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Observation Of Lump Echo Structures During Southwest Monsoon

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“Southwest monsoon is the wettest month in Visakhapatnam. Lump structures were observed on many days during the season. However, a case study of 15-16 August merited a detailed description here, as it possessed all the essential unique environmental settings. A general discussion on the remaining cases during the season is briefly presented”.

Introduction: Monsoon

The greatest seasonal change in the Earth's global circulation is the monsoon (Fein and Stephens, 1987; Hastenrath, 1985; Loo et al., 2015). Contrary to popular belief, monsoon does not mean 'rainy season', rather it refers to a wind system that exhibits a pronounced seasonal reversal in the direction. It is known that winter is associated with winds that blow predominantly off the continents that produce a dry winter monsoon. By contrast, in summer warm moisture-laden air blows from the sea towards land. Thus, the summer monsoon, which is usually associated with abundant precipitation, is the source of the misconception.

The word monsoon is derived from the Arabic word 'mausim' which means season. Indian monsoons are well developed when compared to other monsoons in other parts of the world. The Indian summer monsoon is an air stream loaded with moisture. Its arrival is a gradual process beginning with a short period of transition from extreme heat to a humid atmosphere. It involves complete replacement of the dry hot air with the equatorial maritime air up to a vertical extent of about 3 to 5 km over the land and water surface (Chang, 1967).

Indian southwest monsoon

The arrival of the summer monsoon over the Kerala coast is found to be reasonably regular either towards the end of May or beginning of June (Ramesh et al., 1996; Prasad and Hayashi 2005; Taniguchi and Koike 2006, Goswami and Gouda, 2010). The monitoring and forecasting of the summer monsoon onset over the Indian subcontinent are very important for the guidelines for the operational forecaster reference. This migration and location of the heat source associated with summer monsoon has important implications for the withdrawal of monsoon over South Asia (Syroka and Toumi, 2004). The marked difference between the response of a large land mass and an oceanic surface to the heat received from the sun creates temperature difference on surface of land and sea. In summer, the air over the continents is much warmer and less dense than over oceans. This and earth's rotation, and its effect on lower atmosphere, create different temperature and pressure set up and this helps in formation of the monsoon system is argument of many meteorologists. This was the first theory propounded by Edmund Halley in 1686.

In May, there is low pressure because of high temperatures of summers in the northern hemisphere and high pressure because of winters in the southern hemisphere (Figure 1). The pressure zones are created by heat and cold, among other factors and the winds keep swirling all over the world, trying to neutralize these pressures. The winds move from cooler and high pressured, Central Australia, in a north-westerly direction, towards the huge Sahara Desert because it is hot and low pressure there. It is known that high pressure systems, as seen from space tend to spin clockwise in the northern hemisphere and counter-clockwise in the southern hemisphere and low-pressure systems spin the respective reverse direction. The equatorial bulge is believed to be the cause for this change in the wind direction (Galvin, 2008).

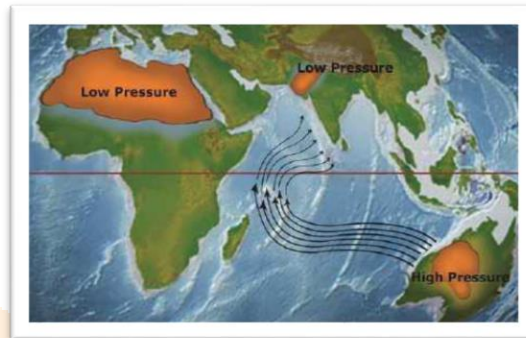


Figure 1 Origin of southwest monsoon (after: D.K. Hari).

The onset of the monsoon over the Indian peninsula begins in Bay of Bengal sometime in the last week of May. Just before the onset, southeasterlies prevail south of the equator and southwesterlies prevail in the Bay. In between these two, north of the equator, light variable winds prevail in the narrow belt of 2-3° latitude width. The onset of the monsoon follows the vanishing of these light winds. Southeasterlies of the southern hemisphere cross the equator and veer to southwest and continue their motion further north. Normal dates of onset of the monsoon in India are shown in Figure 2. The monsoon sets in over the south Andaman Sea and lower Burma by about last week of May and advances north-westwards reaching the Indian mainland by 1 June. It reaches the north most limits in the extreme northwest by 1 July.

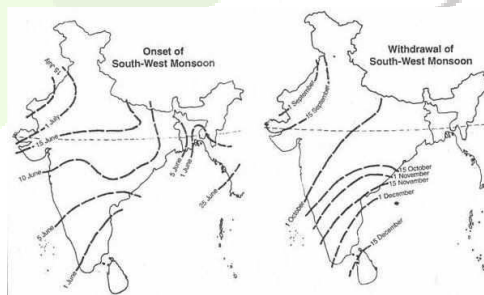


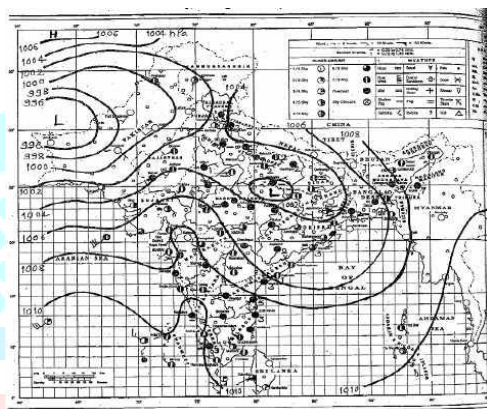
Figure 2 Normal dates of onset and withdrawal of southwest monsoon over the Indian subcontinent (courtesy: IMD).

The normal duration of the summer monsoon is roughly 100 days beginning from 1st June. The thickness of the monsoon stream is not constant at all places. It has maximum thickness of 7 km near southwest coast of the peninsula and least over northwest India. It is fairly uniform over northeast India and North Bay (Subbaramayya, 1961). The summer monsoon rainfall forms a major part (70%) of the annual precipitation in India. The northwest ward spread of the monsoon rains is accompanied by a fall in day maximum temperature. The onset of monsoon is associated with an increase in rainfall on a rainy day by a factor of as large as 3, an increase in the frequency of rains from 1 day in 10 days to 1 day in 2 days, a decrease in maximum temperature by 4-10°C, a decrease in diurnal range of temperature by 3-8°C, an increase in total cloud amount by 3-5 octas and low cloud amount by 2-4 octas (Krishnamurthy and Kinter, 2003).

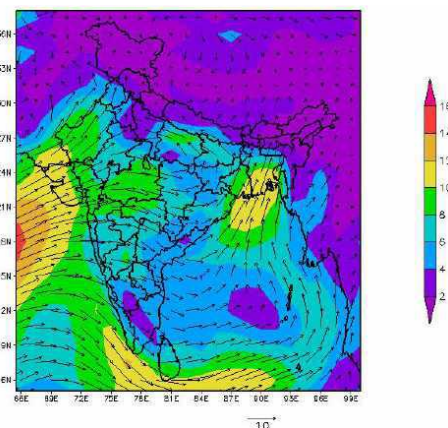
The summer monsoon begins to withdraw from the middle of September. The withdrawal of the monsoon is a more gradual process than its onset. The normal dates of the withdrawal of the summer monsoon are shown in Figure 2. It is difficult to decide when the summer monsoon ends and when the winter monsoon (northeast) monsoon begins over the extreme south of the Indian peninsula. The winter monsoon sets in over the southern half of the Indian peninsula in October. The summer monsoon is, for all practical purposes, in the last stages of its life towards the end of October (Prasad and Hayashi, 2005).

A case study: 15 – 16 August 2009

The surface weather chart of 15 August 2009 at 08:30 hrs is shown in Figure 3. The southwest monsoon is vigorous in coastal Andhra Pradesh. The sky is cloudy. The axis of the monsoon trough extends from Himachal Pradesh to head of the Bay of Bengal through Ferozepur, Karnal, Etowah, Sidhi, Hazharibagh, Jamshedpur, and Digha. It extends up to about 2.1 km above the sea level and also covered Patiala, Kanpur, Ambikapur and Paradip. A weak offshore trough at sea level exists from the Maharashtra coast to the Karnataka coast. A low-pressure area is prevailing over southwest Pakistan also. Another low-pressure area is persisting over eastern Uttar Pradesh and Bihar.



(Figure 3)



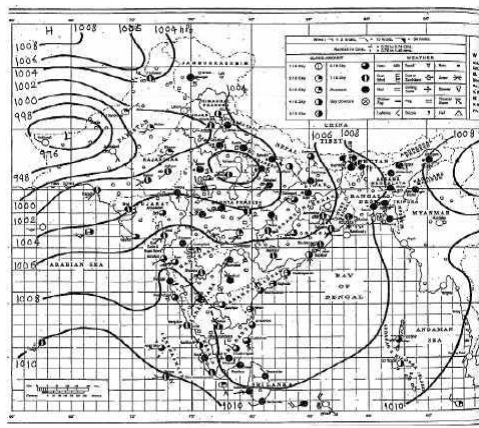
(Figure 4)

Figure 3 Surface weather chart of 15 August 2009 at 08:30 hrs (Courtesy: IMD).

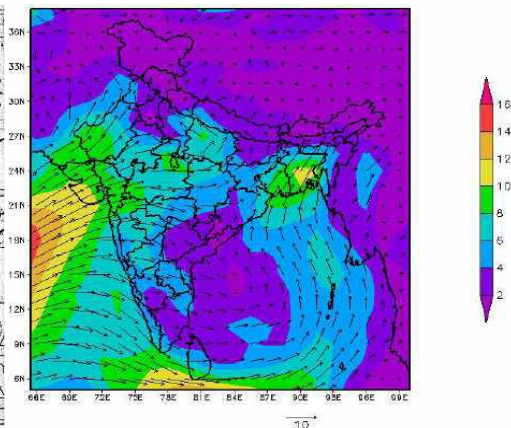
Figure 4 Simulated wind field pattern of 15 August 2009 at 08:30 hrs (Courtesy: National Centre for Environmental Prediction of NOAA, www.ncep.noaa.gov).

Simulated wind field pattern at 850 hPa level (roughly at 1.5 km height) for 15 August 2009 using WRF mesoscale model provided by the National Centre for Environmental Prediction (NCEP) is presented in Figure 4.4. The predicted wind direction is represented by arrows and the wind speed is indicated with colours on the map. As usual, the arrows point in the direction of the wind. It is known that 850 hPa levels are not influenced by the diurnal temperature variation of the underlying surface.

The strong winds from the Arabian Sea are moving towards the east Bay of Bengal and north-eastern part of the Peninsular India (Figure 4). These winds appear to be high due to rarefied air at the upper levels. The strong and rapidly moving circumpolar westerly air circulation in a narrow belt of a few hundred kilometres width in the upper troposphere is called jet stream (Lockwood, 2009; Dimri and Chevuturi, 2016). These are also known as geostrophic winds as they are deviated by about 90° due to Coriolis force (Ahrens, 2007). They move from west to east and are also known as westerly winds. They play a major role in affecting the monsoon (Devi et al., 2014). The surface weather chart of 16 August 2009 at 08:30 hrs is shown in Figure 4.5. It is observed that there is no appreciable change in the synoptic situation from the previous day except the formation of a monsoon low pressure system near the head of the Bay of Bengal. Monsoon activity was moderate to strong over the Bay of Bengal with scattered rainfall over the coastal Andhra Pradesh. The sky was cloudy during 15 – 16 August 2009.



(Figure 5)



(Figure 6)

Figure 5 Surface weather chart of 16 August 2009 at 08:30 hrs (courtesy: IMD).

Figure 6 Simulated wind field pattern of 16 August 2009 at 08:30 hrs (Courtesy: National Centre for Environmental Prediction of NOAA, www.ncep.noaa.gov).

Simulated wind field pattern at 850 hPa level 16 August 2009 is presented in Figure 6. It appears that there is no appreciable change in the predicted wind pattern of the previous day due to monsoon activity. In general, low winds prevailed in the southern and south-eastern parts of the country.

The surface weather parameters such as wind speed, wind direction, air temperature, and relative humidity measured by standard instruments placed at a height of about 1.2 m above ground are presented here to understand the unique environmental setting required for the observation of lump structures. This data is taken from the routine measurements being carried out by the Cyclone Warning Centre, India Meteorological Department, which is located a few hundred meters away from the sodar site. Figure 7 presents the surface wind speed recorded from 08:00 hrs to 08:00 hrs of 15-16 August 2009.

The prevailing winds were calm till noon. Later wind speeds have gone up to about 5 knots, as the direction of the wind turned to south-south-westerly (Figure.8). Calm conditions prevailed again from sunset to about mid-night. The winds turned south with speeds up to 3 knots later.

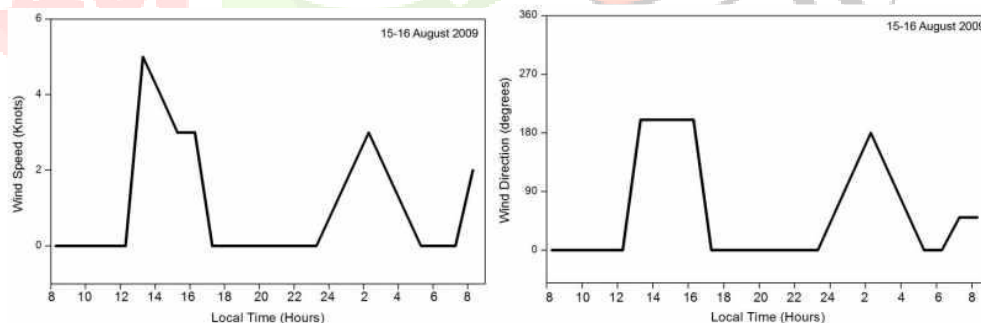


Figure 7 Surface wind speed plot for the period from 08:00 hrs of 15 August to 08:00 hrs of 16 August 2009 (Courtesy: CWC, Visakhapatnam, IMD).

Figure 8 Surface wind direction plot for the period from 08:00 hrs of 15 August to 08:00 hrs of 16 August 2009 (Courtesy: CWC, Visakhapatnam, IMD).

Figure 9 shows the surface temperature record from 08:00 hrs to 08:00 hrs of 15-16 August 2009. The total diurnal temperature variation of temperature is about 2.8°C with a minimum of 27.6°C and a maximum of 30.4°C. Similarly, the diurnal variation of relative humidity for the same time period is shown in Figure 10. It showed 10% variation with a maximum of 88% and a minimum of 78%.

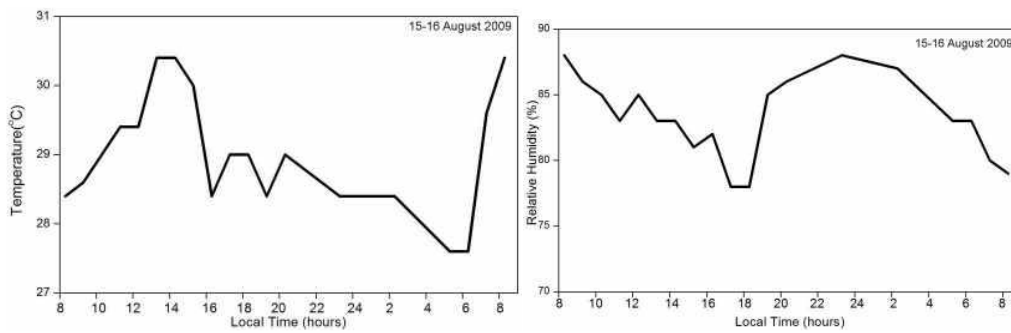


Figure 9 Surface temperature plot for the period from 08:00 hrs of 15 August to 08:00 hrs of 16 August 2009 (Courtesy: Cyclone Warning Centre, Visakhapatnam, IMD).

Figure 10 Surface relative humidity plot for the period from 08:00 hrs of 15 August to 08:00 hrs of 16 August 2009 (Courtesy: CWC, Visakhapatnam, IMD).

The sodar facsimile record obtained for the period 10:35 hrs of 15 August 2009 to 05:54 hrs of 16 August 2009 are presented here under. Figure 11 shows the facsimile record for a 2-hour period from 10:35 hrs to 12:36 hrs.

The development of thermal plume structures can be clearly seen upto about 250 m height. As mentioned earlier, the appearance of thermal plumes on sodar facsimile records is an indication of transfer of heat, moisture and momentum from the surface to the overlying boundary layer (McAllister, 1968; Little, 1969; McAllister et al., 1969). It is known that thermals are the dominant mode of turbulent mixing in highly convective situations (Lenschow and Stephens, 1980).

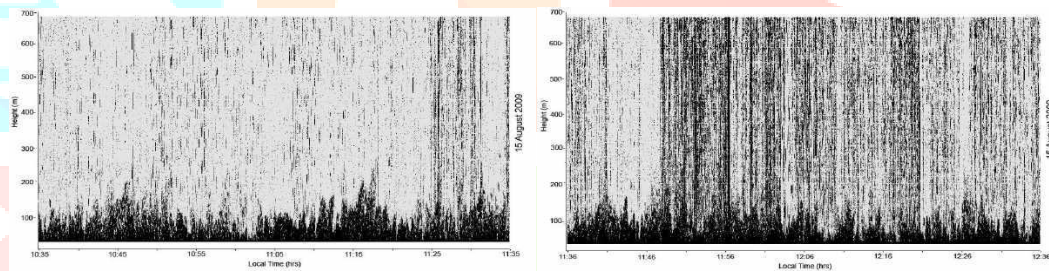


Figure 11 Sodar facsimile records showing thermal plumes from 10:35 hrs to 12:36 hrs on 15 August 2009 (The dark lines extending to the top of this and other records are due to man-made noise).

Thermal plumes are best formed during clear sky, light wind conditions and direct solar heating of dry grassland terrain. They typically extend upto several hundreds of meters height in the boundary layer (Hall et al., 1975; Asimakopoulou et al., 1983; Mouldsley et al., 1985). Such plumes typically reach maximum development shortly after noon and may not show much seasonal structure dependence (Hall, 1972). The disappearance of the plumes with height on the facsimile records is not necessarily because the mixed layer extends no higher. At higher altitudes, the temperature fluctuations are much weaker than at lower ranges, and there is additional absorption/attenuation of transmitted and scattered sound energy at higher heights, making the echoes undetectable by sodar systems (Hall et al., 1975).

Figure 12 shows the facsimile record, for the period 12:38 hrs to 14:39 hrs, depicting the continuation of thermal plume activity, albeit restricting it to below 200 m height due to overcast sky. This is an indication of intense vertical mixing (Kalogiros et al., 1995). The facsimile record is less-noisy from about 13:20 hrs. It was shown in many experiments earlier that it is an alternation of vertically-oriented regions of strong acoustic scattering with regions of little or no scattering (McAllister et al., 1969; Beran et al., 1971; Kjelaas et al., 1974). List and Melling (1974) experimentally showed that there is a definite correlation between the observed upward vertical motion and the presence of acoustic backscattering. Thus, the thermally turbulent air with a positive temperature excess rise. This is also consistent with aircraft observations and plume theory (Konrad and Robison, 1973). There appears to be a tendency for the thermally quiescent air between plumes to have the expected descending motion and lack acoustic backscatter from these regions (Beran et al., 1971; Brown and Hall, 1978).

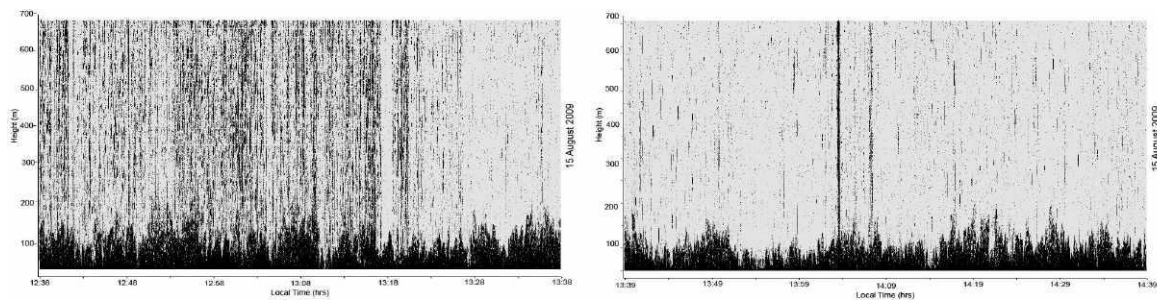


Figure 12 Sodar facsimile records showing thermal plumes from 12:38 hrs to 14:39 hrs on 15 August 2009.

The sodar facsimile record for the period from 14:40 hrs to 17:42 hrs is shown in Figure 13. Thermal plume activity continued up to about 14:55 hrs. The facsimile record started showing diffuse type of echo-signals (Singal, 1975, 1988; Aggarwal et al., 1980; Gera and Sarkar, 1980; Cheung et al., 1990; Gera and Saxena, 1996; Travouillon et al., 2003; Rao et al., 2004; Kankanala, 2007).

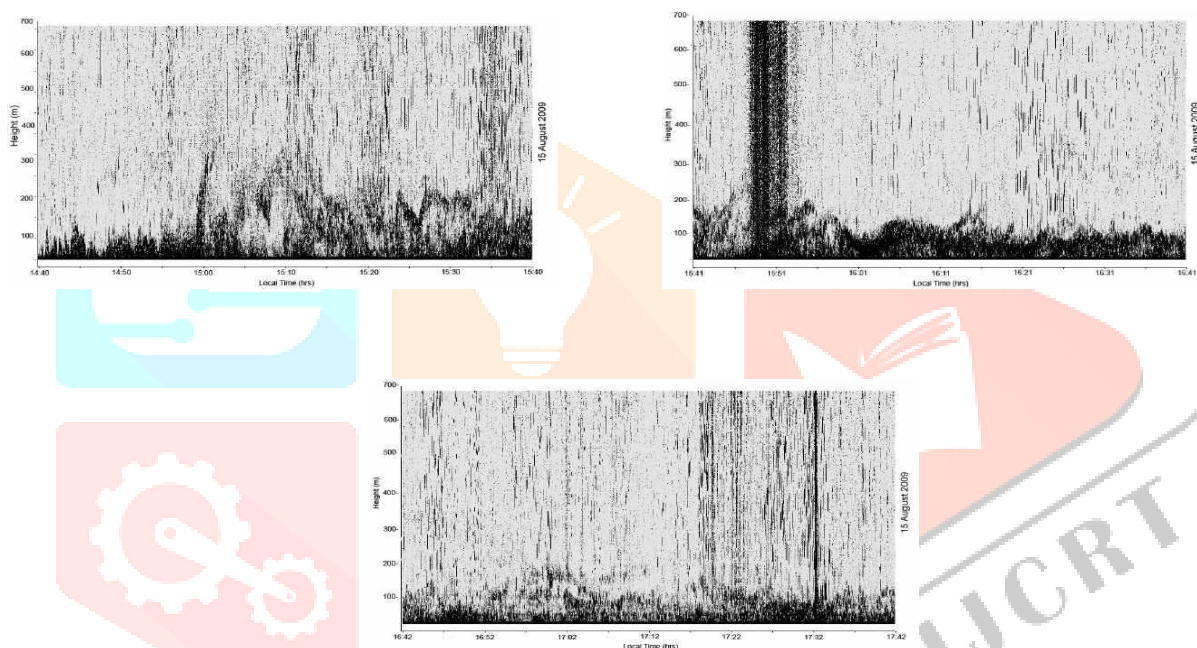


Figure 13 Sodar facsimile records showing the arrival of thunderstorm density current at the site at 14:55 hrs and the consequential shear and other layers till 17:42 hrs on 15 August 2009.

At around 14:55 hrs (see Figure 13), a sudden change in the acoustic echo signal pattern is discernible. A sharp rise of about 300 m in the height of the echo-signal lasting for a few minutes can be noticed on the facsimile record. The echo region showed a clear tilt to the right. Such echo patterns are reported earlier whenever a front-type air mass passes through the antenna beam of the sodar system (Hall et al., 1976; Ralph et al., 1993). Although the surface temperature and humidity measurements presented in Figure 4.9 and Figure 4.10 are not made continuously, but for every hour, a decrease in temperature and a rise in relative humidity can be observed. A thunderstorm of light intensity passed through the experimental site (GBRA, 2004). The tilted sodar echo-signal pattern is an indication of the arrival of the thunderstorm density current (Hall et al., 1976; Rao et al., 2004). In fact, sodar facsimile records reveal complicated but ordered internal structure of the thunderstorm density currents. It is reported that a succession of internal shear layers occurs following the nose of the current (Sun et al., 2002; Latha and Murthy, 2011). The sodar facsimile record presented in Figure 4.13 shows several shear layers from about 15:00 hrs to 15:45 hrs. The amount of the wind shear is known to be related to the temperature difference between the ambient air and the interior of the density current measured near the surface (Hall et al., 1976). It is known that thunderstorms, while occurring under different synoptic and local conditions, leave their characteristic signatures depending on the initiation scenario (Robert et al., 2001, Murthy et al., 2011). There was rain at the site which lasted only for a few minutes. Thereafter, a layer

appeared having an average thickness of 50 m with undulations ranging from 2 to 10 minutes. Figure 14 shows the sodar facsimile record for the period 18:19 hrs to 21:21 hrs of 15 August 2009. It can be seen that lump structures started occurring from about 18:20 hrs. A lump structure is said to be detected when a vertical line of about an acoustic pulse length appeared on sodar facsimile record for at least two successive scans at about the same height range (Mingyu et al., 1981; Singal et al., 1985; Singal, 1988; De et al., 1994; Rao et al., 1995). For example, at about 20:26 hrs at a height range of 250 m (see Figure 5.24) a lump structure is visible for at least 10 scans. Also, the lump structures appear randomly and most of them are limited to height ranges between 100m and 500 m (see Figure 4.14). An important characteristic feature of the lump structures is that they tend to appear when the boundary layer thermal structure is either neutral or near neutral (Castracane et al., 2001). On the sodar facsimile records, lump structures are seen as isolated regions of strong acoustic echo-signals in an otherwise echo-free region (Rao et al., 1995). For example, as depicted in Figure 14, from about 19:50 hrs to 20:00 hrs in the height range above 100 m, there are no other echo-signals, except those related to the lump structures. It may be noticed that there are five wave-like structures appeared in the height range of about 200 m from 18:35 hrs to 19:19 hrs. These patterns in the form of quasi-periodic inclines stripes, or cat's eyes, arise under stable stratification and significant vertical wind shears (Lyulyukin et al., 2015).

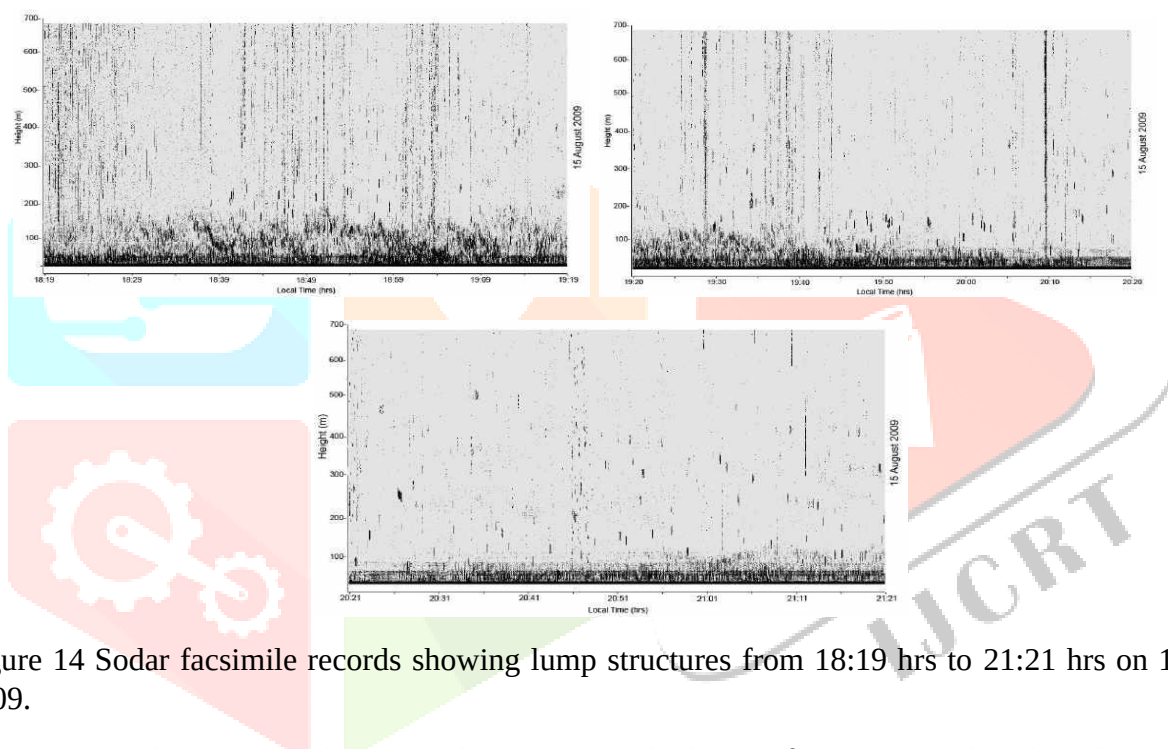


Figure 14 Sodar facsimile records showing lump structures from 18:19 hrs to 21:21 hrs on 15 August 2009.

These are similar to internal gravity-shear waves, which are often associated with Kelvin-Helmholtz waves (Petre and Verlinde, 2004; Wroblewski et al., 2007; Liu et al., 2009; Luce et al., 2010; Petenko et al., 2016). There is a steady increase in the frequency of occurrence of lump structures throughout the remaining part of the facsimile record. Figure 15 shows the facsimile record for the period 21:22 hrs to 23:46 hrs of 15 August 2009. The record clearly shows that the acoustic scattering is restricted to the lowest 100 m indicating the gradual development of ground-based inversion.

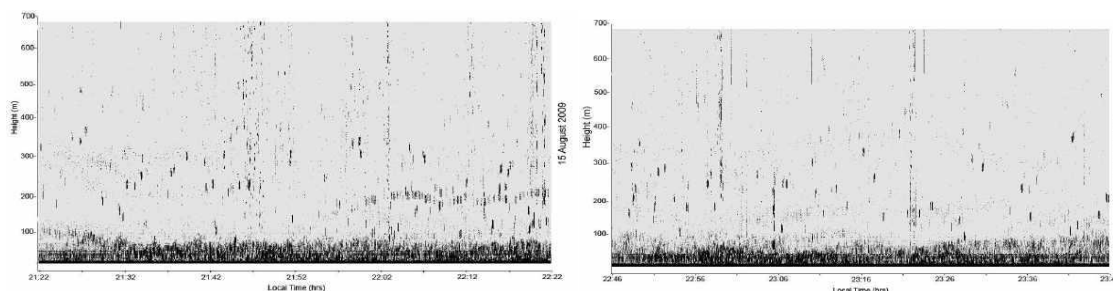


Figure 15 Sodar facsimile records showing lump structures from 21:22 hrs to 23:46 hrs on 15 August 2009.

Although, the occurrence of lump structures is random in both time and height, a series of them appeared just about 200 m height beginning from about 22:00 hrs (Figure 15). They last for about 10 min with a kind of small undulation. The remaining part of the facsimile record shows the occurrence of lump structures. Figure 16 shows an increase in the height of the ground-based acoustic scattering upto about 150m. It can also be seen that there is a sudden surge in the frequency of occurrence of lump structures from 00:20 hrs to 00:40 hrs.

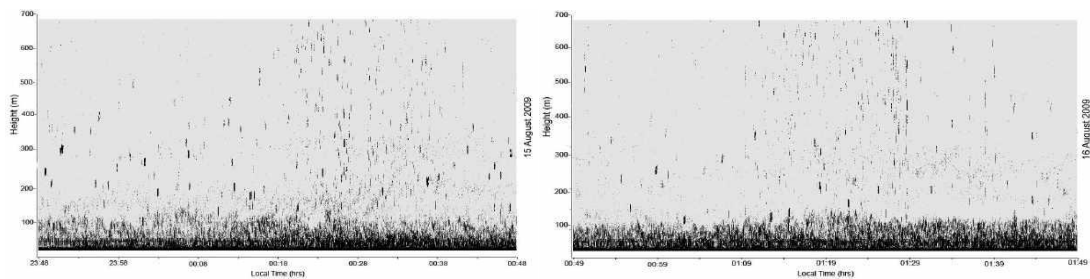


Figure 16 Sodar facsimile records showing lump structures from 23:48 on 15 August 2009 to 01:49 hrs on 16 August 2009.

Such sudden surge can also be seen from about 01:10 hrs to 01:30 hrs on 16 August 2009. During both the occasions, a rise in the height of the surface based acoustic scattering is observed. This is the manifestation of enhanced mixing due to sporadic turbulence that is often seen in an otherwise stable atmosphere in nocturnal boundary layers (Coulter, 1990; Cheung and Little, 1990; Salmond and McKendry, 2005; Singh et al., 2005). A similar event is seen between 02:05 hrs and 02:25 hrs on 16 August 2009 (Figure 17).

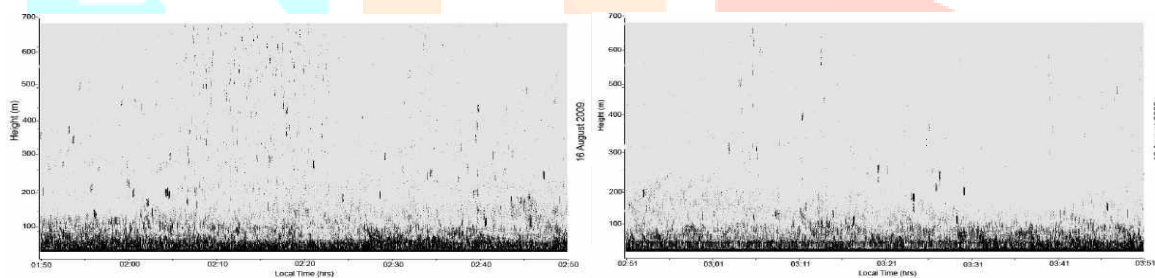
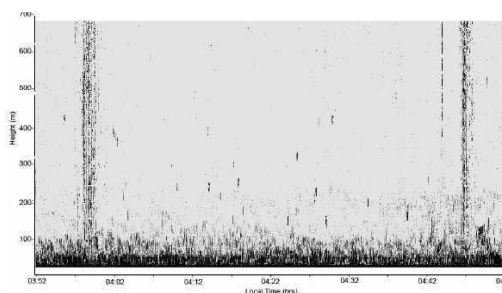
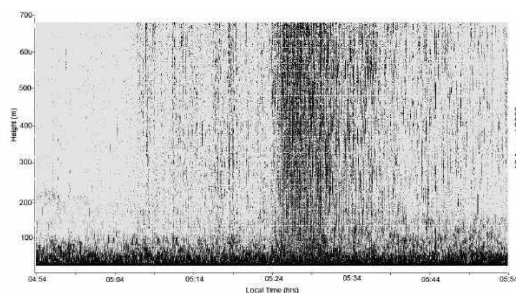


Figure 17 Sodar facsimile records showing lump structures from 01:50 to 03:51 hrs on 16 August 2009.

The echo regions upto top of the record on two occasions, namely, at around 04:00 hrs and again at 04:45 hrs are due to light rain (Figure 4.18). As can be seen from the record, the number of lump structures has started decreasing as dawn approaches.



(Figure 18)



(Figure 19)

Figure 18 Sodar facsimile records showing lump structures from 03:52 to 05:54 hrs on 16 August 2009.

Figure 19 shows the number of lump structures observed during the night of 15-16 August 2009. The number was counted manually from the facsimile record of the sodar. The number plotted at each hour, for example, at 19:00 hrs represent the count of the lump structures during the preceding hour.

Figure 19 shows that the maximum number of lump structures is observed after midnight.

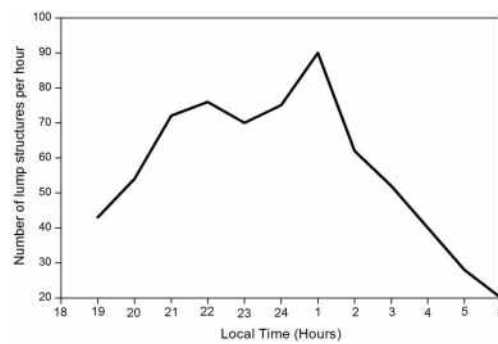


Figure 19 Number of lump structures between dusk and dawn on 15-16 August 2009.

Conclusions

During the two-year period of the present study (2009 and 2010), the Doppler sodar data is available for 172 days for the two southwest monsoons. The lump echo structures are observed during 24 nights. For the purpose of brevity, a case study is presented and discussed above. In general, a passage of thunderstorm or a sea breeze circulation in or around the experimental site seems to be a pre-requisite for the formation of lump structures during the southwest monsoon. Although not shown here in the form of a graph similar to that given in Figure 19, the frequency of occurrence of lump structures peaked after midnight in almost all the 24 days.

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