Surface Boundary Layer Characteristics For Convective And Non – Convective Periods During The Summer Monsoon Season From A Mini Boundary Layer Mast Over A Flat Terrain At Vbit, Hyderabad (17.28^{0}N, 78.43^{0}E).

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Abstract: Surface layer responds differently during convective and non-convective period weather conditions. An attempt is made in this study to examine the contrasting variations in the mean surface layer structure and in surface fluxes between convective and non-convective periods. Micrometeorological measurements made during the southwest monsoon seasons in the years 2013 and 2014 from the instrumentation network established during the PROWNAM programme (Prediction of Regional Weather using Observational meso-Network and Atmospheric Modelling) are used for the present project. Data have been analysed for Hyderabad location (Mini Boundary Layer Mast at VBIT,Hyderabad), and near surface boundary layer characteristics are investigated through the vertical variation of heat and momentum fluxes during the convective and non-convective periods of the years 2013 and 2014. The convective and non-convective periods are identified based on OLR (Outgoing Long wave radiation) from satellite data. If the value is > 200 it is non convective and < 200 convective periods respectively with reference to OLR data. Different surface layer fluxes are computed using a gradient approach at different logarithmic heights. They are observed to vary significantly between convective and non-convective periods. The heat and momentum fluxes showed a maximum peak during convective period.

Keywords: Boundary layer, boundary layer characteristics, Convective and non- Convective.

I. Introduction

The surface layer is the lowest layer of the atmosphere (and troposphere). It is the layer, which air is in contact with surface and where strong vertical gradients in temperature, humidity, wind and scalars exist. The atmosphere responds to surface forcing on the time scale of an hour or less. Temperature, wind, CO_2, humidity and pollutant concentrations exhibit distinct diurnal patterns over the course of a day in the troposphere. The typical height of the surface layer is 100 m during daytime and less than that during night time (Oke, 1978). The variation of fluxes of momentum and heat in surface boundary layer play a vital role in the energy transport mechanism. The primary mechanism is mainly affected by the turbulence, the turbulence in this layer caused mainly due to the wind shear, which is generated by the surface frictional force known as mechanical turbulence (Arya, 1988). Thermal and dynamic interaction between the atmosphere and underlying surface occur through the turbulence exchange of momentum, heat and moisture at their interface.

The flow in the atmospheric surface layer has a turbulent character, transporting heat, momentum, moisture and pollutants both horizontally and vertically (Sorbjan,1989; Garratt,1992; kaimal andFinnigan,1994). This turbulent nature allows the flow to respond to the changing surface –layer forcing (Stull, 1988). Many experimental studies on the atmospheric surface layer have been reported in the literature (Businger et al., 1971; Kaimal et al., 1976,1982; kaimal and Wyngaard,1990). But these types of field experiments conducted in the tropics are rare compared with those conducted in extratropical and mid-latitude regions. In the tropics, significant diurnal oscillations in wind speed, static instability, turbulent exchange and convective activity are observed within the atmospheric boundary layer (ABL; Asnani,1993). A few experiments conducted over the Indian sub- continent include the coastal boundary- layer studies over Trivandrum (Prakash et al ., 1993; Kunnhikrishnan et al., 1993;

Ramachandran et al., 1994), the monsoon boundary –layer experiment (MONTBLEX-1990) conducted during the south-weat summer monsoon season over the monsoon trough region of the Gangetic plains (Goel and Srivastava,1990; Kusuma et al., 1996; Kailas and Goel, 1996) and land surface process Experiments (LASPEX-1997) conducted over the Sabarmathi basin of Gujarat (Pillai et al ., 1998; satyanarayana et al., 2000). But only a few studies have been conducted on surface-layer turbulence characteristics over the tropical Indian region. Understanding the surface –layer characteristics and energy exchange processes is a necessary prerequisite for understanding the local climate, and modeling of the turbulent exchange in tropical region scale numerical models. These studies also attain importance when dealing with problems related with pollution transport and other applications. The present study is partly addressing this need. The objectives of the paper are twofold,(1) to study the seasonal variations of mean surface- layer parameters and fluxes, 2) to estimate the variation of surface boundary layer fluxes for different conditions of atmosphere at VBIT under the framework of Monin –Obukhov (MO) similarity theory using surface –layer data below 10-m level.Mini Boundary Layer Mast (MBLM) centre was set up by the Indian Space Research Organisation (ISRO) at VBIT for atmospheric surface layer study. The system uses advanced high resolution sensors to measure ambient temperature, relative humidity and wind vector at three different levels at 4.0 m, 8.0 m and 14.9 m. MBLM data of two years 2013 and 2014 have been collected for the present study for the estimation of surface boundary layer characteristics over a flat terrain at VBIT, Hyderabad.

Surface layer responds differently during convective and non-convective period weather conditions. An attempt is made in this study to examine the contrasting variations in the mean surface layer structure and in surface fluxes between convective and non-convective periods. Micrometeorological measurements made during the southwest monsoon seasons in the years 2013 and 2014 from the instrumentation network established during the PROWNAM programme (Prediction of Regional Weather using Observational meso-Network and Atmospheric Modelling) are used for the present project. Data have been analyzed for Hyderabad location (Mini Boundary Layer Mast at VBIT,Hyderabad), and near surface boundary layer characteristics are investigated through the vertical variation of heat and momentum fluxes during the convective and non-convective periods of the years 2013 and 2014. The convective and non-convective periods are identified based on OLR (Outgoing Long wave radiation) from satellite data. If the value is > 200 it is non convective and < 200 convective periods respectively with reference to OLR data. Different surface layer fluxes are computed using a gradient approach at different logarithmic heights. They are observed to vary significantly between convective and non-convective periods. The heat and momentum fluxes showed a maximum peak during convective period.

All the data is collected at one second resolution and averaged for every hour for calculating surface fluxes.The turbulent fluxes (Panofsky and Dutton, 1984) of momentum, heat and moisture can be expressed using an analogy to molecular diffusion as:

$$\tau = K_m \, \rho \, (\partial \bar{u}/\partial z) \qquad (1)$$

$$H = - K_h \, \rho \, C_P \, (\partial \bar{\Theta}/\partial z) \qquad (2)$$

$$E = - K_q \, \rho \, C_P (\partial \bar{q}/\partial z) \qquad (3)$$

where τ, H and E are the flux of momentum, heat and moisture, respectively; K_m, K_h, K_q are the exchange coefficients of momentum, heat and moisture fluxes, respectively; and $\bar{u}$, $\bar{\Theta}$, $\bar{q}$ are the means of wind velocity, potential temperature and specific humidity, respectively. C_P is the specific heat of air at constant pressure and ρ is the density of air. The fluxes are approximately constant with height in the surface layer (Businger et al., 1971; Deardorff, 1974). The interaction between the low level shear and the gust front is vital for the maintenance of erect updrafts in long-lived convective systems (Rotunno et al., 1988). The friction velocity u* represents the velocity scale. The vertical change in the mean wind can be represented by u* as

$$(\partial \bar{u}/\partial z) = u*/ k z \qquad (4)$$

where k is the von Karman constant.

Integration of Eq. (4) from z = z_o to a height z gives the logarithmic profile of wind:

$u = (u*/ k) \ln (z/z_o)$ (5)

The fluxes can be computed using flux-profile relationships (Eqs. [1]-[3]) from gradient theory near the ground (i.e. < 10 m). It can be assumed that, close to the ground, $K_m = K_h = K_q$

Sutton, 1953). If the profiles are approximately logarithmic then the fluxes of momentum, heat and moisture take the form

$$(\tau/ \rho) = [k/\ln(z2 / z1)]^2(\bar{u}_2 - \bar{u}_1)^2 \qquad (6)$$

$$(H/ \rho) = [k/\ln(z2 / z1)]^2(\bar{u}_2 - \bar{u}_1)(\bar{\Theta}_2 - \bar{\Theta}_1) \qquad (7)$$

$$(E/ \rho) = [k/\ln(z2 / z1)]^2(\bar{u}_2 - \bar{u}_1)(\bar{q}_2 - \bar{q}_1) \qquad (8)$$

The surface boundary layer fluxes are computed using Eqs. (6), (7) and (8).

The estimates of the above parameters and their variability using MBLM data for convective and non-convective periods during the summer monsoon season are the main objectives this work. The transport of energy and momentum through the Atmospheric Boundary Layer (ABL) links the free atmosphere and the earth's surface and hence determines to a large extent the energetics of the atmosphere. Hence the estimates of the above parameters and their variability with different weather conditions using MBLM data of this study will partly fulfill this purpose. And also this study will be useful for understanding the local climate and modeling of the turbulent exchange in tropical regional scale numerical models.

II. Instrumentation and Data collection

A network of mini Boundary Layer Mast (15 m high, MBLM-NET) has been established over the Indian land region with the objective to accurately represent surface layer parameters for varying land surface and terrain patterns under PRWONAM project. MBLMs are installed at 29 different locations by covering various categories of region/ terrain/ land surface patterns. Measurements of reach MBLM comprise of wind. Temperature, relative humidity from slow sensors mounted on MBLM at three levels, rain fall, surface pressure, surface radiative fluxes, soil moisture at six depths and soil temperatures at seven depths. This network of MBLMs provide accurate representation of surface layer parameters, the scaling laws and the eddy fluxes of momentum, sensible and latent heat in mesoscale models(Mohan and Bhati, 2010) for a variety of land surface patterns which is still an important issue in spite of several parameterization schemes put forth in the recent past (Hong and Pan, 1996, Noh et al., 2003; Pleim J.E.,2007,). These measurements are used to study the observed behavior of the surface layer parameters, namely, the roughness lengths, the drag coefficient, the exchange coefficients of heat and humidity, the universal scaling laws, etc., at a few locations over the Indian land region representation of varying land surface patterns and terrain instrumented MBLMs have been installed at 29 locations across India. One of these MBLMS installed at VBIT (Inhomogeneous flat terrain), Hyderabad on 9th April 2011.

MBLM Equipment:

The MBLM is a 15 m high, guyed, uniform triangular lattice structure designed to withstand wind speed of 60 m s^{-1}. The booms on MBLM are fitted at 4 m, 8 m and 15 m heights above the ground. The slow wind sensors were mounted on the vertical mount points provided in the booms at three heights above the ground (4 m, 8 m, and 15 m) for measurements of wind speed and wind direction. The slow temperature sensors were fixed using clamps adjacent to the tower for air temperature and relative humidity measurements. In addition, the pressure sensor, the rain gauge, the Incoming Short Wave (SW) and the Incoming Long Wave (LW) radiation sensors were installed on the ground. Subsurface sensors were installed for soil moisture and soil temperature measurements.(refer Table-1)

Table 1: Description of MBLM Sensors.

SL.No.	Parameter	Make & Model No. of the Sensor	ACCURACY	Sensor Installation heights above the ground	Sensor basic output parameters and Sensors range
1.	Wind Speed and Wind Direction	RM Young 05305	Wind Speed: ± 0.2 ms^{-1} Wind direction $\pm 3^0$	4 m, 8 m, 15 m	Wind speed: 0-100 m/s Wind direction: 360^0 mechanical 355^0 electrical
2	Air temperature/ Relative Humidity	Rotoronics MP100H, HygroClip	Temperature: $\pm 0.1^0$c Relative Humidity$\pm 1\%$	4 m, 8 m, 15 m	Air temperature: -40^0c to $+60^0$c Relative Humidity 0 to 100%
3	Atmospheric Pressure	Komoline KDS-021/ISRO Pressure Sensor	Atmospeheric Pressure: ± 0.2hPa	1 m,	Atmospeheric Pressure 600 to 1100 hPa
4	Long Wave Radiation	Kipp & Zonen CGR 3	Long wave Radiation± 10 W m^{-2}	2.5 m	Downward Atmospheric Long wave radiation:-250 to +250 W m^{-2} (Net Irradiance)
5	Short Wave Radiation	Kipp & Zonen CMP 3	Solar Radiation: ± 10 W m^{-2}	2.5 m	Global Solar radation: 0 to 200 W m^{-2}
6	Rain Guage	RM Young 52203	0.5 mm upto 25mm/hr 1.5 mm up to 50mm/hr	1 m	Rain Catchment Area: 200 cm^2 Resolution :0.1 mm
7	Soil moisture profiler	Delta-T Devices Ltd. PR2/6 profiler with the Augering and extraction kit	± 0.04 m^3/m^3	0 cm, -10cm,-20 cm, -40 cm, -60 cm,-100cm	Soil moisture at six level depths(m^3/m$^{3)}$ Range : 0 to 1 m^3/m^3 Resolution : 0.01 m^3/m^3
8	Soil Temperature Probe	Komoline KDS-031	0.1^0c	+5 cm,0cm,-5 cm, -10 cm, 20 cm,-40cm, 100 cm	Soil Temperature at seven levels (^{0}c) Range: -40 to 55 ^{0}c Resolution:0.01^0c

III. Description of the data:

In the present study, the micrometeorological measurements from MBLM VBIT, Hyderabad are used to analyze the variations of different surface layer parameters(air temperature, relative humidity, wind speed and pressure) between convective and non-convective periods for monsoon season, using two years data (2013 and 2014). The convective and non-convective periods are identified based on the values of Outgoing Long wave radiation (OLR). If the value of OLRis > 200 it is considered as non convective and < 200 as convective period. The number of days in convective and non-convective periods is 38 and 58 respectively during Jun- Sep 2013. The numbers of days are 36 and 67(each day with 24 data points on an hourly basis for all above mentioned parameters) for convective and non convective periods during Jun- Sep 2014 as shown in figure1 and 2 respectively. From both the figures it is clear that the number of days in the month of July is mostly convective for both the years when compared to other months due to precipitation.
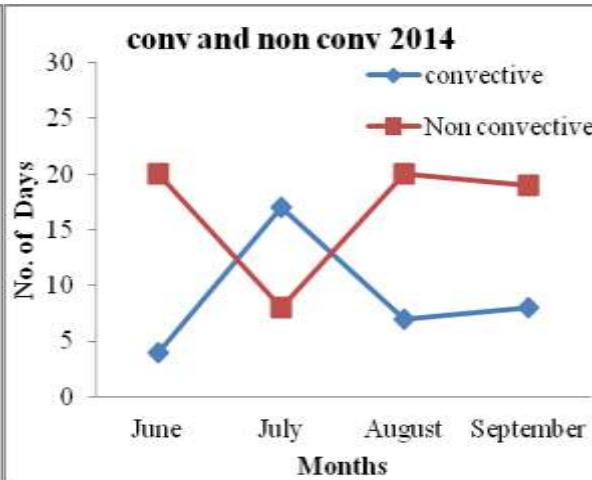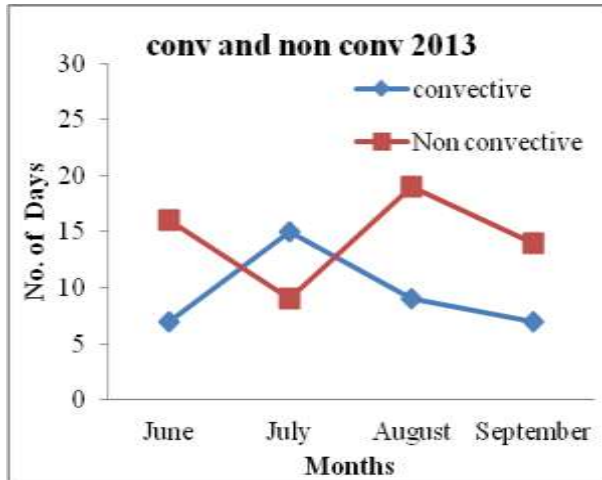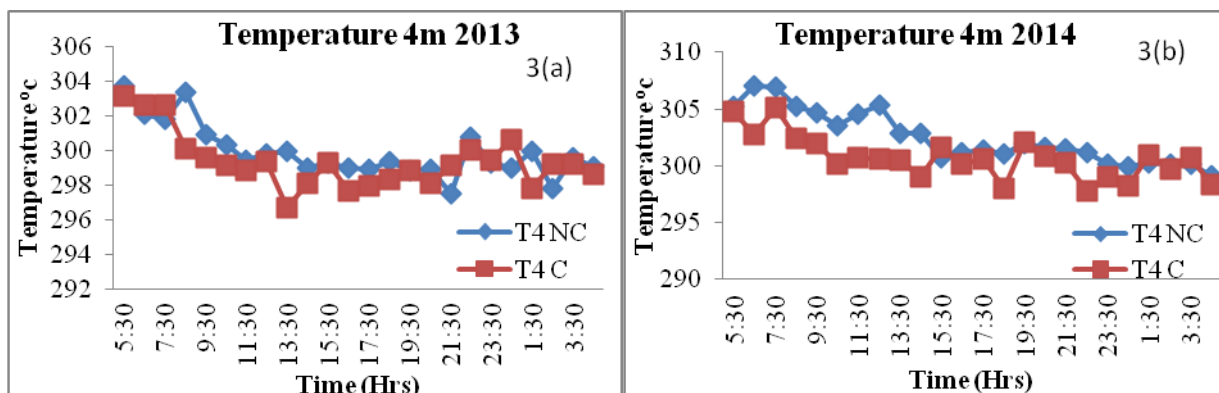

Figure1: Number of days in convective and non-convective periods during (June-Sep) 2013.   **Figure2: Number of days in convective and non-convective periods during (June-Sep) 2014.**
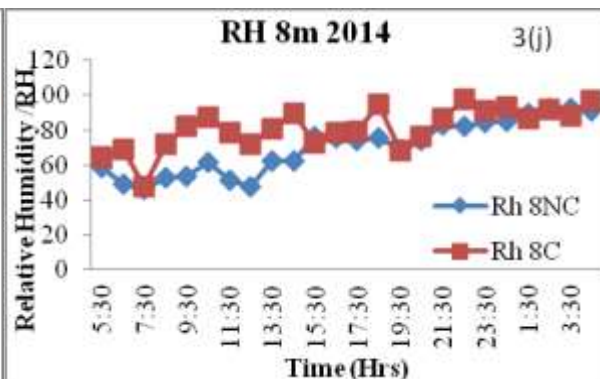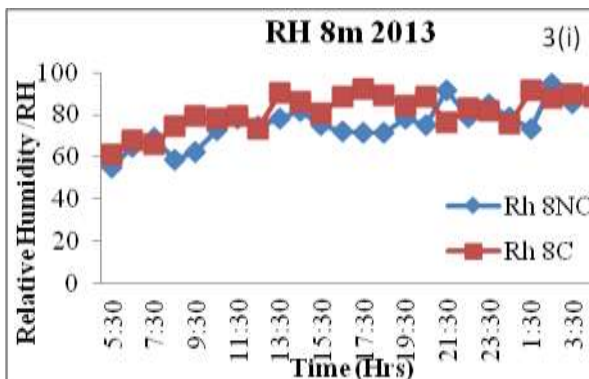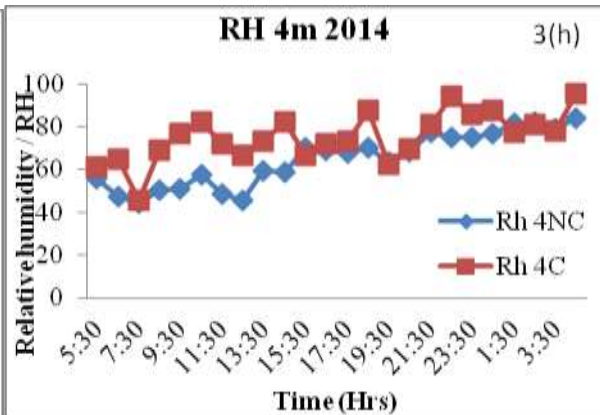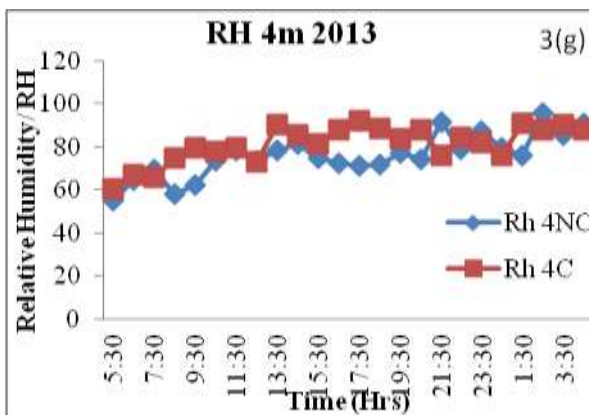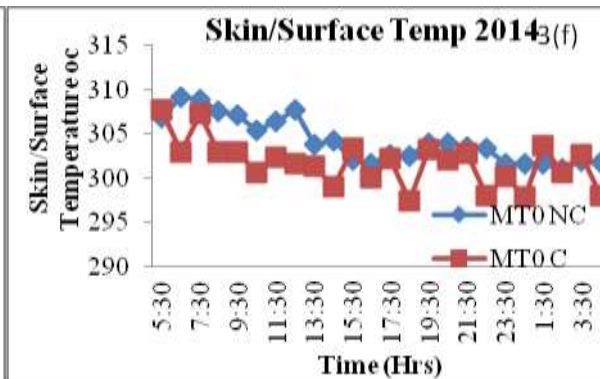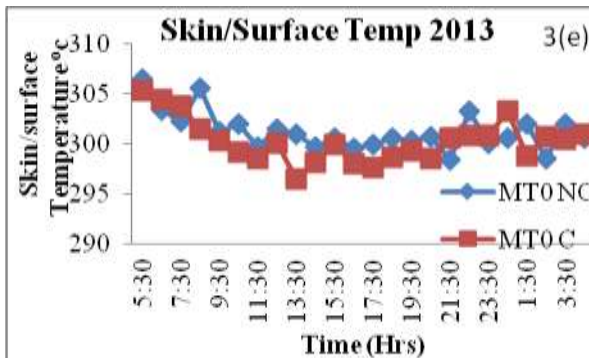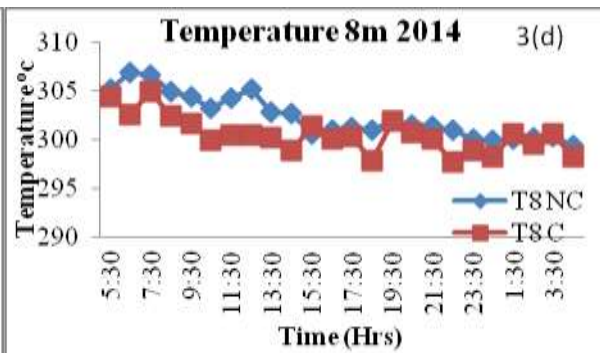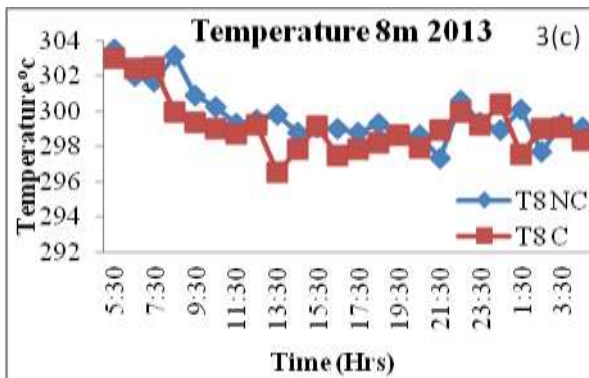
IV. Results and Discussion

Surface layer parameters during convective and non-convective periods:

Figure 3(a,c,e,g,i,k,m,o) and 3(b,d,f,h,j,l,n,p) show the different surface layer parameter during convective and non-convective periods from (June-Sep) 2013 and 2014 respectively. The surface parameters like air temperature, relative humidity, wind speed and pressure during the convective and non- convective periods showed some significant variations for monsoon season from (June-Sep) 2013 and 2014.

Temperature 8m 2013   3(c)

Temperature 8m 2014   3(d)

Skin/Surface Temp 2013   3(e)

Skin/Surface Temp 2014 3(f)

RH 4m 2013   3(g)

RH 4m 2014   3(h)

RH 8m 2013   3(i)

RH 8m 2014   3(j)
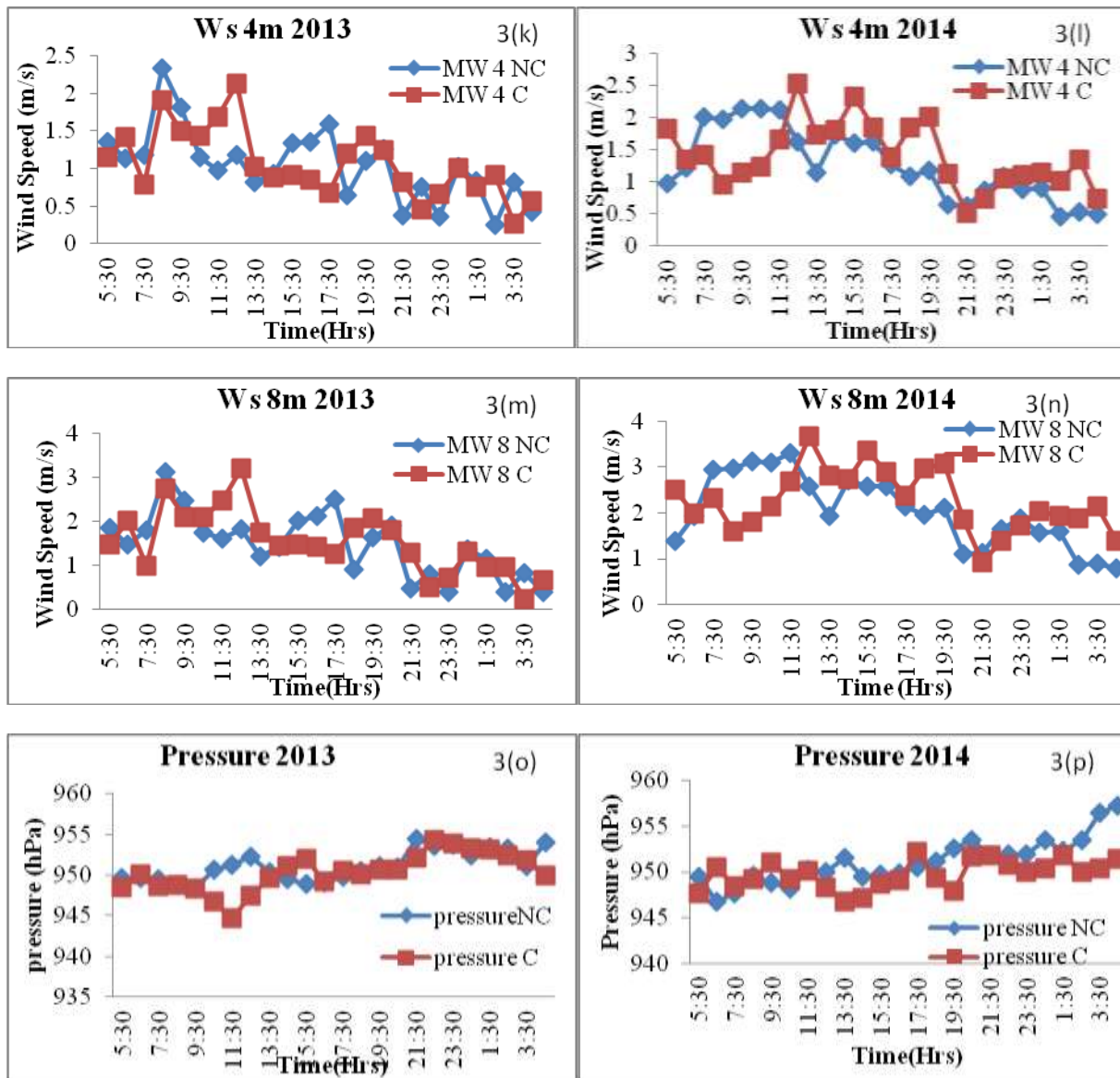
Figure 3: (a-f) temperature, (g-j) relative humidity, (k-n) wind speed, (o-p) pressure for the non convective and convective periods during the monsoon season of 2013 and 2014.

a) Air temperature

- **(i)** The variations of air temperature for different heights i.e. at 4m, 8m and surface/skin was either negligible or was very small during the convective and non- convective periods from (June-Sep) 2013 and 2014 as shown in figure 3(a-f) respectively.
- **(ii)** The air temperature showed a minimum value around 297°c and a maximum value around 306°c during non-convective and convective periods for 2013 and there is a slight increase in air temperature i.e. varying between 297 °c and 309 °c in 2014 during non-convective and convective periods due to heat wave. These results are showing similar trends as studied by (Reddy, N.N., and Rao, K.G., 2017; Rao, K.G., and Reddy, N.N., 2018).

b) Relative Humidity

(i)   The relative humidity is inversely proportional to air temperature. The relative humidity is in range of 54-95% and 60-92% for 4m height during non-convective and convective periods for 2013 and there is a slight difference in relative humidity for 2014 for the same periods varying from 44-84% and 45-95% respectively. The relative humidity in 2014 is less when compared to 2013 as the air temperature is higher as shown in figure 3(g-h)

(ii) The relative humidity for 8m height during non-convective and convective periods for 2013 are 55-94% and 60-92% respectively and there is a slight decrease in relative humidity i.e. 46-92% and 47-99% respectively for 2014. The relative humidity in 2014 is less when compared to 2013 as the air temperature is higher as shown in figure 3(i-j).

c) Wind Speed

(i)   The wind speeds at 4m height are more during morning showing a maximum value 2.3 m/sec around 08:30 and 2.1m/sec around 12:30 and a minimum value of 0.2m/sec at midnight during non-convective and convective periods for 2013.The wind speeds for 2014 show slightly different trend when compared to 2013 where the wind speeds are more during morning for non- convective periods and shows a maximum value of 2.1m/sec around 09:30 whereas for the convective period the wind speed attains a maximum value of 2.5m/sec around 12:30. The wind speeds decreases during night and attains a minimum value of 0.5m/sec for convective period and the increases slightly and for non convective period a minimum value of 0.4m/sec is attained around midnight at 02:30 for both convective and non-convective periods as shown in figures 3(k-l).

(ii) Wind speeds are more at 8m height when compared to 4m height. The wind speeds at 8m height are more during morning showing a maximum value 3.1 m/sec around 08:30 and around 12:30 for non-convective and convective periods and a minimum value of 0.3m/sec and 0.2m/sec at midnight during non- convective and convective periods for 2013. On the other side wind speeds for 2014 show slightly different trend when compared to 2013 where the wind speeds are more during morning for non- convective periods and shows a maximum value of 3.2m/sec around 11:30 whereas for the convective period the wind speed attains a maximum value of 3.6m/sec around 12:30. The wind speeds decreases during night and attains a minimum value of 0.9m/sec for convective period and the increases slightly and for non-convective periods the wind speed attains a minimum value of 0.8m/sec around 04:30 as shown in figures 3(m-n). Similar trends are seen as studied by (Reddy, N.N., and Rao, K.G., 2017; Rao, K.G., and Reddy, N.N., 2018).

d) Surface Pressure

The surface pressure variations are in the range of 948.2-954.4 hPa and 944.7-954.3 hPa for non-convective and convective periods for 2013 and for 2014 the surface pressure variations are 946.7-957.3hPa and 946.7-952.1 hPa respectively as shown in figure3(o-p). The surface pressure variations in 2013 shows the convective period shows an increase trend from 10:30 – 12:30 and during the same time pressure shows a decrease trend. In 2014 after 11:30 the surface pressure shows an increasing trend.
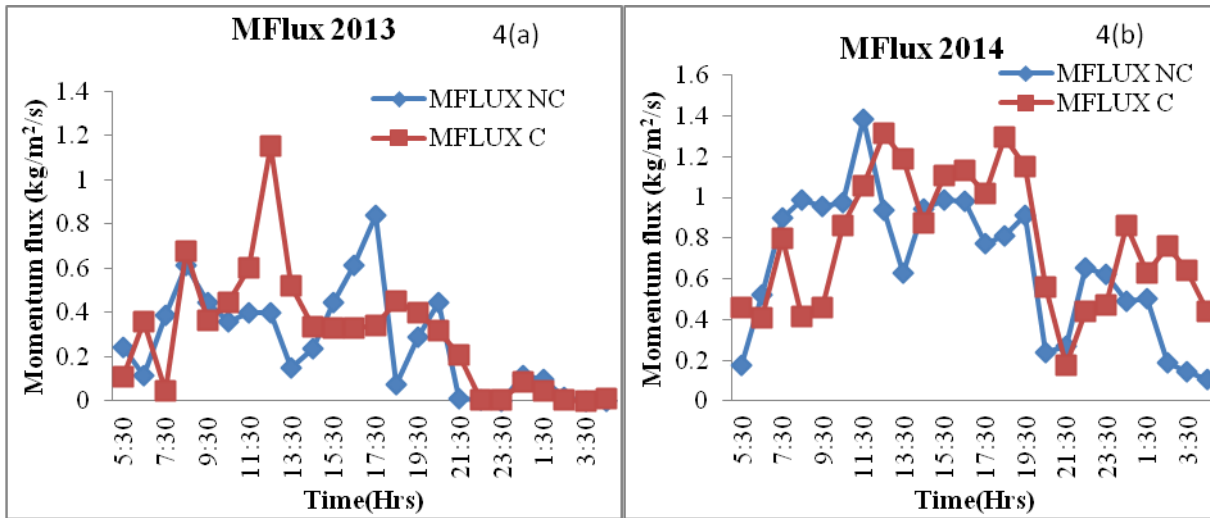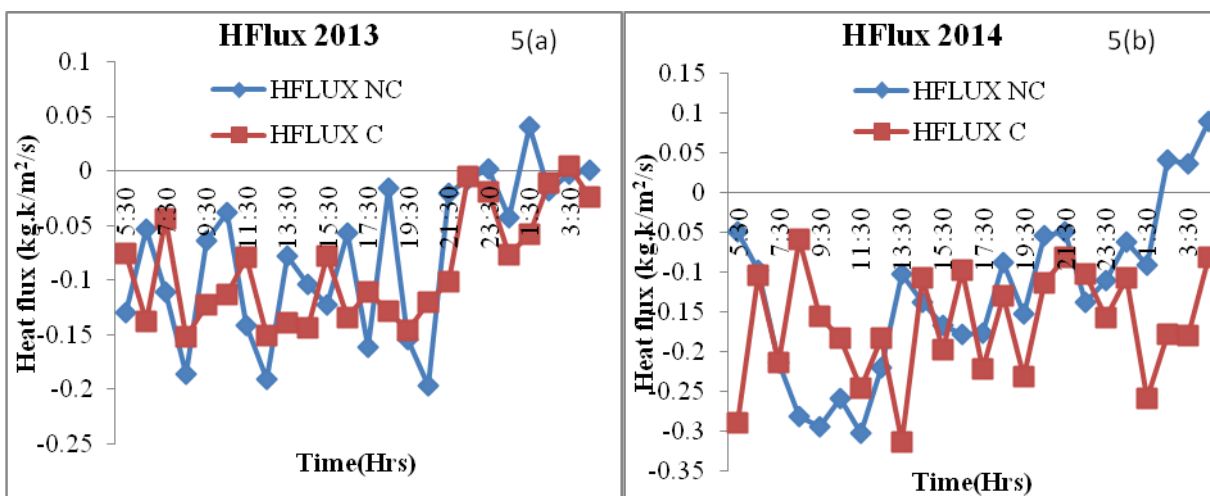
Figure 4: (a-b) Momentum Flux for the non convective and convective periods during the monsoon season of 2013 and 2014.

e) Momentum Flux

The momentum flux shows a minimum value of 0.0001(kg/m^2/s) during midnight around 03:30 for both non-convective and convective periods to maximum value of 0.83(kg/m^2/s) at 17:30 and 1.15 (kg/m^2/s) at 12:30 for 2013 during non-convective and convective periods and for 2014 the momentum flux shows some different results when compared to 2013 shows a minimum value of 0.1(kg/m^2/s) at 04:30 and 21:30 and where as the maximum value is 1.38(kg/m^2/s) at 11:30 and 1.31(kg/m^2/s) at 12:30 respectively for both non-convective and convective periods. The momentum flux variations show high during convective period and during the same period it shows low for non-convective periods and vice versa from 11:30-21:30 for 2013 as shown in figure 4(a). The momentum flux shows similar trend for both convective and non-convective periods during 2014 except for midnight and early mornings where the momentum flux is more for convective periods due to more wind speeds and less during non-convective period as shown in figure 4(b). Similar study was conducted by (Chaudhuri S., and A. Middey 2013) at Kharagpur and Ranchi during (2007 and 2009) and by (Reddy, N.N., and Rao, K.G., 2017) at Bangalore during (2009 and 2010).

Figure 5: (a-b) Heat Flux for the non convective and convective periods during the monsoon season of 2013 and 2014.

f) Heat Flux

The heat flux shows a minimum value of -0.19(kg.k/m^2/s) at night 20:30 and -0.15(kg.k/m^2/s) at 08:30 in the morning and a maximum value of 0.040(kg.k/m^2/s) at midnight 01:30 and 0.0036(kg.k/m^2/s) at midnight 03:30 respectively for both non-convective and convective periods during 2013. In 2014 heat flux showed a minimum value of -0.30 (kg.k/m^2/s) at 11:30 and -0.31(kg.k/m^2/s) at 13:30 and a maximum value of 0.088(kg.k/m^2/s) during early morning at 04:30 and -0.059(kg.k/m^2/s) during morning at 08:30 respectively for both non-convective and convective periods. In 2013 heat flux is almost negative except for a small time during midnight around 01:30 and most of the time when heat flux is more during non-convective period it is low in convective period as shown in figure 5(a). In 2014 the heat flux showed maxima during midnight and early morning for non-convective period. Most of time heat flux showed similar trends for both periods except for early morning where the heat flux was more during non-convective period. Whereas heat flux showed minimum value for non-convective in the morning 09:30-11:30 during the same time heat flux showed maxima for convective period as shown in figure 5(b). Similar study was conducted by (Chaudhuri S., and A. Middey 2013) at Kharagpur and Ranchi during (2007 and 2009) and by (Reddy, N.N., and Rao, K.G., 2017) at Bangalore during (2009 and 2010).

V. Conclusion:

Micrometeorological measurements made during the summer monsoon seasons in the year's 2013 and 2014 from the instrumentation network established during the PRWONAM program (Rao K.G., 2008a, 2008b; Rao K.G., et al., 2011a, 2011b) have been analyzed and mean surface layer structure and surface fluxes are estimated during convective and non convective periods for Hyderabad location. The convective and non-convective periods are identified based on OLR (Outgoing Long wave radiation) from satellite data. If the value is > 200 it is non convective and < 200 convective periods respectively with reference to OLR data. Surface layer fluxes are observed to vary significantly between convective and non-convective periods.

VI. Acknowledgement :

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