Pre-squall Mesolow, Mesohigh and Wake Low in Association with Premonsoon Thunderstorms - An Observational Study

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ABSTRACT

Observations during premonsoon season of 2008-09 in STORM field experiment are used to examine surface characteristics, in particular surface pressure characteristics, of the convective systems that occurred over the semi-arid part of Gangetic West Bengal. Analyses of automatic weather station data identify transient presquall mesolow, mesohigh (MH) and wake low (WL) during the entire life cycle of the systems. Convective activities are found to be associated with short-lived MH and relatively long-lived WL in 60% events. Average pressure rise of 1.9 - 2.5 mb in MH followed by WL with average pressure drop of 4.2 - 8.9 mb are noticed. Doppler weather radar imageries further reveal that formation of MH & WL takes place in case of organized convective systems. More (less) organized convective systems show more (less) pressure perturbations in MHs & WLs. Most interestingly it has been observed that wind speed shows its maximum value when pressure rises in MH while in WL the environment becomes nearly calm. WLs are also found to be highly localized so that air parcels do not stay for a longer time within the strong pressure gradient fields to achieve higher velocities. As a result these WLs, unlike other locations in USA, do not produce damaging extreme winds in their vicinity.

Keywords*: Mesolow, Mesohigh, Wake Low and Pre-monsoon.*

1. Introduction

Premonsoon thunderstorms over Gangetic West Bengal (GWB), locally known as ‘Kalbaishakhi’, received attention to the researchers since the beginning of the second decade of the Twentieth century (Normand, 1921). Since then, various aspects of this type of convective activities have been studied and reported in the literature. But the details of their evolution, life cycles, spatial and temporal extent were not known till the beginning of the Twenty-First century, perhaps due to non-availability of required observations. Installation of a Doppler Weather Radar (DWR) in Kolkata helped the researchers, for the first time in India, to attempt a case study on the evolution and propagation of a super-cell convective system that occurred over GWB on 12th March, 2003 (Sinha and Pradhan, 2006). To improve our understanding on the genesis and evolution during the entire life cycle of premonsoon thunderstorms over eastern and north-eastern parts of India, a nationally co-ordinated programme, Severe Thunderstorm Observation and Regional Modelling (STORM), was launched by the Department of Science and Technology, Government of India, during the period 2006-10 (Litta and Mohanty, 2008). Using STORM data, mainly with the help of DWR imageries and upper air observations (Dalal et al., 2012), it was shown that besides scattered formation of premonsoon thunderstorm cells, on several occasions, they organized themselves into Mesoscale Convective Systems (MCS). Following the criteria laid down by Houze et al. (1989), 50 cases of MCS were analyzed and categorized them into three modes: Leading Stratiform (LS) where the stratiform cloud leads the convective line; Parallel Stratiform (PS) with stratiform cloud on either side of the convective line; and Trailing Stratiform (TS) where stratiform cloud trails the convective line (Dalal et al., 2012). However, surface characteristics, particularly surface pressure perturbations and associated winds, in connection with either scattered premonsoon thunderstorms or any of the organized modes of MCS have not been reported over GWB or elsewhere in India except a case study at a particular station Kharagpur over GWB (Dawn and Mandal, 2013). Moreover surface pressure perturbations are short-lived mesoscale phenomena; and difficult to understand and predict in advance by operational forecasters.

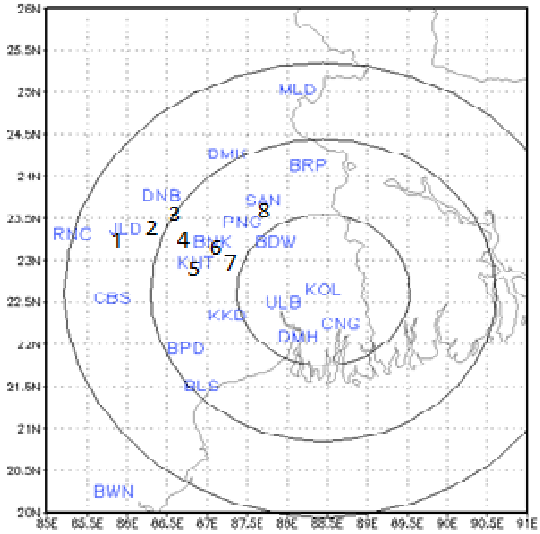

Figure 1: Study area showing the locations of the eight automatic weather stations marked as 1 through 8. The circles centered on Kolkata (KOL), having radii 100, 200 and 300 km, show the area covered by Doppler radar installed at Kolkata

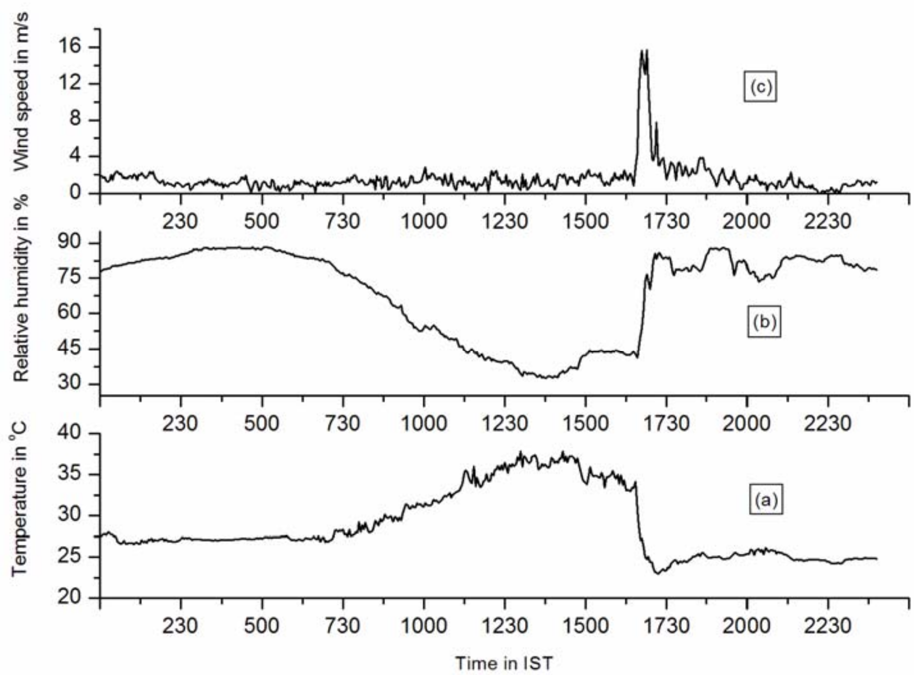

Figure 2: AWS recording of 3-minute averaged data for (a) temperature (b) relative humidity and (c) wind speed on a particular day (8th May, 2008) at SLD, claiming thunderstorm activity at about 1630 IST

The main objective of this paper is, therefore, to report a detailed study related to surface characteristics associated with the premonsoon convective activities over the semi-arid region of GWB during the period 2008-09 using STORM data for better understanding of the events which can be a great help to the operational forecasters.

2. Study Area

The study area mainly comprises with Purulia, Bankura and Birbhum districts in the south-western part of GWB (Fig. 1). The area is actually the tail end of Chottanagpur plateau having 100 – 300 m height above sea level. Though it is about 200 km away from the Bay of Bengal (BOB), the area is characterized by dryline discontinuity at the low-levels as a result of warm moist surface SSW-ly/SW-ly wind from the BOB and relatively cool dry wind from the north-west during the premonsoon season. The atmosphere thus exhibits latent instability during the season. Again strong insolation during the daytime makes the situation convectively unstable under favourable synoptic setting, resulting thunderstorm activity often associated with squalls in the early afternoon hours.

3. Data and Methodology

The study used data sets that were collected in STORM programme. One of the authors (DL) participated in the programme through installation of eight Automatic Weather Stations (AWS) covering three semi-arid districts of GWB, namely, Bankura, Purulia and Birbhum. The location of the AWSs were at (1) Jhalda (JLD; 85.98^{o}E,23.37^{o}N) ; (2) Purulia(PRL ; 86.38^{o}E, 23.33^{o}N); (3) Raghunathpur (RGP; 86.67^{o}E, 23.55^{o}N); (4) Shaldiha (SLD; 86.72^{o}E, 23.20^{o}N); (5) Khatra (KHT; 86.85^{o}E, 22.98^{o}N); (6) Puabagan (PUB; 87.07E, 23.23N);(7) Bishnupur (BIS; 87.32^{o}E,23.08^{o}N); and (8) Shantiniketan (SNT; 87.70^{o}E,23.72^{o}N) as shown in the Fig. 1. Each AWS consists of a 10 m tower fitted with several sensors to measure surface atmospheric parameters, soil parameters, solar radiation and rainfall. Surface atmospheric parameters include temperature, relative humidity, pressure, wind speed and wind direction. Among the various sensors, pressure sensor (61205V Young from Cambell Scientific Corporation) was kept at 1.5 m height while wind speed and direction sensor (RM Young from Cambell Scientific Corporation) was placed at 10 m height. Data logger was configured to collect 3-minute average data for all the surface atmospheric parameters while 1-hour average data were stored for solar radiation, rainfall and soil parameters. Besides storing 3-minute average data for wind speed, option for recording the highest wind speed among the samples within 3-minute duration was kept in the data logger.

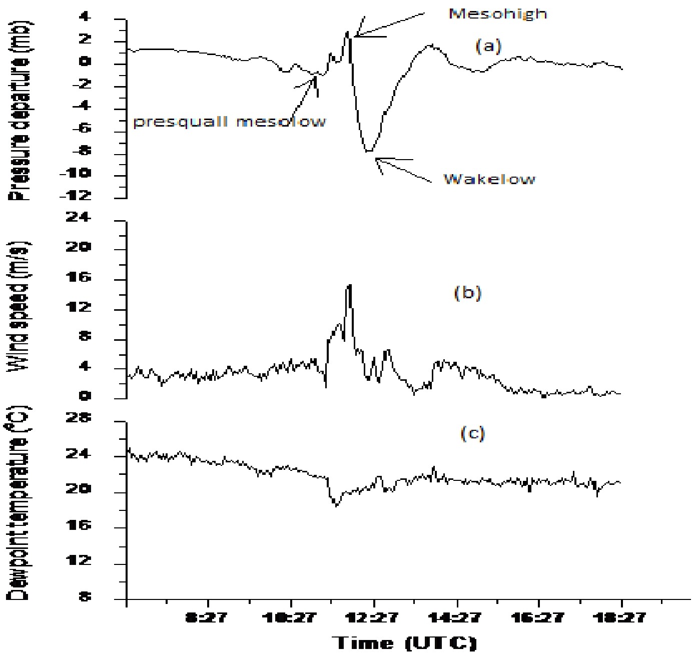

Figure 3: AWS recording of (a) pressure departure, (b) wind speed and (c) dewpoint temperature on 8th May, 2008 at SLD

These data sets along with the Doppler radar imageries are used for the present purpose of the study.

4. Results and Discussion

AWS recordings of the parameters are checked first to identify whether a station experiences convective activity. Usually temperature falls, humidity rises and wind speed increases in a short period of time as a result of thunderstorm activity (Fig. 2). A similar situation has already been reported (Lohar et al., 1992) as a result of onset of seabreezes over the study area, but the magnitudes of the changes are quite remarkable compared to other locations in India or elsewhere. Rainfall is a good indicator of thunderstorm activity but it should be kept in our mind that AWS may not record rainfall in case of dry thunderstorm. In fact, for such cases, precipitation gets evaporated before it reaches to the ground and rainfall amount becomes zero. These are not uncommon over the semi-arid part of GWB, particularly in the month of March and early April. A thunderstorm event is considered here in case at least one of the eight stations experiences the activity supported by AWSs records located at the station. In case more

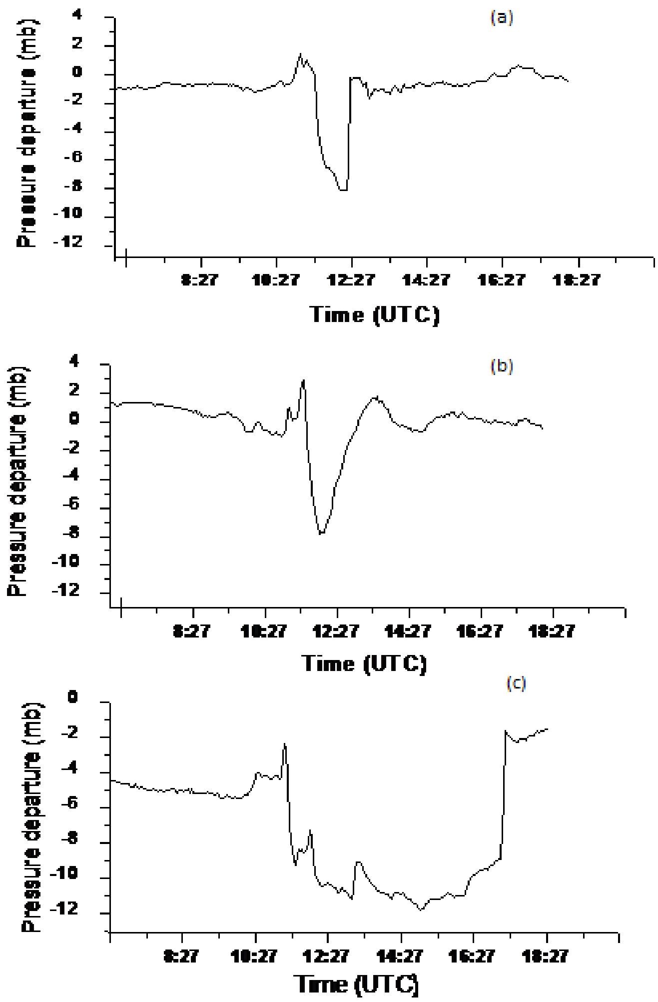

Figure 4: AWS recording of pressure perturbation at SLD on (A) 4th May, (b) 8th May and (c) 18th May, 2008

much higher in case of thunderstorm activities. More than 10°C change in temperature, 40% change in relative humidity and 10 m/s change in wind speed often occur in a short period of time in connection with such activities. Such sharp changes of surface characteristics are than one stations experience a single organized MCS in a day then they are considered as different thunderstorms events. Accordingly 104 thunderstorm events are identified during the period of study. In this study emphasis has been given for surface pressure perturbation during the full cycle of thunderstorm event.

Therefore in order to avoid diurnal variation in pressure field; and for better presentation, pressure departures from long-term mean have been calculated and displayed in all subsequent figures. A close look on the pressure departure pattern shows that pressure decreases for a longer time and shows a minimum before it sharply rises in association with gust wind. This minimum pressure is termed as a presquallmesolow (Fig. 3). Change in pressure in case of presquallmesolow is often not very sharp and therefore statistical details of them are not studied here. The rise in pressure accompanied with gusty wind is known as mesohigh (MH); followed by a sharp fall in pressure and dew point temperature (Fig.3). The latter is known as wake low (WL), similar to cases reported elsewhere (Fujita, 1959; Johnson and Hamilton, 1988; Johnson, 2001; Dawn and Mandal, 2013).

Pressure rise in MH is restricted to 2-4 mb and it takes place within a period of approximately 15 minutes. Thereafter pressure falls and reaches a minimum within about half an hour. MHs are produced by saturated downdrafts that raise pressure hydrostatically because of atmosphere's response to cooling by evaporation, sublimation and melting (Fujita, 1959). Dynamic pressure may also rises when downdrafts strike the ground as found by Wakimoto (1982). On the other hand, WLs are the results of subsidence warming when adiabatic warming due to subsidence offsets the evaporative cooling. Fujita (1985) also noted that a drop in dewpoint temperature could be caused by the entrainment of drier environmental air into the downdrafts.

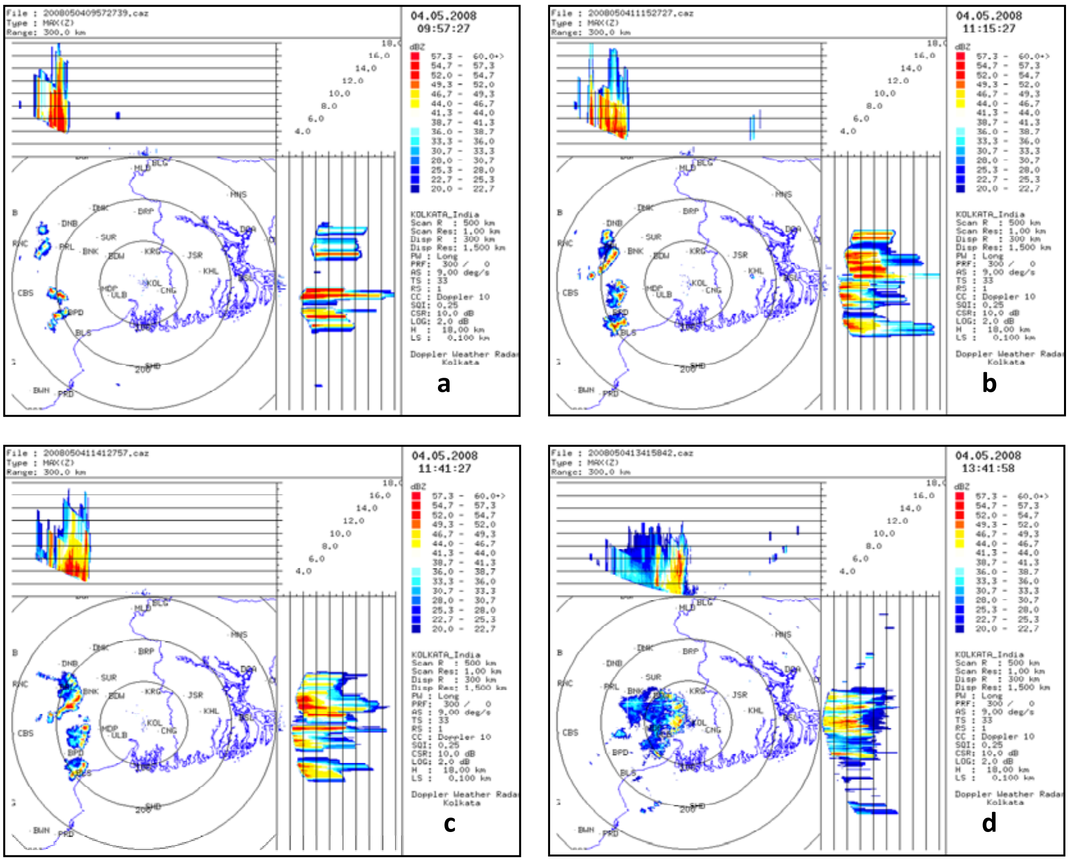

Figure 5:Life cycle of Mesoscale Convective System (MCS) that occurred on 04th May 2008. (a) First appearance of convective cells are seen west and north-west of PRL and over Orissa at about 0957 UTC, (b) & (c) cells between PUB and PRL get more organized and (d) the system reaches KOL at 1341 UTC.

Table1. Pressure Perturbation Statistics of Mesohigh (MH) and Wake low (WL) during the Premonsoon Seasons of 2008-09

Total MH-WL events	Mode of organization	No. of events in each mode	Pressure rise (mb) in case of MHs		Pressure fall (mb) in case of WLs	
			Mean	Standard deviation	Mean	Standard deviation
64	PS	25	2.5	0.9	8.9	4.4
	TS	34	2.7	1.1	9.7	4.1
	SC	04	1.9	0.2	4.2	2.7

Out of 104 thunderstorm events, 64 events are found to be associated with MH and WL (Table 1). This suggests that MH and WL do not occur in all cases; rather 60% cases register them. It requires further investigation to identify situations which favour formation of MH and WL. Doppler radar imageries provide some structural detail of the cloud pattern as well as evolution of the convective systems throughout their life cycles. With the support of these imageries, it is further noticed that nearly 53% (39%) cases of MH-WL formation take places in TS (PS) mode of organization. No LS mode of organization is found to be associated with MH-WL formation. This finding supports the dynamics of the formation of WL, i.e., WL forms in rear side of the convective line where stratiform cloud plays a significant role. On the other hand, possibility of formation of MH-WL becomes less in case of scattered convective cloud (SC), i.e., under relatively weak synoptic support when the convective clouds do not get organized into either PS or TS mode. Again it is noticed that once pressure reaches its minimum, it may come back to normal within one hour or on occasions, it takes longer time. As shown in Fig. 4a, AWS recordings at SLD show WL disappears within less than one hour while it takes more than one hour but less than three hours (Fig. 4b) and more than three hours (Fig. 4c) respectively for other cases. Moreover, TS mode of organization of the convective systems show nearly 47% (44%) of the events which belong to Fig. 4b (Fig. 4c) type while only 9% events are of Fig. 4a type.

Table 2: Values of some parameters at AWS stations as recorded on 4th May, 2008

AWS station	Pressure departure in mb (MH)	Pressure departure in mb (WL)	Wind gust in m/s	Rainfall in mm
JLD	No signature	No signature	11.8	Trace
PRL	2.4	No signature	13.8	2.0
RGP	2.1	No signature	15.4	Trace
SLD	2.2	7.2	12.2	2.2
KHT	2.3	6.7	18.3	13.4
PUB	3.1	8.8	10.9	Trace
BIS	3.9	6.3	16.4	Trace

This result supports the main mechanism behind formation of WL, i.e., they form due to the precipitation evaporation of stratiform region of TS mode of organization produced adiabatic warming that exceeds evaporative cooling at the low level and hence maintains the low pressure for a long time at the surface. Whereas for PS (SC) mode, Fig. 4a type of WLs are found to be 44% (60%), which means that the small extent of stratiform region can not lead to precipitation evaporation for a long time and hence produce a short lived WL at the surface.

5. A Case study of MH-WL events on 4th May, 2008

NCEP/NCAR reanalysis data on 4th May, 2008 at 06 UTC (not shown here) shows that surface south-easterly/easterly winds penetrate into the region of interest. These winds meet north-westerlies at inland and form so-called wind discontinuity at the low levels. Mid-level is characterized by cold and moist north-westerlies. At 150 mb level, wind field shows weak anti-cyclonic circulation. All these indicate a weak synoptic background for the convective development. Moisture distribution (not shown here) also indicates a strong negative gradient towards the inland. Therefore under relatively weak synoptic background, strong moisture gradient and wind discontinuity at the surface along with possibly faourable thermodynamic conditions, convective activity at the mesoscale takes place over the study area. At about 1000 UTC few discrete cells appear over west, north-west of PRL; and over Chaibasa-Baripada region in the south-western part of the study area (Fig. 5a). These convective cells move in the east ward direction and gradually get organized into TS mode between PRL and PUB (Fig. 5b-c) which further proceed to reach Kolkata at 1341 UTC.

As per the criteria set in order to identify thunderstorm activity; and MH, WL in association with this convective activity, it is observed that out of eight AWS stations, seven stations experience thunderstorm activity.

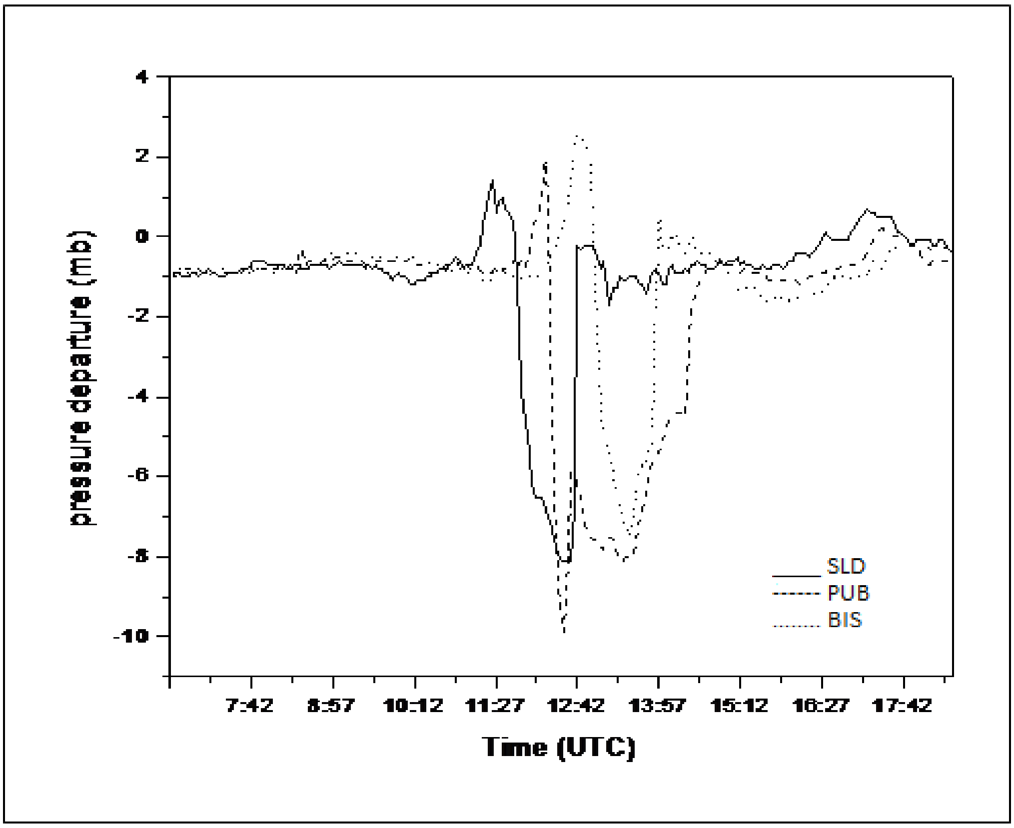

Figure 6: Pressure perturbations of SLD, PUB and BIS on 4th May, 2008

Therefore in this case seven thunderstorm events are considered on this particular day. Some of the parameters of the seven thunderstorm events are displayed in Table 2. It may be mentioned here that pressure departure is calculated using 3-minute averaged pressure data while gusty wind speed is not the averaged data, rather represent single sample having highest speed. Rainfall record is, on the other hand, 1-hour averaged data and value displayed here practically represents total rainfall amount of the event. JLD, the extreme AWS station in the north-west part of the region of interest, experiences thunderstorm activity with gusty wind of 11.8 m/s, but there is no signature of either MH or WL. But MH forms at PRL and RGP, nearby stations of JLD, while WL is absent in both these stations even though PRL records 2.0 mm rainfall. Rest four stations (SLD, KHT, PUB and BIS) experience both MH and WL even though PUB and BIS do not record rainfall. Therefore in this case, only four MH-WL events are considered though thunderstorm events are seven in number. Lack of meso-network of AWSs does not allow us to find the exact spatial extent of the WLs. To have some idea about their spatial extents, pressure departures of three stations (SLD, PUB and BIS) have been shown in Fig. 6. WL persists for less than one hour at SLD and PUB while it continues for longer time at PUB. It also appears that pressure departure of a station is unaffected by the nearby station even at an aerial distance of about 25 kms, justifying their localized nature of formation. Possibly it is because of localized nature of the WLs over the region, strong and damaging winds do not develop as also suggested by Vescio and Johnson (1992). This is an important characteristic difference of the WLs occur over the region with the WL events identified elsewhere with very high damaging winds of about 25 m/s with a pressure departure of only 8mb (Coleman and Knupp, 2011).

6. Conclusions

Surface characteristics associated with premonsoon thunderstorms over semi-arid part of Gangetic West Bengal have been studied using 3-minute averaged AWS data supported by Doppler radar imageries during 2008-09. Data analyses reveal that the changes in surface characteristics, such as temperature, relative humidity and pressure associated with thunderstorm activities are significantly higher than that reported elsewhere. Attention is focused on surface pressure perturbation patterns which usually go unnoticed in routine observations. A pre-squall mesolow, followed by a mesohigh (MH) and wakelow (WL) is the usual surface perturbation pattern. Nearly 60% of the thunderstorm events support the formation of MH followed by WL while the rest 40% events do not follow the pattern. The latter is due to either unorganized mode (SC) of convective system or if it organized then it is a case of leading stratiform (LS) mode of organized convective system. Pressure perturbation in MH is about 2-4 mb while it is 5-10 mb in WL. MH is a result of saturated downdraft accompanying gusty wind persists for about 15 minutes. WL, on the other hand, is due to subsidence warming offsetting the evaporative cooling at the low level, persists for longer time. On occasions they may persists for more than three hours. Such a strong surface pressure gradient between MH and WL unlike cases reported elsewhere, does not produce wind gust. It is because the system is highly localized and air parcels do not get sufficient time to accelerate to higher velocities within this strong gradient of surface pressure.

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