CHAPTER 5

CHARACTERISTICS OF INTERNAL BOUNDARY LAYER (IBL) OVER AN INDIAN WEST COAST AND EAST COAST SITES

5.1 INTRODUCTION

The turbulence characteristics of wind components and temperature in the atmospheric surface layer over different terrains have been presented and discussed in the previous chapter. In this chapter, profiles of wind, temperature and humidity and surface energy fluxes over a tropical west coast station, Vasco-da-Gama, Goa and east coast station, Anupuram (12°30’N, 80°10’E) have been examined to understand the characteristics of internal boundary layer.

The station Goa has the characteristics of coastal atmospheric boundary layer, inherently heterogeneous, dominated by variations in topography, large temperature gradients and changes in roughness etc. The coastal ocean is characterized by large variations in SST and roughness and a non-equilibrium sea state. These conditions produce interactions between sea-breezes and meso-scale eddies and the terrain-generated winds cause complex flow patterns (Stull, 1988). The station Anupuram is also having the characteristics of coastal atmospheric boundary layer with homogenous terrain surrounded by small bushes near the experimental site. The topography of the experimental site along with tower instrumentation at Vasco-da-gamma is shown in Figure 2.2 of Chapter 2. The NCAOR buildings are situated to the north of the micro-meteorological tower about 100-150 m away. During monsoon season grass (~ 1 m tall) grew over the terrain on the northwest-northeast sector of the experimental site. During the ARMEX (Phase-I) experimental campaign period, the prevailing winds were south-westerly to westerly at Goa. The Arabian Sea is located in the south-west sector relative to the tower. Thus the experimental site has a large fetch (open sea) in the upwind southwest direction. There is a step change in surface roughness and surface temperature for the wind from the sea to the land. Hence, internal boundary layer (IBL) is expected to develop at the boundary between land and sea with its depth increasing inland.

During the period of the above field campaign, the ambient monsoon flow enhances the local thermally driven sea breeze circulation. The foot print of the
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measurement on the tower signifies mostly the maritime air. When IBL develops near the coast, some sensors on the meteorological tower would be in IBL. Thus, the measurements near surface will reflect the effect of the local surface whereas those above the IBL will represent the marine air characteristics. Large-scale monsoon flow, if strong enough, may prevail over the geographically generated circulations like IBL due to small-scale irregularities at the surface.

5.2 DATA AND METHODOLOGY

The data sets collected during ARMEX Phase I and II campaigns in the year 2002-03 were selected to examine the profiles of wind, temperature and humidity in the atmospheric surface layer in order to understand the temporal variation of these meteorological parameters and the surface fluxes near the coast. Profiles of 30 minute mean of wind, temperature and humidity were used to study the characteristics of IBL and thermodynamic structure of the lower troposphere very close to the sea coast and were also used to estimate sensible heat flux. Turbulence observations (10 Hz sampling) by sonic anemometer and hygrometer at 5 m AGL over Goa were used to estimate half-hourly surface fluxes of momentum, sensible heat, latent heat, water vapour and CO₂. At the east coast experimental station Anupuram, observations on wind speed, direction, air temperature, relative humidity, potential temperature and mixing ratio were collected from tethersonde (Kytoon) and were used to study the signatures of thermal internal boundary layer prior to, during and after the onset of sea breeze during July 2001 (SW monsoon) and December 2001 (NE monsoon).

5.3 SYNOPTIC CONDITIONS

During the period of ARMEX Phase I and II over Goa, the offshore trough off the west coast of India was observed on a number of occasions during both strong and weak monsoon conditions. Weather over the Arabian Sea and the region around Goa during July 2002 was characterized by scattered low/medium clouds over the sea, particularly close to the coast. Monsoon conditions over sea continued to be weak/moderate in July 2002 and hence no pronounced convective activity was observed in the eastern region of the Arabian Sea. The outgoing long-wave radiation (OLR) over the study area shows relatively high values of about 250 W/m² suggesting suppressed convection and near the coast it decreased to 240 - 230 W/m² during July 2002. A weak trough over the sea off Kerala coast was noticed with light to moderate
rainfall during this period along the west coast of India. In the month of July, the wind anomaly at 850 hPa revealed the absence of monsoon trough line over the Indo-Gangetic plains, weak low level Somali jet and weaker south-east trades in the southern Indian Ocean west of 70° E (Mohanty et al., 2002). In general, monsoon circulation (thermal and moisture) features showed weak monsoon regime during July 2002 (Mohanty et al., 2002). During the period of March to April 2003 which was primarily meant for observing the formation and development of warm pool over south west Arabian Sea as per the objectives of ARMEX campaign, synoptically there was no significant weather system. Mainly dry weather prevailed over the experimental station during April 2003. Over the east coast the dry weather prevailed during the month of July 2001. During the month of December 2001 a low pressure system persisted along east coast with rainfall activity, whereas the station Anupuram experienced cloudy condition along with light rain in this month.

5.4 RESULTS

5.4.1 Characteristics of IBL at a coastal site

The layer of air whose properties have been affected by the change in surface properties is referred to as IBL. Discontinuities in wind profile or wind-profile ‘kinks’ indicate top of the IBL (Garratt, 1990). Within the IBL there exists an equilibrium layer, defined in terms of 90% level of adjustment in the stress (or other vertical flux in non-neutral case).

The IBL depth (only roughness change) is parameterized as a power of the fetch (Panofsky et al., 1982; Smedman-Hogstrom and Hogstrom, 1978; Rao et al., 1974) given as:

$$\frac{\delta}{z_{o1}} = a \left[ \frac{x}{z_{o1}} \right]^b$$

(5.1)

where $z_{o1}$ is the aerodynamic roughness length upwind of the border and $x$ is the fetch. The power, $b$ is equal to about 0.8 for statically neutral, slightly smaller (0.6 to 0.7) in stable and larger (0.8 to 1.0) for unstable conditions. Parameter $a_{IBL}$ is in the range of 0.2 to 0.8, being large for unstable conditions and small for stable ones. ‘$a$’ is parameterized as a function of roughness. At greater distances, deeper layers feel the increased roughness. Above the top of IBL, i.e., above the kink in the wind profile, the wind maintains a profile characteristic of the upwind roughness (Beljaars, 1987).
In convective conditions in the coastal region, Thermal IBL (TIBL) top is readily identified where potential temperature profile has a discontinuity (Raynor et al., 1975) or at the top of a well-mixed layer (Venkatram, 1977). Raynor et al. (1975; 1979) observed that the heights of TIBL (h) were found to agree with an empirical model derived from physical and dimensional reasoning. Hsu (1986) found several sets of data satisfying $h = 1.9 \times x^{1/2}$, with $h$ and $x$ in meters. For stable conditions, covering a fetch range from 5 to 500 km, Hsu (1986) arrived at a value of $h = 0.57 \times x^{1/2}$. Thus, $h$ increases with greater land roughness and greater temperature difference and decreases with greater stability above the IBL for a given fetch $x$.

5.4.2 Profiles of wind, temperature and humidity in the surface layer over Goa

Profiles of mean wind, temperature and humidity in the atmospheric surface layer have been used to study the characteristics of IBL very close to the sea coast at Vasco-da-Gama, Goa. It is observed that most of the time winds are about 5 – 6 ms$^{-1}$. The profiles of the horizontal wind and temperature observed at 1, 2 and 8 m for low (< 2 ms$^{-1}$), moderate (5-6 ms$^{-1}$) and high (> 11 ms$^{-1}$) wind speeds on 01-03, 05, 07-09 and 12 July 2002 are presented in Figure 5.1a, 5.1b and 5.1c respectively. For low and moderate wind speeds, a kink is observed in the wind profile between 2 and 8 m height. For high winds, this kink in the wind profile has gradually disappeared and the profile has become log-linear as observed over a homogeneous terrain. This kink in the wind profiles may possibly be due to change of surface roughness from smooth to rough and the development of internal boundary layer as wind blows from the sea to the land. The IBL height can be determined using equation 5.1. The wind profile below the kink represents local surface roughness where as that above it has characteristic of upstream surface (sea). The profile for $U_8 > 11$ ms$^{-1}$ shows a linear increase in wind speed with $z$, indicating the roughness length of 0.003 m over sea as the kink due to IBL is absent (Figure 5.2). Substituting $z_o=0.003$ m, $b=0.8$ and $a=0.8$ (unstable), the IBL height ($\delta$ ), from equation 5.1, is 3.8 m for $x=30$ m. Thus, the kinks in the wind profiles for low and moderate wind speeds indicate that the 1 and 2 m measurement levels on the tower lie within IBL and the 8 m one above the IBL. But for high wind speeds (> 11 ms$^{-1}$), the IBL is not clearly observed. The reason could be due to prevailing condition of monsoon flow which influences small-scale irregularities like roughness and temperature change at the surface.
In reality there is land-sea temperature contrast at the site. So TIBL develops over the land as monsoon wind blows across the coast. Theory of IBL/TIBL was developed for moderate winds in the absence of synoptic flow. Observed temperature profiles showed inversion above 2 m (Fig. 5.1). Hence very close to the boundary (a few meters) wind and temperature profiles showed kinks at the same heights, 2 m. Similar to wind profiles, temperature profiles also showed the characteristics of homogeneous terrain (absence of inversions in the profile for unstable conditions) for high wind (> 11 ms\(^{-1}\)) conditions (Fig. 5.1). However, relative humidity profiles have not shown the tendency to smooth out kinks at high wind speed conditions (not shown). Kinks in the relative humidity (RH) profiles existed for low, moderate and high wind conditions. One cannot rely much on RH profiles, as the inherent accuracy of RH sensor is at most 5%. In this case, under high humid conditions (RH 90-100 %) and with measurement levels very close to surface, the small gradients in RH values are insignificant.
Figure 5.1. Profiles of wind and temperature on the west coast at Vasco-da-Gama, Goa.
5.4.3 Vertical structure of wind, temperature and humidity over west coast (Goa)

The vertical structure of the wind speed, direction, air temperature and relative humidity in the boundary layer at 1200 hrs GMT over the west coast was analyzed using radiosonde data over Goa during weak Phase (01-05 August 2002) of monsoon. Figure 5.3 shows the vertical profiles of different parameters as obtained from radiosonde soundings. The vertical profiles of wind speed and wind direction for 02 August 2002 are shown in Figures 5.3c and 5.3d. Similarly profiles of speed and direction measured on 05 August 2002 are shown in Figures 5.4c and 5.4d. The vertical profiles of wind speed and direction over Goa showed similarity in the upper levels, whereas in the planetary boundary layer (PBL \( \approx 2 \) km), winds were observed...
in WSW-WNW sectors. Wind speed and direction were between SW-NW sectors in 2-7 km range above the boundary layer. Weakening of winds and significant fluctuations in RH in the range 40 – 90 % in the layer 2-5 km AGL indicates possible existence of clouds.

Table 5.1 Mixed layer height over Goa

<table>
<thead>
<tr>
<th>Date</th>
<th>Mixed layer height(m)</th>
</tr>
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<tbody>
<tr>
<td>01.08.02</td>
<td>1050</td>
</tr>
<tr>
<td>02.08.02</td>
<td>800</td>
</tr>
<tr>
<td>03.08.02</td>
<td>1100</td>
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<tr>
<td>04.08.02</td>
<td>1500</td>
</tr>
<tr>
<td>05.08.02</td>
<td>1600</td>
</tr>
</tbody>
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Table 5.1 shows the mixed layer heights over Goa during the period 01-05 August 2002. The mixed layer depth is determined by following non-local parcel movement method (Stull, 1988). It was observed that the depth of mixed layer over Goa was about 1 km during the period, while the first 200 m was showing super adiabatic lapse rate over Goa (Figure 5.4a). The depth of mixed layer was about 1050 m on 01 and 03 August 2002, 800 m on 02 August, 1500 m on 04 August 2002 and 1600 m on 05 August 2002. The vertical profiles of virtual potential temperature showed a stable layer above the mixed layer. However, the virtual potential temperature profiles on 02 August over Goa (Figure 5.3b) showed that the atmosphere was stable in the boundary layer.
Figure 5.3. Profiles of (a) air temperature, (b) virtual potential temperature, (c) wind speed, (d) direction and (e) relative humidity over Goa on 02 August 2002.
Figure 5.4. Profiles of (a) air temperature, (b) virtual potential temperature, (c) wind speed (d) direction and (e) relative humidity over Goa on 05 August 2002.

The RH in the mixed layer (0-1 km AGL) was in the range 70 % – 90 % for 02 and 05 August (Figures 5.3e and 5.4e). The dryness above 2 km layer is due to the advection.
of dry air from north and northwest India during the observation period as revealed by
the back trajectory analysis of NOAA HYSPLIT Model. There were significant
fluctuations in RH in the range 40 % – 90 % with a weak stable layer above 2 km
AGL.

5.4.4 **Vertical structure of wind, temperature and humidity over east coast**
*(Anupuram)*

The data collected from tethersonde (kytoon) system manufactured by Air Inc.,
USA at Anupuram (12°30′ N, 80°10′ E) station on the east coast during south-west and
north-east monsoon season of the year 2001 was used to study the vertical structure of
wind speed, direction, temperature, potential temperature, relative humidity and
mixing ratio in the atmospheric boundary layer. The station Anupuram is located 8
km away from the Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam
and 5.5 km away from Bay of Bengal coast to its east.

Profiles of the above parameters obtained from tethersonde system under
different stability condition such as neutral, unstable and stable conditions on 10
December 2001 at 0800 hrs, 1700 hrs, 1415 hrs and 2200 hrs IST during north-east
monsoon season over Anupuram are shown in Figure 5.5 to Figure 5.8 respectively.
The morning soundings depict strong temperature inversion of potential temperature
(0.01° km⁻¹) up to 200 m AGL (Figure 5.5c and Figure 5.5d). The temperature
inversion is associated with increasing wind speed (Figure 5.5a) and sudden change in
wind direction in the lower level from WNW to NNE (Figure 5.5b).

Relative humidity (RH) and mixing ratio decrease with increasing height up to
200 m under neutral conditions are seen from the Figures 5.5e and 5.5f. During
convective conditions, winds are steady and vary between 4 and 7 ms⁻¹ (Figure 5.6a).
Wind direction is mostly from the northeast (Figure 5.6b). The air temperature
decreases with increasing height (Figure 5.6c) while potential temperature remains
constant during convective conditions (Figure 5.6d). The increase in RH and decrease
in mixing ratio with increasing height was observed during these conditions (Figures
5.6e and 5.6f).
Figure 5.5. Profiles of (a) wind speed, (b) direction, (c) air temperature, (d) potential temperature, (e) relative humidity and (f) mixing ratio under neutral conditions at 0800 hrs on 10.12.2001 over east coast station, Anupuram.
Figure 5.6. Profiles of (a) wind speed, (b) direction, (c) air temperature, (d) potential temperature, (e) relative humidity and (f) mixing ratio under unstable conditions at 1415 hrs on 10.12.2001 over east coast station, Anupuram.
Figure 5.7. Profiles of (a) wind speed, (b) direction, (c) air temperature, (d) potential temperature, (e) relative humidity and (f) mixing ratio under neutral conditions at 1700 hrs on 10.12.2001 over east coast station, Anupuram.
**Figure 5.8.** Profiles of (a) wind speed, (b) direction, (c) air temperature, (d) potential temperature, (e) relative humidity and (f) mixing ratio under stable conditions at 2200 hrs on 10.12.2001 over east coast station, Anupuram.
The wind speed varies between 7 and 8 ms$^{-1}$ while the direction remains constant with height during neutral condition in the evening hours (Figures 5.7a and 5.7b). The increase in RH and decrease in mixing ratio with increasing height was observed in the evening hours (Figures 5.7e and 5.7f). The steady variation in wind speed and the direction change from NNW to NEN is observed during stable conditions (Figures 5.8a and 5.8b). It is noticed that the temperature inversion is seen in the lower level up to 150 m (Figure 5.8c). The RH and mixing ratio decrease with increasing height under stable conditions are seen from the profiles (Figures 5.8e and 5.8f). However, a single profile obtained from the tethersonde sounding on 10 July 2001 at 1430 IST during convective conditions over Anupuram shows evidence of onset of sea breeze and the thermal internal boundary layer formation (Figure 5.9). A large fluctuation in wind speed profiles was observed at this hour. Wind direction profile confirmed that the sea breeze has set in during the ascent marked by a sudden change in wind direction from west to south. Air temperature dropped by 2$^\circ$C and RH increased by 15% and mixing ratio increased by 5 gm/Kg. The TIBL height is about 200 m at 1145 hrs IST and very shallow at 1430 hrs over this east coast station.

Since the synoptic wind was already from the sea (often parallel to the coastline from NNE or NE) sea breeze could be identified only from a change in wind direction from NNE to E. The wind direction was mostly in the N-NE quadrant during the period. A few successful flights could be made before and after sea breeze on some days as could be seen from the profiles on 10 and 11 July 2001 over Anupuram. The wind direction shifted from 30$^\circ$ to 60$^\circ$ at around 1100 hrs IST on all these days indicating the sea breeze onset. This was in contrast to the SW monsoon period when about 180$^\circ$ change in direction could be seen. Figure 5.10 shows the potential temperature profiles before and after sea breeze onset. The TIBL height was found to be varying with time. The TIBL height is about 150 m. Another layer of inversion is seen at 300 m over the station. It could be identified as a sharp change in the gradient immediately after sea breeze onset but was difficult to identify at later hours. The height could be identified to be about 200 m after onset of sea breeze and became shallow in the afternoon hours.
Figure 5.9. Temperature profile from tethersonde at Anupuram on 10 July 2001 at 1000 hrs IST (the sea breeze onset was around 1100 hrs IST).

Figure 5.10. Temperature profile from tethersonde at Anupuram on 11 July 2001 at 1000 hrs IST (the sea breeze onset was around 1100 hrs IST).
5.4.5 *Sensible heat flux during Arabian Sea Monsoon Experiment (ARMEX) over Goa*

Surface energy fluxes play an important role in determining the temperature and moisture profiles in the ABL. The net solar energy received at the surface is partitioned into sensible and latent heat fluxes and transported vertically to higher levels in ABL by turbulence. The depth of turbulent mixing and lifting condensation level (LCL) depend mainly on sensible heat flux and evaporation at the surface respectively. Over coastal areas large gradients in air temperature due to land-sea contrast results in the formation of land and sea breezes. These local circulations change the weather on either side of the coast significantly over a few hundred kilometers.

Surface sensible heat flux (SHF) at Goa during the two Phases of ARMEX campaign (02-17 July 2002 and 14-18 April 2003) was computed by eddy correlation method using sonic anemometer data. Diurnal variation of SHF during the two periods is shown in Figure 5.11a and 5.11b respectively. During July 02-17, 2002 the monsoon in the Arabian Sea was weak/moderate and continuous sonic anemometer data were available. It was observed that peak SHF at 1400 hr IST during Phase-II (~300 Wm$^{-2}$) was 1.5 times of that during Phase-I (~200 Wm$^{-2}$). During night hours SHF in Phase-I became negative (~ -40 Wm$^{-2}$) where as it was 10 W m$^{-2}$ during Phase-II respectively. It indicates that the surface layer was either unstable or near neutral during Phase-II and not becoming stable even during night hours. This may be due to the negative temperature gradient between the ground and surface layer is maintained even after sunset due to cooler sea-breeze flowing across the shore over Goa.

Time series of SHF during the above two periods (Phase I and II) of ARMEX is shown in Figure 5.11c and 5.11d. During Phase I the temporal variation of SHF may be due to passing clouds in the monsoon flow over the coastal site during the period. SHF attained its diurnal peak between 1200-1400 hr IST during Phase I. Day-to-day variation in the magnitude of peak SHF during this period is due to variation in the intensity of monsoon activity at the observational site.
Figure 5.11a-b. Diurnal variation of sensible heat flux from sonic anemometer during (a) July 02-17, 2002 and (b) April 14-18, 2003 at Goa.
Figure 5.11c-d. Time series of sensible heat flux from sonic anemometer during (a) July 02-17, 2002 and (b) April 14-18, 2003 at Goa.

It is observed that the sudden drop in SHF on July 04-05 (Fig. 5.11c) and rise on July 06 is associated with rainfall (~ 25-40 mm) on July 15-16 and 2 mm rainfall on July 06. The period July 02-17 experienced continuous rainfall of ~ 10 mm daily which has resulted in relatively low SHF during this period. During April 14-18, 2003 (Phase II) SHF attained maximum value between 1100 – 1200 hr IST. Day-to-day variation in the maximum value of SHF was 250-350 Wm$^{-2}$ during Phase II as shown in Figure 5.11d.

Comparison of SHF estimated by eddy correlation method and simplified profile method for a day each i.e. on 13 July 2002 (Phase I) and on 03 April 2003.
Characteristics of Internal Boundary Layer (IBL) over an Indian west coast and east coast sites (Phase II) is shown in Figure 5.12 (a & b). Eddy correlation method is considered as the direct method that gives very accurate estimate of SHF over complex terrain since contribution from all frequencies (eddies of all sizes) is measured by a fast-response instrument like the sonic anemometer. Profile method uses vertical gradients of hourly/half-hourly mean parameters (wind and temperature) measured by cup anemometer which cannot measure high frequency variations and hence results in under-estimation of flux. Over a homogeneous terrain both the methods are supposed to agree well. SHF values (30 minute mean in Phase I and 60 minute mean in Phase II) by profile method was observed to be -50 to 100 Wm$^{-2}$ in Phase I (July 13, 2002) and 10 to 210 Wm$^{-2}$ in Phase II (April 03, 2003) of ARMEX. Over this terrain a difference of ~ 100 Wm$^{-2}$ was observed at 1300-1400 hr IST between the two methods (Figure 5.12b). Under very unstable (peak SHF) conditions in the surface layer, turbulence intensity being relatively high, the contribution from high frequencies (small eddies) to the SHF seems to be significant.

The slow response sensor cup anemometer may not be able to respond to these high frequencies which results in large under estimation of SHF by profile method during very unstable conditions around 1300-1400 hr IST. However, the diurnal variation of SHF by both the methods is similar. Here, hourly mean data at 1 and 2 m AGL were used in estimating SHF by simplified profile method.

In the profile method, the measurements from first two levels on the micrometeorological tower were used as they fall within the IBL. Thus, the difference in the estimates of SHF at all times by the two methods can be attributed to the effect due to the existence of IBL. Hence, the value of SHF within IBL and above IBL need not be the same. This could be one of the reasons for relatively large difference in the flux estimates by these two methods.
Figure 5.12. Diurnal variation of sensible heat flux at Goa by eddy correlation and profile methods.

5.5 DISCUSSION

Structure of vertical profiles of wind, temperature and humidity in the atmospheric surface layer over the west coast station, Goa has been presented. For low and moderate wind speeds, a kink is observed in the wind profile between 2 and 8 m height. For high winds, this kink in the wind profile has gradually disappeared and the profile has become log-linear as observed over a homogeneous terrain. Thus the kinks in the wind profiles for low and moderate wind speeds indicate that the measurements at 1 and 2 m levels of the micrometeorological tower lie within the IBL and those at 8 m level lie above the IBL.
The vertical profiles of wind speed and direction over Goa showed similarity in the upper levels whereas in the PBL (~ 2 km) over Goa, winds were observed in WSW-WNW sectors. Wind speed and direction were between SW-NW sectors in 2-7 km range above the boundary layer. Weakening of winds and significant fluctuations in RH in the range 40 – 90 % in the layer 2-5 km AGL indicated possible existence of clouds.

The vertical profiles of virtual potential temperature showed a stable layer above the mixed layer over Goa. The dryness above 2 km layer is due to the advection of dry air from north and northwest India during the period as revealed in the back trajectory analysis of NOAA HYSPLIT Model (not shown here).

Results on temporal variation in the fluxes of sensible and latent heat in the atmospheric surface layer over the west coast station during monsoon as well as summer season of the year 2002 and 2003. The surface SHF was observed to peak at 1400 hr IST during Phase-II (~300 Wm$^{-2}$) was 1.5 times of that during Phase-I (~200 Wm$^{-2}$). During night hours SHF in Phase-I became negative (~ - 40 Wm$^{-2}$) where as it was 10 W m$^{-2}$ during Phase-II respectively. It indicates that the surface layer was either unstable or near neutral during Phase-II and not becoming stable even during night hours. Time series in day-to-day variation of peak SHF during the period is due to variation in the intensity of monsoon activity at the observational site. The difference in the estimates of SHF at all times by both eddy correlation and profile methods can be attributed to the effect due to the existence of IBL over the west coast.

5.6 CONCLUSION

The data collected during ARMEX Phase I and II during the years 2002-03 at west coastal station, Goa and at the east coastal station, Anupuram in the year 2001 during southwest and northeast monsoon seasons have been used to study the internal boundary characteristics using profiles of wind, temperature, humidity and fluxes in the atmospheric boundary layer. The following conclusions are drawn from the study.

- There exists an internal boundary layer (IBL) extending up to about 4 m from the surface at Goa. Hence, the fluxes measured directly above this height at 5 m level on the tower shall represent coastal surface fluxes.

- The depth of mixed layer over Goa varied from 1050 m to 1600 m during 01, 03 and 05 August 2002.
• Significant fluctuations in RH (30 - 70%) and weak winds above 2.5 km over Goa were observed indicating relatively dry air at different levels which may be due the advection of dry air from north and northwest Indian region.

• The difference in the estimates of SHF at all times by the eddy correlation and profile methods can be attributed to the effect due to the existence of IBL.

• Morning stable layers, elevated inversions and multiple layers have been noticed from the temperature profiles over Anupuram.

• The height of the thermal internal boundary layer (TIBL) at Anupuram station determined from profile of potential temperature is about 100 m during the southwest monsoon and about 200 m during northeast monsoon.