CHAPTER - 3

ATMOSPHERIC BOUNDARY LAYER CHARACTERISTICS ASSOCIATED WITH ACTIVE AND WEAK PHASES OF MONSOON
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3.1 Introduction

Indian summer monsoon is associated with a large convective heat source on the ITCZ in the northern hemispheric tropics extending from the Arabian Sea to the West Pacific Ocean. A strong cross-equatorial Low Level Jet-stream (LLJ) with core around 850 hPa exists over the south Asia during the boreal summer monsoon season June to September. Analysing the wind data of five years collected by the radiosonde / radio-wind network of India, Joseph and Raman (1966) established the existence of a westerly LLJ over peninsular India with strong vertical and horizontal wind shears. This LLJ is seen over peninsular India on many days in the month of July with core at about 1.5 km above mean sea level with a core speeds in the range of 40-60 knots. Findlater (1969) found that the Asian summer monsoon LLJ has its origin in the south Indian Ocean north of the Mascarene high as an easterly current and it crosses the equator in a narrow longitudinal belt close to the east African coast as a southerly current with the speed exceeds 100 knots occasionally. It turns into a westerly current over the Arabian Sea and passes through India to the western Pacific Ocean. Findlater’s LLJ is a combination of the LLJs found by Bunker (1965) for the Arabian Sea and Joseph and Raman (1966) for peninsular India.

3.2 Active and weak cycles of southwest monsoon

A strong inter hemispheric Low Level Jetstream with peak wind speed at 850 hPa exists with large variability to bring the active and break cycles over Indian monsoon region during summer. This active and weak spells of monsoon are distinct events in the intraseasonal oscillation (Sikka and Gadgil, 1980) where eastwest oriented convective cloud band and the wind core at 850 hPa are found to move northwards/north-eastwards from the equatorial region at intervals of 30 to 50 days (Yasunari, 1979; 1981; Sikka and Gadgil, 1980; Krishnamurty and Subramanyam, 1982). The oscillation of the cloud band begins with the onset of southwest monsoon from the southern region of south Kerala and dissipates over the Himalayan region.
By the decay of this band, a fresh band is formed over the central Indian Ocean and repeats the same process. This formation and propagation of the cloud band and associated movement of the LLJ core are manifestations of the active and weak cycles of Indian Summer Monsoon Rainfall (ISMR). The normal date of onset of southwest monsoon is 1st June with a standard deviation of 8 days (Rao, 1976). Traditionally the term ‘break’ refer to very weak spells of rainfall over the Indian monsoon region, different scientist uses the same term to express the different features of the convection/circulation over different regions (Webster et al, 1998). Large intraseasonal fluctuations in the Indian monsoon rainfall between active and break spells have been known since over a century (Gadgil and Joseph, 2003). The number of active and break days in a monsoon season has significant influence on the annual rainfall and it make changes in the surface boundary layer parameters such as surface fluxes, momentum transfer, energy budget, etc. Joseph and Sijikumar, (2004) studied the features of the break and active spells for a 11 year period (1979-1990) in terms of wind at 850 hPa using NCEP/NCAR reanalysis data set and NOAA OLR data. Fig.3.1 and Fig.3.2 show the spatial structure of LLJ and OLR during the active phase and weak phase of monsoon. During active condition the LLJ passes through central India and shows high convection from OLR. During weak situation the LLJ bypasses over south Kerala and passes to the south China sea and OLR minimum values are found at the south of south India. By the onset of monsoon, the outgoing long wave radiation over the Kerala region is small (less than 180 Wm$^{-2}$), indicating high organized convection and the strength of the wind at 850 hPa is more than 15 ms$^{-1}$. Similar situations are repeated two or more times during the same season, indicating active phases of monsoon. The monsoon trough also shows a significant variation during active and weak cycles. In general the monsoon trough is located along the Gangetic plane dipping in to the Bay of Bengal for the period June to September during the active phase of the monsoon and shifts northward when there is break (Ramage, 1971). Thermodynamic structure and boundary layer parameters over the monsoon trough region indicate significant and consistent variation between active and weak phases of monsoon (Kusuma, et al, 1991).
In south India, during the southwest monsoon season prominent wind in the surface layer of the atmosphere is northwesterly. Between March and May the prominent wind direction over the sea in this region changes gradually from northeasterly to northwesterly and then to westerly (Anonymous 1966). By the onset of monsoon the westerly wind over Kerala coast strengthens and prominent surface wind direction during the monsoon season over this region is northwesterly. On the other hand, during the weak monsoon situations, the wind direction turns southerly off
the Kerala coast and oriented with along shore component near Kerala coast although the intensity is small.

### 3.3 Scope of the study

Indian southwest monsoon has very dominant active and weak phases. This active and weak situations are very important in the human activity because more the number of active monsoon situation, more the quantity of the rainfall over the region. By the present study, the atmospheric boundary layer parameters during active and weak monsoon situations are studied using different datasets. The variation of surface fluxes, wind at 850 hPa, Outgoing Longwave Radiation (OLR) are studied during different phases of summer monsoon. Thermodynamic features show significant variations associated with the surge of monsoon. So, the study of these parameters helps to provide an indication of convection. In addition, the oscillations of the surface parameters are also examined using wavelet technique to identify its embedded harmonics.

### 3.4 Data and methods

The boundary layer features during active and weak phases of monsoon are studied using the data sets taken from the NCEP/NCAR reanalysis, it has a research quality data used for meteorological and oceanographical studies (Kalnay at al, 1996) having a spatial resolution of 2.5 x 2.5 latitude-longitude grid and from the All India Daily Monsoon Rainfall (AIDMR) available from the IMD. OLR data taken from NOAA satellite were also used (Gruber and Krueger, 1984) with a resolution of 2.5 x 2.5 latitude-longitude grid. The active and weak phases of the monsoon are estimated from the area average of zonal wind at 850 hPa over 10°N-20°N & 70°E-80°E suggested by Joseph and Sijikumar (2004) and AIDMR. The active days are the days in which the area averaged zonal wind over the area is 15 ms\(^{-1}\) or more and weak days are when it 9 ms\(^{-1}\) or less. Active days considered in June and July and weak days considered in July and August. The active and weak days estimated by wind and AIDMR were strongly correlated.

Dines Pressure Tube (DPT) anemograph are also used for Mangalore and Bangalore during the period of July for 12 years from 1987 to 1998. The active and weak days during the period are identified as explained earlier. Mangalore is a
windward side and Bangalore is the leeward side of the LLJ core. During active monsoon situation, the boundary layer exhibits its features differently over windward side and leeward side. DPT charts available from the India Meteorological Department (IMD) are used for the analysis.

Radiosonde data for 00Z are used to estimate the thermodynamics of boundary layer during different phases of monsoon. The radiosonde data is accessed from the website of http://weather.uwyo.edu/upperair/sounding.html

The fluxes of momentum and sensible heat flux and other parameters are computed using the equations explained in the Chapter 2.

The virtual potential temperature and humidity were computed using the standard equations. The equations are given below

3.4.1 **Vapour pressure (e)**

\[ e = 6.1078 \exp\left[\frac{(TD \times A)}{(TD + B)}\right] \]  \hspace{1cm} (3.1)

where TD is the dew point temperature in degree C.

3.4.2 **Saturated vapour pressure (es)**

\[ es = 6.1078 \exp\left[\frac{(T \times A)}{(T + B)}\right] \]  \hspace{1cm} (3.2)

where T is the temperature in degree C.

the coefficients A and B for water and ice are different as given below

\[ A = 7.5 \]
\[ B = 237.3 \] \text{ with respect to WATER}

\[ * A = 9.5 \]
\[ B = 265.5 \] \text{ with respect to ICE}

**specific humidity (q)** is given by the equation

\[ q = 0.623e / (P-0.377e) \]  \hspace{1cm} (3.3)
where \( e \) and \( P \) are in the same units (hPa) and \( q \) is dimensionless and can be expressed in kg.kg\(^{-1}\).

### 3.4.3 Virtual potential temperature \((\theta_v)\)

\[
\theta_v = \theta(1 + 0.61r)
\]

(3.4)

where \( \theta_v \) is virtual potential temperature, \( r \) is mixing ratio and \( \theta \) is the potential temperature and

\[
\theta = T \left( \frac{1000}{P} \right)^{0.786}
\]

(3.5)

where \( P \) is the pressure and \( T \) is the temperature.

### 3.5 Wind structure at different levels

The active and weak phases of monsoon are identified from the time series plot of the area averaged (10°N-20°N & 70°E-80°E) zonal wind at 850 hPa and the dates were confirmed using All India daily monsoon rainfall (AIDMR). Fig.3.3 shows the spatial structure of the zonal wind at different levels (1000 hPa, 925 hPa, 850 hPa, 700 hPa and 500 hPa) for active and weak phases, considering all active and weak phases from 1999 to 2003. The spatial structure of the wind is varying according to the activity of the monsoon. The changes in the atmospheric variables are evident in the entire atmospheric column from the surface to the top of the atmosphere associated with the monsoon activity. It is found that the variations are high in the lower levels. The spatial surge is more in the surface levels such as 1000 hPa, 925 hPa and 850 hPa. The 850 hPa level has the maximum intensity of the Low Level Jetstream (LLJ) and is very critical by showing high response to the monsoon oscillations. From this level either to surface or to the top of the atmosphere, the response to the monsoon surge gets weakened. During active monsoon situation the core of the zonal wind passes from the central Arabian Sea through the central India and then to Bay of Bengal. The wind core speed at 850 hPa is \( \sim 18 \text{ ms}^{-1} \) in the Arabian Sea but in the surface the core speed over the area is \( \sim 14 \text{ ms}^{-1} \). This decrease is due to the frictional effect from the surface. The wind from the southern part of Indian Ocean carrying ample of moisture enters to the Arabian Sea by crossing the
Fig. 3.3. Spatial structure of wind at 850 hPa with magnitude and direction during active and weak phases of monsoon at different levels a) 1000 hPa, b) 925 hPa, c) 850 hPa, d) 700 hPa and e) 500 hPa.

Equatorial Somali coast over a narrow belt and strengthens its speed from the Arabian Sea. During weak situation the core of the wind speed turns towards south and passes through the west coast of India and then to Bay of Bengal through the Sri Lanka region. It is clear that the wind during active and weak situation is different in the southern part of Indian peninsula, but the difference is comparatively feeble than over the central India. As the wind pattern changes from active to weak, all the boundary layer parameters undergo changes because the surface parameters mainly depend on the wind and temperature pattern of the surface.
3.6 Variation of boundary layer fluxes over Cochin

Surface boundary layer parameters show significant variation during active and weak phases of monsoon due to the variability in the surface wind and temperature. The thorough understanding of this variation is very important in the many studies related to Indian monsoon. Variation in the boundary layer parameters are studied with available data from the micrometeorological tower system and the data set is very crucial for this region because no such data is available before for this kind of study. Momentum and sensible heat fluxes for active and weak monsoon situations are examined very closely. Active monsoon situation is taken from 8th to 14th of August and the weak situation from 30th July to 2nd August in 2002. Fig.3.4 explains the variation in momentum and sensible heat fluxes during active and weak epochs of monsoon. The surface fluxes were calculated using the Monin Obukhov similarity theory and was explained in Chapter-2.

![Variations of surface fluxes of momentum and sensible heat during active and weak phases of monsoon](image)

The flux values vary considerably during active and weak phases. During active phase, momentum flux values are high in the daytime compared to the flux
values during the weak situation. This can be due to the high surface wind shear caused by the strong surface wind associated with the LLJ during active monsoon situation. Similarly, the sensible heat flux values are also high in the active case compared to that in the weak monsoon situation. However, a few high upward directed sensible heat flux situations are noticed during the daytime of weak monsoon situation. Weak monsoon situation is characterised by weak surface wind and clear sky or intermittent cloudy condition without or very little rain. This helps the insolation to reach more at the surface creating high upward surface sensible heat flux. The similar type of variation is noticed in frictional velocity, temperature scale and drag coefficient.

3.7 Conserved variable analysis ($\theta_e$-$q$ plot)

Conserved Variable Analysis (CVA) is carried out during the active and weak spells of southwest monsoon situations. This CVA is made for selected stations in the west coast namely Trivandrum and Mangalore using radiosonde observations taken at 12 UTC. The west coastal stations show significant variations during monsoon season according to the movement of LLJ and subsequent convective clouds. The convective clouds can influence radiative process and hence the thermodynamic structure of the atmosphere (Betts and Albrecht, 1987). The thermodynamic structure of the east coastal stations and marine atmosphere of Bay of Bengal was studied using BOBMEX-99 data set employing conserved variable analysis (Maorwal and Seetharamayya, 2003). Bala subramanyam and Radhika Ramachandran (2003) made similar analysis using the IDOEX-90 cruise data set over the central Arabian Sea. Prasnis and Morwal (1991) carried out the CVA of convective boundary layer for the southwest monsoon over Deccan Plateau. Kusuma et al 1991 reported that the boundary layer height is high during weak monsoon and it is low during active monsoon phase. An attempt is made to understand the variation of thermodynamic structure during active and weak phases of monsoon using CVA over west peninsular region. This helps for diagnostic studies on boundary layer processes and the thermodynamic structure of ABL. During a radiative process the magnitudes of $q$ will not change, but radiative cooling moves points to lower $\theta_e$ at constant $q$. The CBL mixing line shows intense mixing of the lower atmospheric constituents within the mixed layer. Fig. 3.5 and Fig.3.6 show the CVA plots depicting $\theta_e$ versus $q$ for six
consecutive days (from 8\textsuperscript{th} July to 13\textsuperscript{th} July) during active monsoon phase for the evening radiosonde observation (5.30 pm IST) for Trivandrum and Mangalore respectively. In the figure, $q$-axis is reversed so that a sounding plotted superficially resembles a more familiar ($\theta_e - P$) plot. From the figure, it is found that the mixing height is confined within 1 km except in the last day of the active phase. It may be noted that the mixing height can be treated as the top of the Convective Boundary Layer (CBL). The mixing height over Trivandrum for the active situation is 302 m, 569 m, 464 m, 569 m and 1180 m for the days 8\textsuperscript{th}, 9\textsuperscript{th}, 10\textsuperscript{th}, 11\textsuperscript{th} and 13\textsuperscript{th} July respectively. The CVA plot for 11\textsuperscript{th} July is peculiar and it is very difficult to estimate the mixing height. In the case of Mangalore, the mixing height values are more than that of Trivandrum. This may be due to the effect of orographic clouds formed over the windward side of the Western Ghats during active monsoon phase. During active monsoon situation, the surface westerly wind over the station increases due to the influence of strong LLJ associated with active monsoon. The values of mixing height are 915 m, 730 m, 1399 m, 1498 m, 1539 m and 2071 m respectively for the six days during the active monsoon. The values obtained are realistic even though the vertical resolution of the radiosonde observations is small. During the case of weak monsoon situations the convective mixing height is found to be high in all the cases of Trivandrum and Mangalore. Fig. 3.7 and Fig.3.8 show the $\theta_e - q$ plot for the weak monsoon days in the year 2001. Over Trivandrum, the CBL mixing height is higher than that of active monsoon. This increase is attributed to the characteristics of the weak monsoon situation. During weak phase the convective cloud band and LLJ core prevail over the equatorial region. Accordingly, convective cloud band and associated rainfall over Indian continent is less except Himalayan regions. The rest of the place is more or less cloud free and transparent to the insolation. Thus the local heating triggers convective activity and hence increase in the mixing height. The mixing height values over Trivandrum during weak situation are 1056 m, 764 m, 1473 m, 1477 m and 400 m for the respective six weak days 18\textsuperscript{th}, 19\textsuperscript{th}, 20\textsuperscript{th}, 22\textsuperscript{nd} and 23\textsuperscript{rd} respectively. There is no reversal of $q$ in the 21\textsuperscript{st} July, so it is difficult to estimate the mixing height based on the CVA. In the case of Mangalore the CBL mixing heights are 3129 m, 763 m, 1852 m, 2618 m and 2792 m for the 18\textsuperscript{th}, 19\textsuperscript{th}, 21\textsuperscript{st}, 22\textsuperscript{nd} and 23\textsuperscript{rd} respectively.
Fig. 3.5 Conserved variable analysis for Trivandrum during the active period of southwest monsoon
Fig. 3.6 Conserved variable analysis for Mangalore during the active period of southwest monsoon
Fig. 3.7 Conserved variable analysis for Trivandrum during the weak period of southwest monsoon.
Fig. 3.8 Conserved variable analysis for Mangalore during the weak period of southwest monsoon.

Generally, the mixing height is more during weak phase of monsoon due to less cloudiness. The mean mixing height values over Trivandrum and Mangalore for the active phase of southwest monsoon are 617 m and 1359 m respectively. And that
for the weak monsoon situations are 1034 m and 2230 m for Trivandrum and Mangalore respectively.

### 3.8 Vertical variation of thermodynamic parameters

In this section we describe some moisture variables, which are related to the active and weak phases of southwest monsoon and contribute a good role in the atmospheric boundary layer. Here we describe the moisture variables such as specific humidity \( q \), virtual potential temperature \( \theta_v \) and equivalent potential temperature \( \theta_e \).

#### 3.8.1 Specific humidity \( q \)

Specific humidity is the ratio of mass of water vapour to the mass of moist air and is represented by \( 'q' \), which is expressed as gram of water vapour per kilogram of air (g/kg). The equation of specific humidity is described in data and methodology section of the current chapter. Fig.3.9 shows the vertical slices of the \( q \) at six standard levels during July and August of the southwest monsoon as representative years for the stations Mumbai, Mangalore and Trivandrum. The selected stations are all west coastal stations and oriented from North to South. The standard levels presented here are 1000 hPa, 925 hPa, 850 hPa, 700 hPa, 500 hPa and 300 hPa levels. In the figure the blue coloured star represent the values at the station Mumbai, the red coloured plus represent the values at the station Mangalore and the black coloured cross represent the values at the station Trivandrum. As expected the magnitude of the \( q \) decreases with height during the entire period of study. The values of \( q \) are almost constant in the surface level (1000 hPa) and the value ranges from 16 g.kg\(^{-1}\) to 21 g.kg\(^{-1}\), maximum value of specific humidity is found in Mumbai and it decreases towards the southern stations. It may due to the variation of wind strength. In the 925 hPa, 850 hPa and 700 hPa the values of \( q \) vary widely as the propagation of the monsoon surge, but the maximum and minimum values of the \( q \) do not have direct link with the dates of active and weak monsoon phases. In the higher levels (500 hPa and 300 hPa) the variation is negligible. In 300 hPa the value of \( q \) is less than 1 g.kg\(^{-1}\). The high fluctuations in the upper levels below 500 hPa is directly related to the variability in degree of convection. The convection process is high in the mixed layer and the mixing process is maximum at 850 hPa level (Bala Subramanyan, 2003).
the high convection time the values of $q$ is found to be high in higher levels due to the moisture pumping and it is almost true in the case of active monsoon situation in all the cases.

Fig. 3.9. Variation of the specific humidity during June and July of a) 2001 and b) 2002 in different standard levels.
3.8.2 Virtual potential temperature ($\theta_v$)

Virtual potential temperature is analogous to potential temperature in that it removes the temperature variations caused by changes in pressure altitude of an air parcel. For the boundary layer, where turbulence includes vertical movement of the air, $\theta_v$ is very important parameter for defining various processes. The detailed description of $\theta_v$ is given in Stull (1988). The $\theta_v$ profile is used to identify the top of the atmospheric boundary layer in which a sharp increase of the value is seen. Here, analysis of vertical slices of $\theta_v$ at six standard levels for the three stations of the west coast is carried out and presented in Fig.3.10. It is found that the mixed layer is confined below 850 hPa because above 850 hPa the values show sudden increase with height. The values of $\theta_v$ are constant in the surface layer (1000 hPa) and the value is around 300 K for the stations Mangalore and Trivandrum but for Mumbai it is slightly higher and the values is about 302 K, this small variation is noticed in all the levels. A small variation in the value with time is noticed in all levels except surface. Because surface is always with high humidity and it may not respond to the variations in the monsoon activity. During the monsoon season the core of the LLJ height and the ABL heights are closely linked as reported by Madhu (2004). In this study, the constant value of $\theta_v$ is found up to the core of LLJ and it is about 850 hPa and afterwards it varies sharply.

(a)
Fig. 3.10. Variation of the virtual potential temperature during June and July of a) 2001 and b) 2002 in different standard levels.

3.8.3 Equivalent potential temperature ($\theta_e$)

The equivalent potential temperature ($\theta_e$) is defined as the final temperature which a parcel of air attains when it is lifted dry adiabatically to its LCL, then pseudowet adiabatically (with respect to water saturation) to a great height (dropping out all condensed water in the air parcel) then finally dropping down dry adiabatically to 1000 hPa (Bolton, 1980). In another words, it is the temperature at which an air parcel would have if the latent heat is set free and supplied to the air. In this analysis $\theta_e$ is calculated using the formula

$$\theta_e = \theta \exp \left( \frac{2.67 r}{T_{LCL}} \right)$$

(3.6)

where $r$ is the mixing ratio, $\theta$ is the potential temperature (in K) and $T_{LCL}$ is the temperature at LCL in °C.

Similar to the above figure, Fig. 3.11 gives the vertical variation of the $\theta_e$ in six standard levels for the three stations. As discussed in the specific humidity section, the values of $\theta_e$ is also decreased with height and found to be almost constant in the surface levels and fluctuating in the higher levels as the propagation of the monsoon surge. $\theta_e$ is also a good indicator of the convection and the convective
clouds are associated with active monsoon. Hence during active monsoon the values of $\theta_e$ is generally high as in the case of the specific humidity.

Fig. 3.11. Variation of the virtual equivalent potential temperature during June and July of a) 2001 and b) 2002 in different standard levels.
3.8.4 Relation of specific humidity with $\theta_v$ and $\theta_e$

The virtual potential temperature and equivalent potential are related to the specific humidity. $\theta_v$ is related to the $q$ linearly in the lower levels of the atmosphere. It is inferred that $\theta_v$ is linearly related in the mixed layer of the ABL and the relation is given in Fig.3.12 as a scatter plot in which the black 'x' mark represents the station Trivandrum, the red coloured '+' mark represents the station Mangalore and '*' marked blue colour represents the station Mumbai. In the lower level $q$ does not vary much so that $\theta_v$ also does not vary. But in the levels 925 hPa and 850 hPa $\theta_v$ increases linearly with the increase of the specific humidity. Above mixed layer the relation does not hold good. In the case of $\theta_e$, it is related to the $q$ in a linear way in all the levels as indicated in Fig.3.13. The variation of $\theta_e$ is noticed in the mixed layer except in the surface. In higher altitudes the values of $\theta_e$ and $\theta_v$ increase with a small increase of specific humidity.

![Fig.3.12. Cross relation of specific humidity with virtual potential temperature for the standard levels during the monsoon period.](image-url)
Fig. 3.13. Cross relation of specific humidity with equivalent potential temperature for the standard levels during the monsoon season.

3.9 Major oscillations in the ABL

Intraseasonal oscillations (ISO) is one of the major oscillation in the equatorial region and the 30 – 60 day mode is manifestation in the form of northward propagating intraseasonal oscillation during the boreal summer over the Asian monsoon region (Yasunari, 1979, 1981; Sikka and Gadgil, 1980; Krishnamurthy and Subramanyam, 1982). The Quasi biweekly mode (QBM) is also known as 10 – 20 day oscillation and it can be seen in spectral analysis of precipitation, convection and in many circulation parameters (Chen and Chen, 1993; Numaguti, 1995; Kiladis and Wheeler, 1995). The QBM is an important component of the monsoon ISO as its amplitude is comparable to the northward propagating 30-60 day mode (Goswami et al, 1998; Goswami and Ajayamohan, 2001) and its phase is relative to that of the 30-60 day mode that determines the active and weak spells of the Indian summer monsoon (Krishnamurty and Ardhunuy, 1980; Yasunari, 1981; Goswami et al 2003). It has been recently shown by Sengupta et al (2001) that the observed biweekly fluctuations of the upper ocean zonal transport in the equatorial Indian Ocean is driven by the biweekly fluctuations of the surface stress. The oscillations in boundary layer parameters are show different types of oscillations such as ISO and QBM. Here
an attempt is made to study the QBM and ISO mode of oscillation found in the surface, 925 hPa and 850 hPa and how they connected each other.

Wavelet decomposition is a method of time-frequency localization that is scale independent. This method of decomposition can be employed where a predetermined scaling may not be appropriate because of a wide range of dominant frequencies. Wavelet analysis attempts to solve by decomposing the time series signals into time / frequency space domains simultaneously. This method of signal decomposition provides information on both the amplitude of any periodic signals within the series, and how this amplitude varies with time. In this study, dmey wavelet is utilized to obtain the predominant signals embedded in the time series of vector wind and temperature. Analysis was carried out in MATLAB computing package. The wave decomposition is performed using \([C, L] = \text{wavedec} \ (X, N, 'wname')\) which, returns the wavelet decomposition of the signal \(X\) at level \(N\), using \('wname'\). \(N\) is a positive integer. The output decomposition structure contains the wavelet decomposition vector \(C\) and bookkeeping vector \(L\). \(\text{wrcoef}\) reconstructs the coefficients of a one-dimensional signal, given a wavelet decomposition structure (\(C\) and \(L\)) and either a specified wavelet. \(X = \text{wrcoef} \ ('type', C, L, 'wname', N)\) computes the vector of reconstructed coefficients, based on the wavelet decomposition structure \([C, L]\), at level \(N\). From the reconstructed coefficients the harmonics can be computed (Torrence and Compo, 1998).

3.9.1 Oscillations in wind and temperature

Indian subcontinent has characterised by the seasonal reversal of wind from northeasterly during winter to southwesterly during summer. In major part of the country the rain giving season is southwest monsoon season in which the prominent wind direction is southwesterly. In addition to this intra annual variability, there are low and high frequency variabilities embedded in the meteorological parameters during the southwest monsoon. Atmospheric surface layer characteristics over this season are closely linked with the upper monsoon features and under this perception it is imperative to study the variabilities in the lower troposphere with different altitudes. Praveena et al (2005) studied such variability using UHF radar over an equatorial station. The features of the variability at different time scales over southern part of India are studied at different heights (surface, 925 hPa and 850 hPa) by
subjecting temperature and wind to wavelet analysis for the decomposition of all the harmonics in the original data. From the different harmonics obtained, it is noted that the major harmonics are 30 to 60 day mode and 10 to 20 day mode. Fig 3.14 shows the wind during the southwest monsoon of 2002 at different heights (surface, 925 hPa and 850 hPa) and its major harmonics. In the figure the first, second and third columns show the original signal and its harmonics at 850 hPa, 925 hPa and surface respectively. The zonal wind at 850 hPa shows the clear indication of active (wind speed is more than 15 ms$^{-1}$) and weak (wind speed is less than 9 ms$^{-1}$) spells. The major oscillations are found to be 10 to 20 day mode (QBM) and 30 to 60 day mode (ISO). The QBM has a periodicity of about 11 days and the ISO is around 47 days. The amplitude of the harmonics is higher in the ISO band, so at 850 hPa the major oscillation is ISO band. In the case of 925 hPa, the zonal wind shows the same type of variation as that of the 850 hPa but the magnitude is comparatively less. The QBM periodicity is around 13 days and ISO periodicity is around 43 days. Here, the
important oscillation is ISO band because the amplitude of the harmonics is higher in the ISO band than that of the QBM band. In the case of surface layer, the wind pattern shows almost similar behavior to the layer above. It is obvious that surface friction plays vital role on the surface wind. The important oscillations in this layer is QBM with a periodicity of about 12 days because the amplitude of this harmonics are higher to this mode of oscillation than that of the ISO band. The ISO band has less influence in the surface layer so that its harmonics is far less than that of the QBM and the periodicity (~39 days) is also less compared to the upper levels.

Fig 3.15 Wavelet analysis of the temperature at 850 hPa, 925 hPa and surface during southwest monsoon. The first row represents the original signal, the second row gives the harmonics of wind in the QBM band and the next is same for ISO band.

The temperature at the above levels were also studies in the same way as that of the wind and presented in Fig.3.15. But there are some differences in the variability to temperature from the wind. The 850 hPa and 925 hPa levels have the ISO and QBM periodicities are around 37 and ~10 days respectively and they are almost equal importance because of there harmonics are almost same amplitude. In the surface layer, the most contributed periodicity is QBM band than that of the ISO
mode. The QBM is around 11 days and ISO has around 34 days periodicities. The periodicity of the oscillation in temperature at 850 hPa and 925 hPa levels are comparatively less than that of the wind and the amplitudes are also less to temperature. But in the case of surface layer, the maximum amplitude of the harmonics are seen to the temperature in both QBM and ISO periodicities.

Influence of surface friction and associated turbulent eddies can be attributed as the mechanism responsible for the intense QBM in the surface layer. It is found that the amplitude of ISO band increases towards 850 hPa. This is because the intra seasonal oscillation of the monsoon regime governs oscillations at this level. In other words once can infer that the surface layer controls the QBM periodicity and the upper levels control the ISO periodicity.

From the analysis of ABL characteristics associated with the different epochs of monsoon, it is found that the turbulent parameters are high due to the presence of organized convective clouds in the active monsoon situation and less during weak monsoon situation. It is found that the thermodynamic parameters show variability during active and weak phases of monsoon. From the conserved variable analysis, it is found that the mixing height of the boundary layer over the west coastal stations are high during weak phase of monsoon and low during active monsoon situations. The prominent oscillations in the meteorological parameters in the surface layer are in the QBM and ISO bands. The amplitude of QBM dominates in the surface layer while ISO mode dominates in the 925 hPa and above. It is important to understand the characteristics of the ABL structure over ocean during different seasons and hence next chapter is devoted for the ABL features over marine atmosphere.