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Perspectives on land breeze characteristics over Chennai

B. AMUDHA, P. A. SUBADRA and V. RADHIKA RANI

Regional Meteorological Centre, India Meteorological Department, Chennai – 600 006, India

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e mail : amudha2308@gmail.com

सार – अक्तूबर 2009 में चेन्नै (नुंगमबाक्कम) में एक स्वदेशी उच्च पवन गति रिकार्डर (HWSR) संस्थापित किया गया जो एक मिनट के अंतराल पर पवन की दिशा और पवन की गति को रिकार्ड करता है। इस आधुनिक प्रेक्षण प्रणाली से प्राप्त किए गए उच्च आवृत्ति के आँकड़ों का उपयोग, इस स्टेशन पर वर्ष 2010-2012 में जनवरी से मार्च तक की अवधि के दौरान धरातलीय हवाओं की विशेषताओं को समझने के लिए किया गया है। पूर्वी हवाओं का पश्चिमी हवाओं की दिशा में पवन की दिशा में परिवर्तन की प्रेक्षित नियमितता यह बतलाती है कि आधी रात के बाद और प्रातः काल में धरातलीय हवाएँ बहेंगी, जब धरातलीय हवाएँ चलती हैं तो उसके घंटों के अनुसार आवृति का वितरण होता है, शांत हवा के दौरान पवन गति सामान्य होती है और अन्य महत्वपूर्ण विशेषताएँ दर्शाती है। इस विश्लेषण से पता चला है कि इस अध्ययन के दौरान 94 प्रतिशत अवसरों पर चेन्नै नुंगमबाक्कम में धरातलीय हवाएँ एक नियमित और महत्वपूर्ण विशेषताएँ रही हैं। यहा 50 प्रतिशत अवसरों पर धरातलीय हवाओं के बहने का समय प्रातः काल में भा. मा. स. के अनुसार 00 बजे से 03 बजे के बीच रहा है जबकि 73 प्रतिशत अवसरों पर धरातलीय हवाओं के बहने में क्षय का समय भा.मा.स. के अनुसार 08 बजे से 11.00 बजे के बीच रहा है।

ABSTRACT. An indigenous High Wind Speed Recorder (HWSR) which samples the wind direction and wind speed at one minute interval was installed at Chennai (Nungambakkam) in October 2009. The data obtained from such a modern observing system with high sampling frequency has been utilised to understand the land breeze characteristics over the station during January to March of the period 2010-12. Regularity observed in the transition of wind direction from easterlies to westerlies heralding the commencement of land breeze in the late night and early morning hours, frequency distribution of the hours in which land breeze occurs, the normal wind direction during steady land breeze and other interesting features have been presented. Analysis revealed that on 94 per cent of the occasions during the study period, LB was a regular and significant feature over Chennai Nungambakkam. The time of commencement of LB was in the early morning hours between 00 and 03 hours IST on 50 per cent of the occasions while time of decay of LB was between 08 and 11 hours IST in 73 per cent of the occasions.

Key words – Land breeze, High wind speed recorder, Chennai, Westerlies.

1. Introduction

Coastal cities come under the influence of land breeze (LB) and sea breeze (SB) due to land-sea surface temperature (LST-SST) contrasts and differential cooling between the two surfaces. An excellent overview of observations and theories known of thermally driven LB and SB circulations which are solenoidal has been provided by Defant (1951). SB is more prominent during late afternoons when the wind blows from sea towards land. LB is a nocturnal phenomena occurring towards late night and prevailing up to the early morning hours when wind blows from land towards sea. When compared to SB whose depth can be up to 1.5 km, LB is shallow and would be less than 500 m (Asnani, 2005) in the vertical direction, above mean sea level. Heterogenity in the urban landscape induced due to natural and anthropogenic causes also leads to changes in the intensity in LB (Liu, 2005), and the effect of coriolis force due to earth's rotation is disregarded in such smaller spatial scales. Day-to-day variations in LB are caused presumably by complex micro-climatological imbalances in the atmospheric thermodynamics over a station. LB effects are important because the occurrence and timing of the nocturnal land breeze impact low-level winds, atmospheric stability, low temperatures and fog development. Accurate predictions of the LB are critical for dispersion of pollutants as atmospheric stability can change noticeably with the passage of a LB front.

While the climatology of SB over maritime cities has been researched in-depth, such attempts on LB for examining its characteristics, structure and evolution are limited to Indian cities like Calcutta, now Kolkata (Sen Gupta & Chakraborty, 1947), Bombay, now Mumbai (Dekate, 1968), Goa (Prasad *et al*., 1977), Sriharikota (Sivaramakrishnan and Rao, 1991), Kalpakkam (Panchal, 1993) and Chennai (Raj and Nageshwari, 2000).

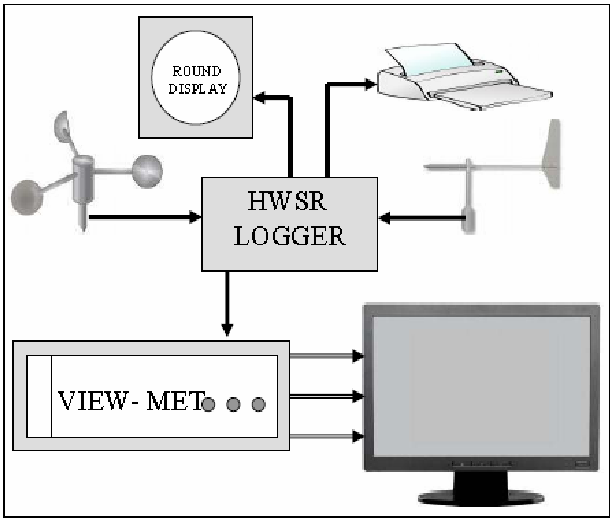


Fig. 1. Block diagram of the High Wind Speed Recorder

The main reason is that LB is a fair weather phenomenon not attracting the attention of the weather forecasters unlike the SB which is a much awaited mesoscale event perceptibly because of the cool respite from heat it brings and the likely convective rainfall activity in the late afternoons / evenings on an oppressive summer day.

Chennai, the coastal capital city of the state of Tamil Nadu, is located in the southeastern coast of India. SB occurs over the city from the Bay of Bengal (BoB) and its characteristics have been studied in detail by Raj *et al*. (2002). LB is also a component of the wind pattern observed in the city during the winter months. Chennai has two low level wind regimes: (a) westerly and (b) easterly. During the westerly regime, the prevailing low level winds are westerlies from mid-April to mid-October and with the onset of SB, easterly winds blow from BoB during forenoon or afternoon and continue till night. During the easterly regime from mid-October to mid-April, the prevailing winds at low levels are easterlies. Predominant westerly winds from land to sea known as LB, develop during late night / early morning hours. LB is more prominent in Chennai after the retreat of northeast monsoon (NEM) season of the period October to December, when the speed of prevalent easterlies shows a slight decrease (*loc.cit.*). There are two conventional surface meteorological observatories in Chennai, one at Nungambakkam (NBK) and the other at Meenambakkam (MBK). Primarily, it was observed from literature survey that an analysis of the LB characteristics over Chennai-NBK (13° 04' N / 80° 15' E) which is located around 4 km westwards from the BoB coast has not been attempted whereas Raj and Nageshwari (2000) utilised the conventional autographic charts for the 10 year period 1971-80 for Chennai-MBK (13° N / 80.25° E) to study the LB characteristics over the station located around 15 km westwards from the sea coast. They inferred that winter LB is much more regular than the summer SB and that the development of LB occurs at early morning hours, 0035 hours IST (Indian Standard Time) in January, 0135 hrs IST in February and 0140 hrs IST in March. This finding is in consonance to the transition of the season from winter to early summer. January, February and March are the months of significant LB occurrence over Chennai.

In this background, the objective of this study is to utilise wind direction (WD) and wind speed (WS) data of the three months January, February and March for the period 2010-12, from the indigenous-make High Wind Speed Recorder (HWSR) installed at NBK in October 2009 and understand the salient features of LB which blows steadily for a definite duration on a daily basis over Chennai-NBK. A brief description of the HWSR is provided in Section 2 and the data used is dealt with in Section 3. The parameters identified for understanding the characteristics of LB have been explained in Section 4 under methodology of computations and analysis. Section 5 is about the spells of LB which commenced from previous day and continued on the day of observation. Section 6 focuses on the results arrived at and Section 7 summarizes the outcome of the study.

2. High wind speed recorder

The technical details of the HWSR designed at the O/o Dy. Director General of Meteorology (Surface Instruments), India Meteorological Department (IMD), Pune have been dealt with by Vashistha *et al*. (2010). The block diagram of the HWSR and the equipments installed in Regional Meteorological Centre, Chennai are provided in Fig. 1. HWSR provides a continuous graphical display of WD and WS through a Thin Film Transistor (TFT) monitor and a 36-point, Light Emitting Diode (LED) circular display for distant monitoring of wind. User-friendly menu driven options facilitate easy operation. The WD and WS data are configured to log averages for one, two and ten minute intervals in the HWSR. One minute samples in IST of WD and WS totalling to 1440 per day are stored as one file per day in the HWSR data logger. The advantage of this wind data is that vector averaging of WD and WS is done while sampling the data through HWSR whereas the WD and WS recorded in a conventional meteorological observatory are scalar averaged. The design and sampling methodology used in the HWSR are primarily based upon ICAO (International Civil Aviation Organisation) criteria so that it can fulfill requirements in airports as well. Such modern observing tools like the HWSR provide valuable real time inputs to the operational weather forecaster to nowcast the commencement / decay of LB.

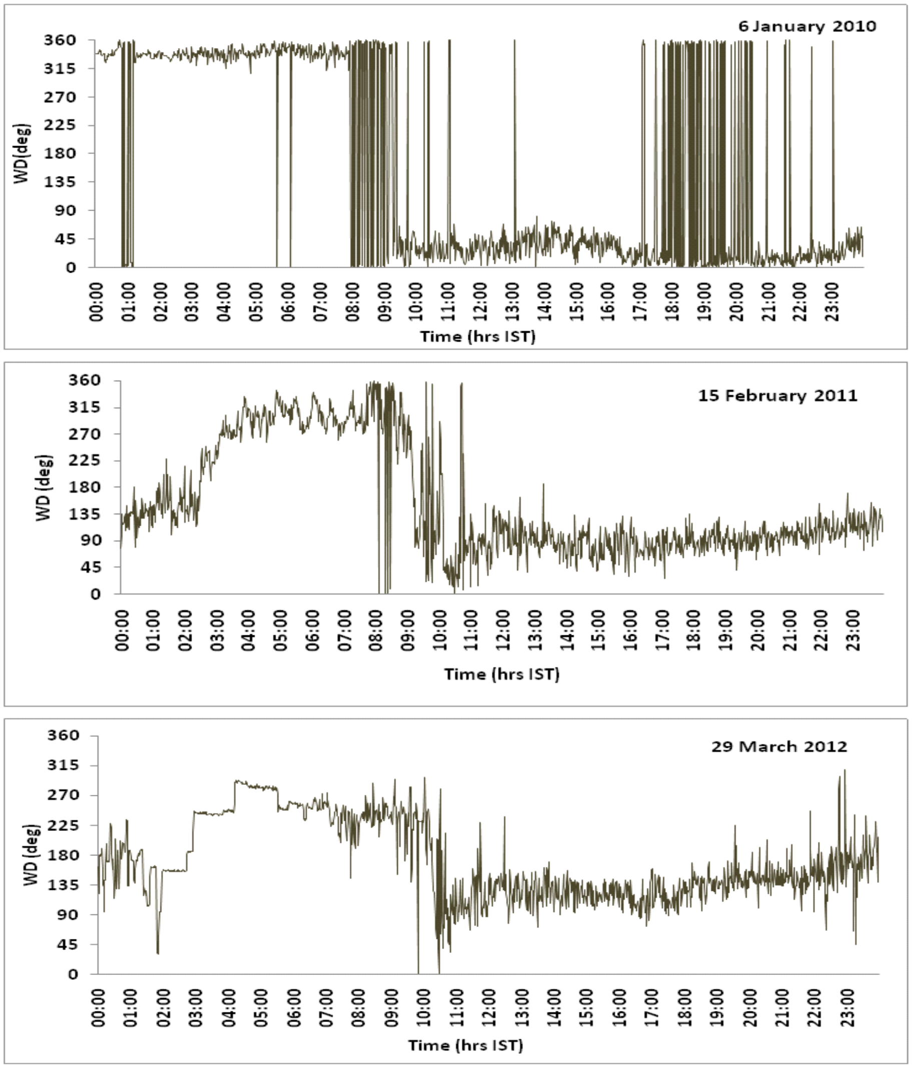


Fig. 2. Transition of wind direction from easterlies to westerlies depicted for representative days of January, February and March

The indigenous HWSR system utilises IMD-make sensors; a servo-micro-torque 10 kilo-ohms potentiometric wind vane for the measurement of WD and optical anemometer for WS. Optical anemometer gives digital as well as analog outputs with respect to the WS in knots. The user-friendly outputs available from automated equipments help the operational weather forecasters in understanding the characteristics of the onset of SB and LB. As an aspect of automation, the validation of the WD and WS recorded by the HWSR during the NEM season (October to December) of year 2009 was done by Amudha and Raj (2010) by performing a spectral analysis of the wind data. The study indicated interesting patterns synonymous with the established climatological persistence and periodicity in wind during NEM season. The daily variability in WD over Chennai depicting the transition from easterlies to westerlies for 6 January, 2010; 15 February, 2011 and 29 March 2012 representative of the months considered for the study are provided in Fig. 2 which are sample graphical outputs from HWSR.

TABLE 1

Data used for the study

Month↓	Number of days		
Year→	2010	2011	2012
January	29	29	29
February	27	25	28
March	31	26	31
Total : 255 days			

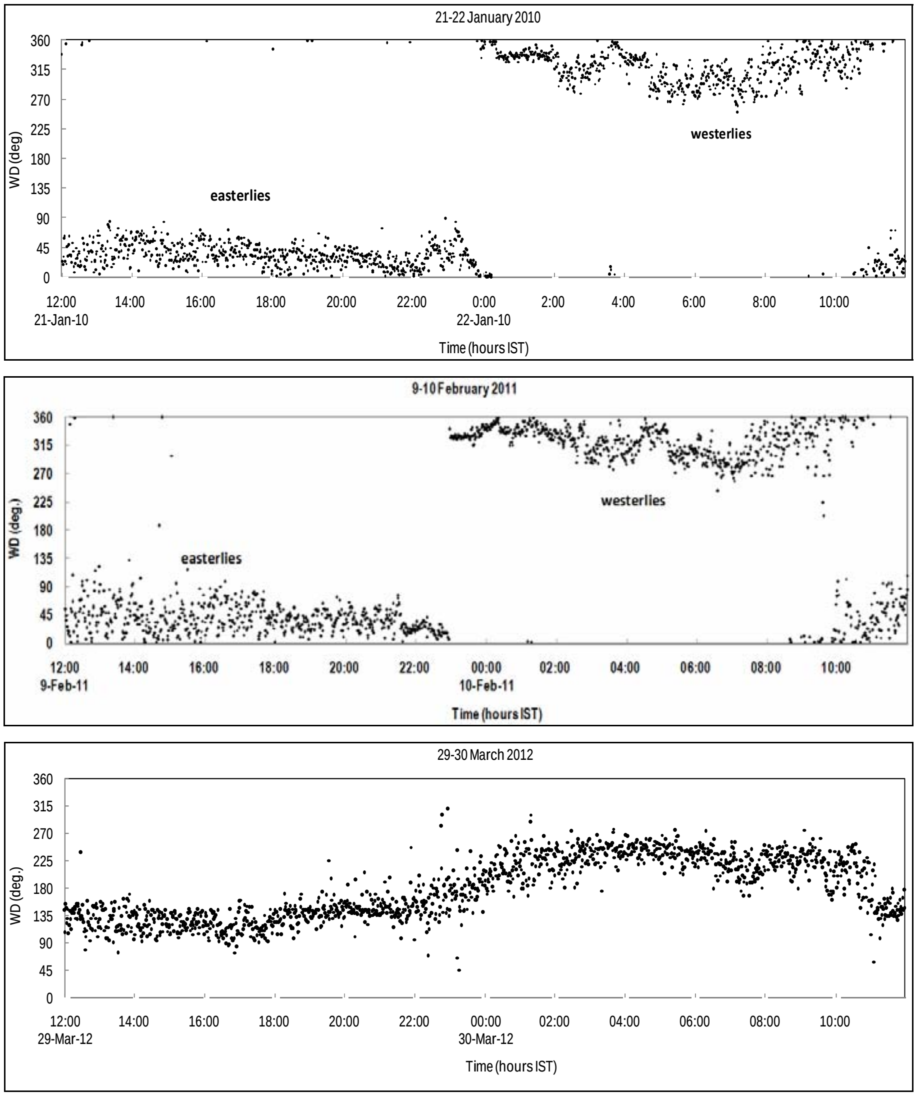


Fig. 3. Depiction of the transition in wind direction when land breeze commenced on the previous day for three instances in January, February and March

3. Data

3.1. WD and WS data retrieved from HWSR data logger for the years 2010, 2011 and 2012 for three months (January & March: 93 days each and February: 85 days = total of 271 days) were utilised. Out of the 271 days, 255 days (Table 1) of data constituting 94 per cent of the total days have been considered.

3.2. Upon scrutiny, the data of 16 days could not be included in the study due to the following reasons:

(*i*) Occurrence of insignificant, small duration spells of westerlies in a day.

(*ii*) Weak westerlies that prevailed for a very short duration in a day, in the evening alone.

(*iii*) Non-logging of data by HWSR due to technical problems which led to missing data of few days.

(*iv*) Absence of clear-cut westerlies on rainy days.

4. Computation methodology and analysis

In order to analyse the WD and WS data, parameters listed in Sections 4.1 to 4.7 were identified to cull out the significant features of LB over NBK. The term "Steady LB" used in the forthcoming sections represents the prevalence of sustained westerlies over a period of time in a day.

Commencement and decay of steady LB is associated with transition of WD only. For WS, a minimum threshold could not be demarcated in view of

TABLE 2

Range (hours IST) of commencement and decay of land breeze during 2010-12

Month	Commencement						Decay					
	2010		2011		2012		2010		2011		2012	
	from	to	from	to	from	to	from	to	from	to	from	to
January	2206 (*)	0715	1740 (*)	0700	2011 (*)	0730	0250	1322	0215	1702	0321	1445
February	0000	0634	2045 (*)	0608	2334 (*)	0842	0740	1339	0740	1149	0726	1116
March	2146 (*)	0634	2215 (*)	0559	2305 (*)	0839	0614	1210	0736	1304	0623	1318

* - *previous day*

TABLE 3

Average duration of steady land breeze

Month & Year	Year-wise	Month-wise for the three year period
	(hours & minutes)	
January 2010	7.45	
2011	9.38	
2012	6.32	7.58
February 2010	6.40	
2011	8.01	
2012	6.18	6.47
March 2010	9.17	
2011	8.35	
2012	8.22	8.44

TABLE 4

Maximum wind speed observed during steady land breeze

Month	Date	Wind speed (knots)	Time of occurrence (hours & minutes)	Wind direction
January	23 Jan 2010	8.7	09.47	345 - NW
	16 Jan 2011	5.8	07.56	343 - NW
	12 Jan 2012	5.9	09.03	348 - NW
February	23 Feb 2010	9.2	10.35	246 - WSW
	01 Feb 2011	7.4	09.44	346 - NW
	03 Feb 2012	5.3	08.06	348 - NNW
March	31 Mar 2010	9.5	10.20	244 - WSW
	30 Mar 2011	10.0	11.25	242 - WSW
	07 Mar 2012	11.0	11.44	238 - WSW

the variability associated with the higher drag encountered by the air flow due to terrain constraints and contributions from aerodynamic roughness over land.

Instances of calm/zero WS observed during the steady LB period and up to the transition in WD to easterlies have been accounted as part of the steady LB only.

Out of the 255 days mentioned in Section 3.1, the steady and continuous spells of westerlies on 221 days of LB that commenced and decayed on the day of

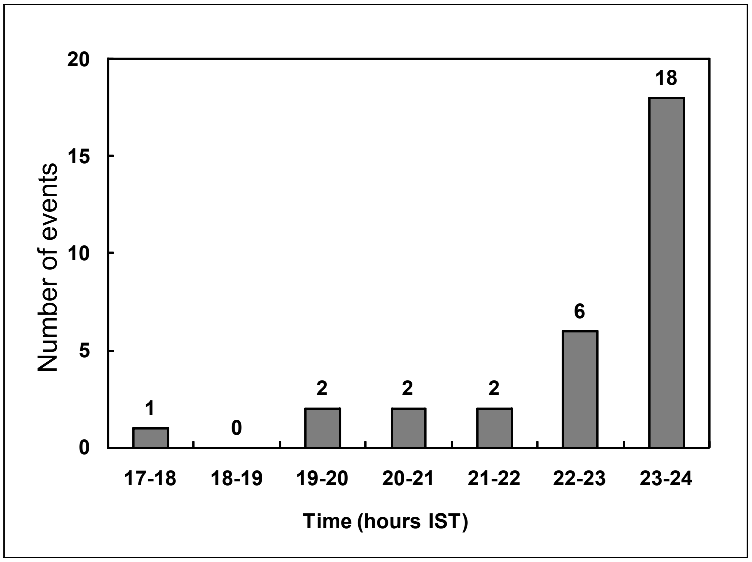


Fig. 4. Frequency distribution of the time of commencement of land breeze events on the previous day

observation could be identified. On some days, though subsequent short spells of weak westerlies occurred after the decay of the first spell of steady westerlies, they were insignificant and hence not considered. Among the 255 days, there were 31 days when LB events commenced from the previous day and continued through the day of observation. Samples taken from each month, representative of such events *viz*., 21-22 January, 2010; 9-10 February, 2011 and 29-30 March 2012 are provided in Fig. 3. Few aspects of these previous day LB events have been discussed in Section 5. In addition, continuous flow of westerlies for more than two days without a break was noticed in two instances of January 2010 and 2011. They were on (a) 8 January, 2010 from 0535 hours IST (which continued on 9 and 10 January, 2010 up to 1153 hours IST) and (b) 6 January, 2011 from 1944 hours IST, for four days up to 1659 hrs of 10 January, 2011. Physical causative factors for the special feature observed on these days could not be comprehended and have not been dealt with in this paper.

The following features defined in detail, have been extracted from the data used:

4.1. *Time of commencement (ToC) and time of decay (ToD) of steady LB*

Commencement of LB is associated with transition from the prevailing easterly WD to westerly, when wind starts blowing from land towards sea. The time at which this change-over in WD to westerlies occurs is defined as Time of Commencement (ToC) of steady LB. Similarly, the time at which the transition in WD from westerlies to easterlies is observed is taken as the Time of Decay (ToD).

4.2. *Monthwise average ToC and ToD of steady LB*

The monthwise average ToC and ToD of steady LB have been computed. The days which had the onset of LB on the previous day's late evening / night are 31 in number and have been excluded in the computation of this parameter in view of the unduly large misrepresentation of ToC that would be arrived at, if the previous day's ToC was included while averaging. In addition, the days when westerlies continued without well-defined commencement / decay on that day have also been excluded.

4.3. *Frequency distribution of the ToC and ToD of steady LB*

Out of the 255 days of January to March for the period 2010-12 under consideration, hourwise frequency distribution of the ToC and ToD could be made for 252 days. The remaining 3 days had neither a ToC nor a ToD because they formed part of the spell of continuous westerlies as mentioned in Section 4.

4.4. *Range in hours of ToC and ToD of steady LB*

The earliest and latest times at which westerlies set in / decayed indicate the range (in hours IST) of ToC /

ToD of steady LB. For the months of January to March during the three years 2010-12, the upper and lower limits of ToC and ToD have been extracted (Table 2) from which the range in the ToC and ToD of LB could be understood.

4.5. *Monthwise average duration of LB*

The duration of westerlies in a day is the time (in hours) between ToC and ToD as mentioned in Section 4.1. Duration on a daily basis has been computed for all the 255 days including (a) 221 days when ToC and ToD were on the same day, b) 31 days of steady LB with ToC on the previous day and ToD on the day of observation and c) 3 days of continous spells of westerlies. From this, month-wise average duration of LB was obtained (Table 3).

4.6. *Average WD during steady LB*

All the one minute samples of WD during the daily steady LB period were resolved into the zonal and meridional components, averaged and then the daily mean WD was obtained. Following a similar procedure, the monthwise average WD, both during steady LB and prior to the steady flow of LB were also calculated.

4.7. *Maximum WS during steady LB*

The daily maximum WS which occurred during the steady LB phase is extracted for each day and from these values, the monthly maximum WS, its corresponding WD and time of occurrence of maximum WS have been retrieved and furnished in Table 4. This parameter enables an understanding of the variability in WS over NBK caused by LB during the winter months.

5. Spells of LB which continued from previous day to the day of observation

As mentioned in Section 4, during 2010-12, 31 days (January - 14; February - 7; March - 10), had the ToC of LB in the late evenings /or nights of previous day itself and continued on the day of observation, decaying after the setting in of easterlies. For example, the LB event which commenced on 6th January, 2011 at 1944 hours IST is the previous day commencement of LB for 7th January, 2011 (the day of observation). Fig. 4 provides the frequency distribution of ToC of previous day LB events. On 18 occasions, ToC of LB occurred in the 23-24 hours IST of the previous day and January had the earliest ToC in the range 17-18 hours IST. Further, ToC of LB on the previous day did not have any influence on the ToD which remained the same as that observed in the rest of the 221 days.

6. Results and discussion

The results that emerged from the analysis of the parameters extracted as mentioned in Section 4.1 to 4.7 are discussed.

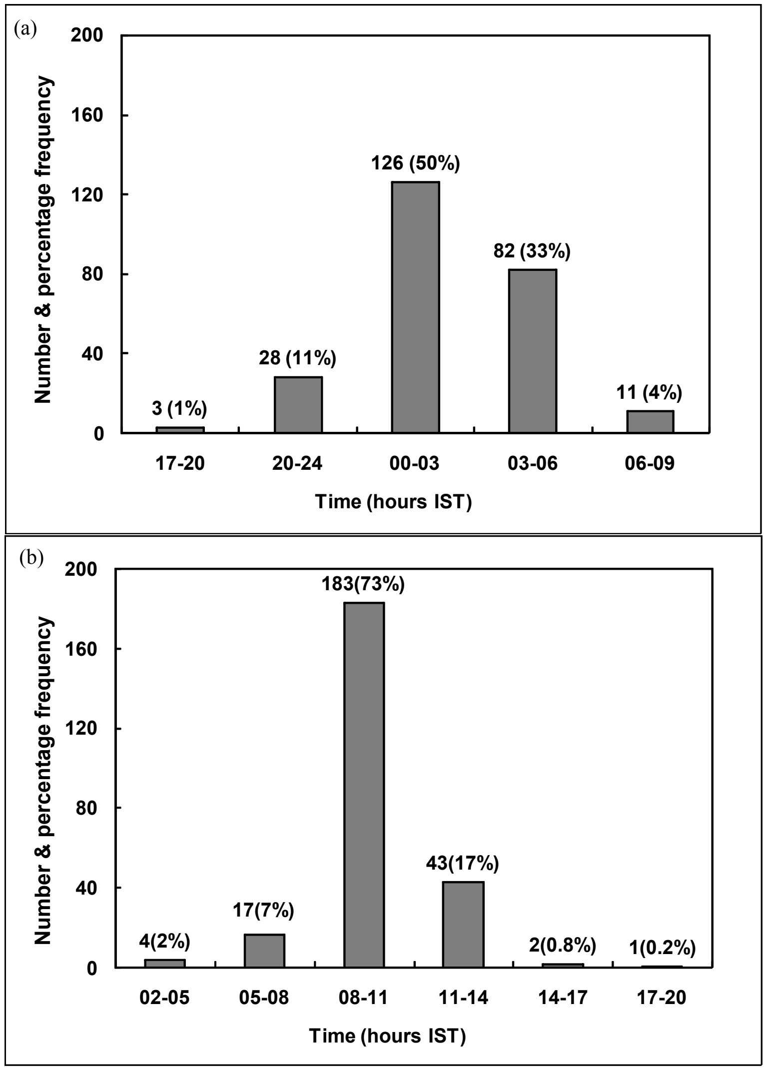
6.1. *Influence of NEM on steady LB*

The dates of withdrawal of NEM season of the years 2009, 2010 and 2011 were on 18 January, 2010; 17 January, 2011 and 10 January, 2012 respectively. Climatologically, in one third of the years, NEM spills over to January which has been observed for three consecutive years of the period of this study (2010-12). In the first two weeks of January, the strong influence of the low level easterlies that prevail for longer duration in the withdrawal phase of the NEM season over NBK is evident from the shorter spells of westerlies associated with LB observed during the month.

6.2. *Distribution of ToC and ToD of steady LB*

The frequency distributions of the ToC and ToD are presented in Figs. 5a&b. Out of 252 days, frequency of 250 days only could be accounted in ToC and TOD. There were two days each without ToC (10th January, 2010 and 2011) and without ToD (8th January, 2010 and 7th January, 2011) because they were part of continuous westerly spells. From the frequency distributions of the ToC [Fig. 5(a)] and ToD [Fig. 5(b)], considering all the months together, it is noticed that 00-03 hours IST is the most preferred ToC of LB (50 per cent), next being 03-06 hours IST (33 per cent). ToD falls in the range 08-11 hours IST in 73 per cent of the days. It is pertinent to note that ToD exhibits a consistency in its cessation hours while hourly frequencies of ToC are spread over from midnight to early morning hours which indicate the influence of the stability conditions of the atmosphere on the ToC of LB. Moreover, LB forms after sunset when radiational cooling of the surface commences (Sills, 1998) which stabilises the nocturnal boundary layer inhibiting the vertical circulation of LB.

Further, it is noticed that the average ToC of steady LB during the months of January (0308 hours IST) and February (0256 hours IST) is nearly the same, due to the almost similar type of weather observed during these winter months over NBK. Compared to the results of Raj and Nageshwari (*loc.cit.,)* for MBK, as mentioned in Section 1, higher average ToC and hence later onset of LB for all the three months over NBK has been obtained. NBK records higher minimum surface temperatures compared to MBK which is located away from the BoB coast. Due to LST-SST differences over the two stations, MBK is cooler than NBK during early morning hours and



Figs. 5(a&b). Hourwise frequency (percentage is given in brackets) distribution of the time of (a) commencement and (b) decay of land breeze during January to March for the period 2010-2012

so ToC of LB is earlier over MBK. However, a slightly delayed ToC of westerlies in January is conspicuous during the years 2010-12, which can be attributed to the effect of the prevailing easterlies of the withdrawal phase of NEM during the month. In March, an average ToC of 0152 hours IST over NBK marks an earlier onset of steady LB in the month, when compared to January and February. ToC of LB is earlier on some days due to onset of early offshore synoptic winds caused by the distinct temperature gradient associated with longer periods of insolation in March over NBK.

On a monthly average basis, January and March had an almost same ToD of 1015 and 1018 hours IST, though delayed when compared to February which had an early ToD of 0934 hours IST.

6.3. *Range of ToC and ToD of steady LB*

During January, February and March, a wide range in the ToC of steady LB (*i.e.*, from the previous day to the day of observation) *viz*., from 1740 to 0733, 2045-0625, 2146-0839 hours IST respectively is observed (Table 2). It is evident that on rare occasions LB can commence in evenings prior to sunset or after sunrise over NBK. However, ToD is on the same day and has ranged from 0215-1702, 0726-1339, 0614-1318 hours IST for January to March respectively. In spite of the extremities observed in the range of ToC and ToD, the preferred ToC and ToD of steady LB are during 00-03 hours IST and 08-11 hours IST respectively as indicated in Figs. 5(a&b). A preliminary analysis of the hourly air temperature and relative humidity profiles over NBK on such days, using data from Automatic Weather Station did not manifest any unusual signal that might have led to such extreme values of ToC and ToD and requires further study.

6.4. *Duration of steady LB*

The average duration of steady LB (Table 3) for the months of January, February and March of the period 2010-12 is 7.58 (7 hours, 58 minutes), 6.47, 8.44 respectively. March had the longest duration of steady LB in each year depicting consistency while there is a significant year-to-year variability in the months of January and February. In the case of January 2011, the spell of westerlies which continued for up to four days (as mentioned in Section 4) seems to have influenced the average duration leading to the longest duration of steady LB (9 hours 38 minutes) amongst the months considered. However, though uniformity in the average duration of steady LB is noticed in March during 2010-12, such a pattern was absent in January and February. Perhaps longer years of analysis would lead to better conclusions about the factors which influence month-to-month variations in the duration of steady LB.

6.5. *Average wind direction during steady LB*

During steady LB periods of January, February and March, it is observed that the average WD is north-north-westerly (NNW-ly), north-westerly (NW-ly) and south-westerly (SW-ly) respectively. Backing of winds is observed over NBK from January to March. Climatologically, the prevailing average WD over NBK in the early morning hours of these months is the same as that observed through the HWSR data. In the month of March, maximum WS in the range of 9-11 knots (Table 4) occurred late in the mornings between 10 and 12 hours IST compared to January and February where the occurrence was earlier. According to Pielke and Segal (1986), maximum WS within the LB circulation is significantly lower than SB in view of the shallowness of LB in the vertical. However, stationwise variabilities in WS during LB are likely, depending upon the local topography and micro-environmental changes. Higher WS similar to that of SB are quite possible during LB events in March also over NBK, especially when LST-SST contrast is higher.

6.6. *Average WD prior to steady LB*

Average WD prior to steady LB was also computed. Veering from NNE to SSE at the ToC and backing from NNW to SW at the ToD for the months of January-March have occurred. The topography of the coast is likely to vary for each coastal station and hence the direction from which wind blows changes as well. Chennai-NBK has a flat terrain and is located almost on the perpendicular north-south orientation of the straight coastline adjoining BoB. Hence, LB tends to blow perpendicular to the coast and hence the direction closest to west is needed to verify this feature. It is seen from the monthwise average WD that there is no significant meridional impact and WD closest to west was WNW in January whereas it is purely westerlies in February and March substantiating the observation made above.

7. Summary

The results of the study are summarised below:

(*i*) During January to March of the study period 2010-12, LB was a regular and significant feature over Chennai NBK in 94 per cent of the occasions.

(*ii*) The feeble strength of LB observed in the month of January could be attributed to the influence of the low level easterlies that prevailed since the withdrawal of NEM season took place in January during 2010-12.

(*iii*) The ToC of LB was in the early morning hours between 00 and 03 hours IST on 50 per cent of the occasions. Whenever LB commenced on the day prior to the date of observation, the preferred ToC of LB was 23-24 hours IST.

(*iv*) On 73 per cent of the occasions, ToD of LB the period of study was between 08 and 11 hours IST.

(*v*) The average WD that prevailed during steady LB periods of January, February and March are NNWly, NWly and SWly respectively.

(*vi*) Average WD prior to steady LB, indicated veering from NNE to SSE at the ToC and backing from NNW to SW at the ToD for the months of January to March.

(*vii*) Higher WS of 9-11 knots are possible when LB blows, with the significant influence of LST-SST contrast in March.

(*viii*) March had the longest average duration of 8 hours and 44 minutes of steady LB compared to January and February in view of the significantly higher LST-SST contrast due to higher insolation received during the month.

(*ix*) LB commences late over NBK as surface air temperatures are higher than MBK during winter months.

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