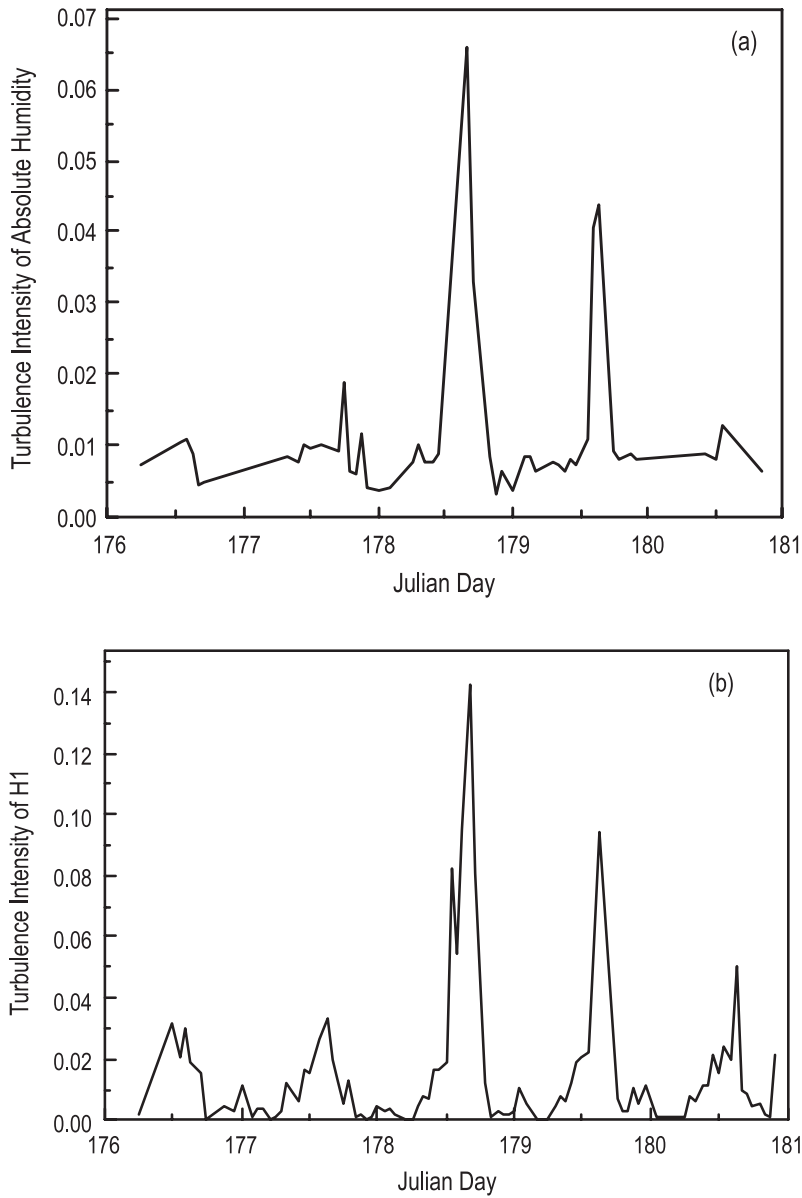


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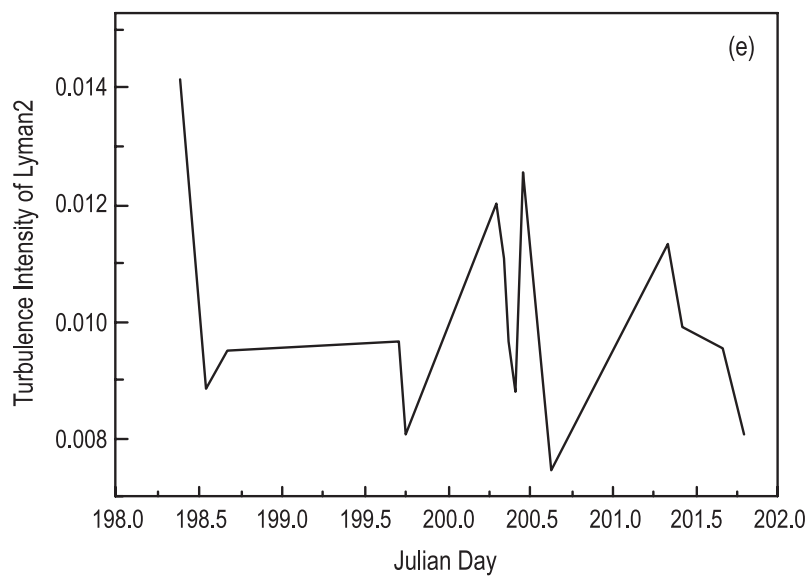
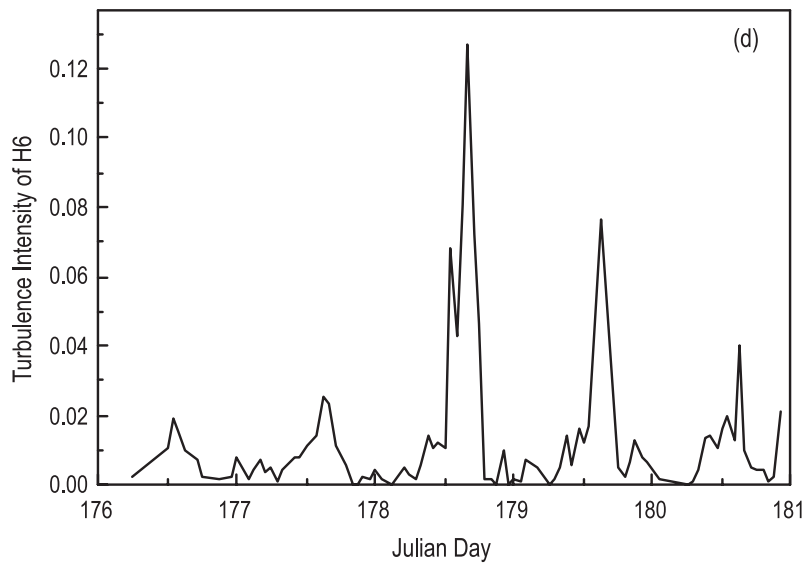
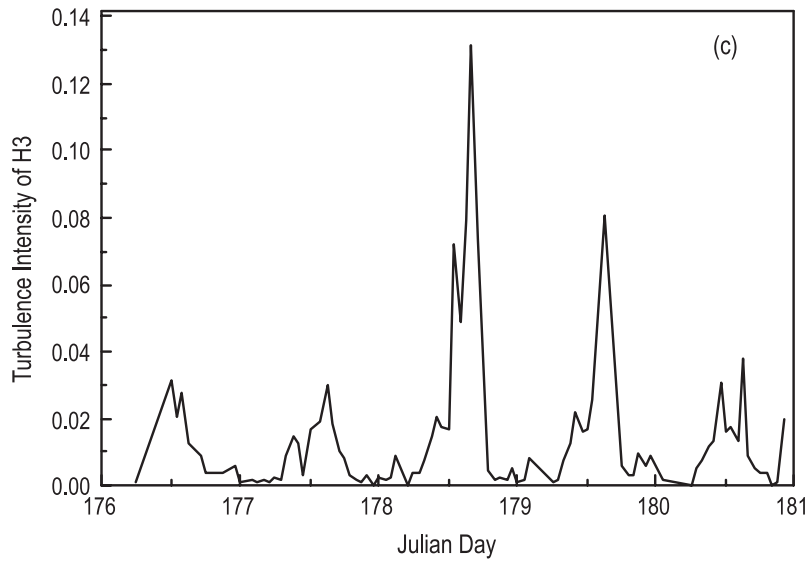


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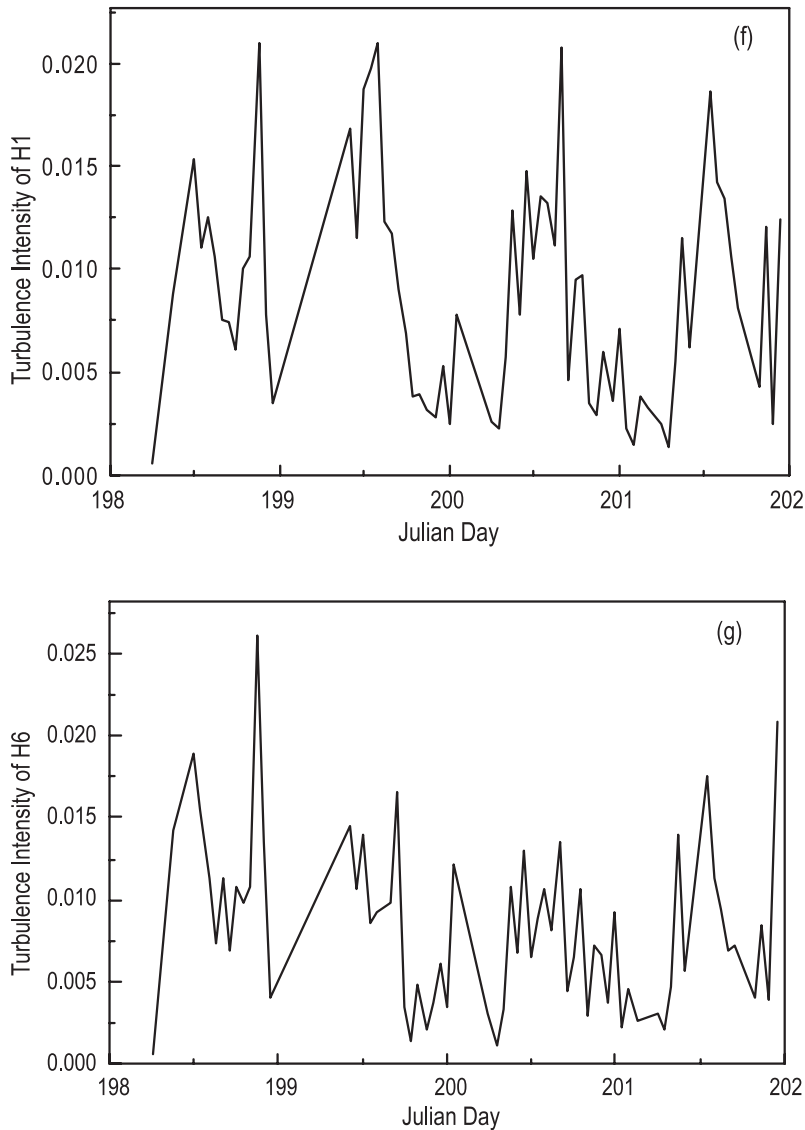


Figure 4. Variation of turbulence intensity (a) absolute humidity during premonsoon phase (b) relative humidity at 1 m height during premonsoon phase (c) relative humidity at 4 m height during premonsoon phase (d) relative humidity at 30 m height during premonsoon phase (e) absolute humidity during monsoon phase (f) relative humidity at 1 m height during monsoon phase (g) relative humidity at 30 m height during monsoon phase.

indicates high magnitude of surface heat flux. So it has been observed that approach A is better only for those days when a system was present, and for the other days, i.e., when deep convection is not present, approach B is better than approach A.

To obtain the result rather quantitatively r.m.s. (root mean square) error has been estimated for the surface heat fluxes obtained by both the approaches separately. This is done, considering the outcomes of eddy correlation method as an authentic one. The error is presented for premonsoon and monsoon period separately (table 1). Here the eddy correlation has been performed using the data set given by Gill fast response sensor.

## 5.2 Comparison between the different humidity measuring sensors

Turbulence intensity of the relative humidity on 27th and 28th June gradually decreases with altitude in the case of Humicap sensors, but its magnitude is still quite high. It should be remembered that those days had deep convection. But for the other days of study during premonsoon season (i.e., 25th, 26th and 29th June), the magnitude of turbulence intensity is not so high and there is a slow decrease with height. For the month of July, the turbulence intensity is erratic and the magnitude is weak.

Table 2 shows the correlation among the turbulence intensities from different humidity measuring

Table 4. Maximum value of turbulence intensity for relative humidity at 1 m, 4 m and 30 m height during premonsoon phase.

Date and time (in I.S.T)	Humicap placed at the height (in m)	Turbulence intensity
27th June 1600 hrs.	1	0.142
27th June 1600 hrs.	4	0.131
27th June 1600 hrs.	30	0.127
28th June 1500 hrs.	1	0.095
28th June 1500 hrs.	4	0.080
28th June 1500 hrs.	30	0.076

sensors. From this table it can be said that the correlation for turbulence intensity of Lyman-Alpha sensor data and Humicap1, Humicap3 and Humicap6 sensor data respectively is quite good for the month of June. However, for the month of July, the correlation is poor. In the case of premonsoon season, for all the days concerned, except for 26th June, good correlation between Lyman-Alpha and Humicap1 sensor data is observed. On 24th June correlation is not evaluated due to lack of sufficient observations. For the month of July correlation is insignificant (i.e., negative correlation) between Lyman-Alpha on the one side and Humicap1 or Humicap6 sensor data on the other side. As stated previously, for the month of July, no Humicap hygrometer is placed at level 3. It has also been perceived that the correlation value is best on 27th June, which is quite similar to the previous work, where it has been shown that all the correlations between different parameters has its best

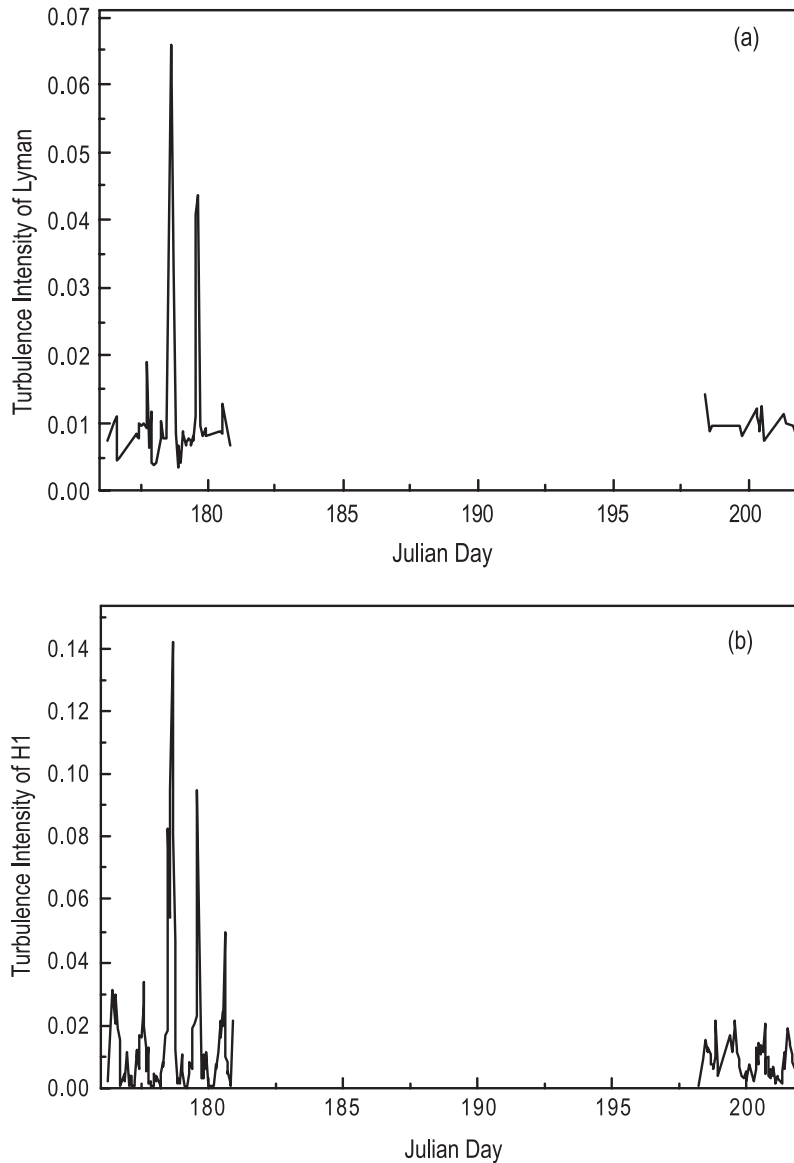


Figure 5. (Continued)

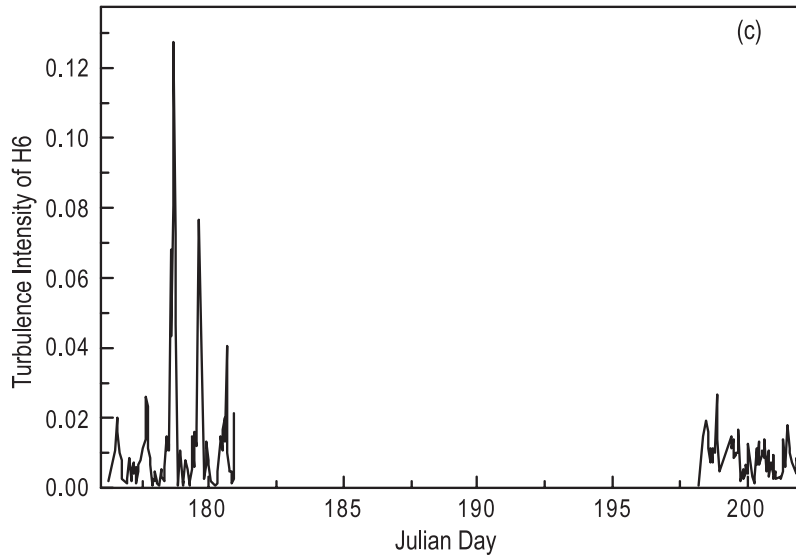


Figure 5. Variation of turbulence intensity during premonsoon and monsoon phase (a) for absolute humidity (b) for relative humidity at 1 m height (c) for relative humidity at 30 m height.

Table 5. Overall surface layer parameters for our period of study.

Julian day	Time in IST		Heat flux		Absolute humidity	Relative humidity			Systems present
			Approach A	Approach B		1 m	4 m	30 m	
175	15-00	Max	49.37	73.20	9.809	–	–	–	–
	03-00	Min	–1.20	4.81	–	–	–	–	
176	12-00	Max	35.81	59.85	9.795	42.8	47.7	49.9	–
	21-00	Min	0.42	4.21	–	40.8	42.6	42.2	
177	12-00	Max	74.14	86.40	9.800	39.8	43.6	45.9	–
	03-00	Min	–0.58	2.81	–	51.9	53.7	54.0	
178	15-00	Max	172.97	97.66	9.919	30.5	34.3	35.5	Rain with thunderstorm and duststorm
	06-00	Min	–0.23	4.69	9.790	37.8	39.5	39.3	
179	15-00	Max	102.01	88.36	9.874	33.1	36.9	39.0	Rain with thunderstorm
	06-00	Min	–0.22	6.29	9.757	55.3	57.3	57.9	
180	12-00	Max	61.72	82.40	9.812	39.0	42.9	45.1	–
	00-00	Min	–0.73	2.88	–	59.9	61.8	62.6	
198	15-00	Max	69.38	102.60	9.811	54.2	–	51.9	Rain
	00-00	Min	7.79	16.56	–	–	–	–	
199	12-00	Max	72.66	130.00	–	57.9	–	58.8	–
	03-00	Min	9.00	19.82	–	–	–	–	
200	15-00	Max	54.06	95.65	9.798	54.5	–	52.3	–
	03-00	Min	8.61	18.94	–	78.7	–	73.2	
201	15-00	Max	55.04	99.53	9.799	55.8	–	54.4	–
	03-00	Min	7.37	17.09	–	82.1	–	77.3	

Table 6. Information about humidity for the total period of study.

Julian day	Absolute humidity		Relative humidity					
	Maximum value with time in IST	Maximum value with time in IST	Maximum value with time			Maximum value with time		
			1 m	4 m	30 m	1 m	4 m	30 m
175	–	–	–	–	–	–	–	–
176	9.804 at 17-00	9.730 at 06-00	62 at 06	64 at 06	65 at 06	35 at 17	38 at 17	40 at 17
177	9.875 at 18-00	9.754 at 08-00	58 at 06	60 at 06	62 at 08	29 at 17	32 at 17	34 at 17
178	9.919 at 16-00	9.750 at 06-00	55 at 06	57 at 07	58 at 07	28 at 19	31 at 19	31 at 19
179	9.874 at 15-00	9.754 at 21-00	59 at 23	60 at 23	60 at 18	31 at 13	36 at 13	37 at 00
180	9.820 at 13-00	9.791 at 10-00	63 at 06	64 at 06	65 at 06	35 at 14	38 at 19	39 at 18
198	9.811 at 16-00	9.751 at 09-00	83 at 09	–	83 at 09	50 at 17	–	46 at 17
199	–	–	68 at 23	–	68 at 10	51 at 17	–	47 at 18
200	9.798 at 15-00	9.732 at 07-00	84 at 07	–	82 at 07	53 at 16	–	50 at 16
201	9.799 at 16-00	9.741 at 08-00	83 at 07	–	80 at 07	53 at 17	–	50 at 17

value on that deep convective day (Das *et al* 2001). The correlation between the actual humidity data of Lyman-Alpha sensor with relative humidity data of Humicap1 and Humicap6 sensor is evaluated for the month of July and it turns out to be very poor (i.e., almost no correlation). It is also extremely poor for the month of June.

Figure 2 is presented to compare the correlation index of the data from hygrometers placed at different levels. Here index agreement for linear as well as polynomial of various orders has been examined and the value for best fitted curve is considered for the comparison job.

Figure 2 reveals that the correlation is in general better during the unstable period. This indicates that the moisture is transported to the higher altitude by the process of turbulence and this turbulence becomes vigorous during the unstable period of the atmospheric surface layer.

Figure 3 shows that the maximum value of the correlation coefficient between Humicap1 and Humicap3 for the premonsoon phase has high values for 27th June and 28th June. From table 3, we see that the highest value of the correlation coefficient between Humicap1 and Humicap3 is found on 27th June (i.e., on the deep convective day). This inference is compatible with earlier work (Das *et al* 2001). Figures 4(a), 4(b), 4(c) and 4(d) and table 4 also support this conclusion. It is clear from the figures 4(a), 4(b), 4(c) and 4(d) that the turbulence intensity of absolute humidity as well as relative humidity exhibited a sharp rise on 27th June and 28th June (see table 4). Figures 5(a), 5(b) and 5(c) show that the magnitude of ' $T$ ' (equation 16) is larger during the premonsoon phase than during the monsoon phase. This is because, during monsoon activities, the weather is more stable. This also reveals that the turbulence is stronger in the

premonsoon phase. This is concluded from the figures 5(a), 5(b) and 5(c) for Lyman-Alpha as well as Humicap sensors.

Tables 5 and 6 give heat flux and humidity (both absolute and relative), during the period of study.

## 6. Conclusions

Of the two methodologies followed here for the calculation of surface layer parameters, it is not possible to conclude which is more suitable. It appears that approach B is better both in premonsoon as well as in the monsoon period, except during deep convective days. So, when working with the deep convective situation, approach A is more suitable, otherwise approach B should be used.

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