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A Preliminary study on anomalous atmospheric pressure changes during occurrence of seismic events over the Kachchh region, Gujarat, India

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Abstract

We have studied the anomalous atmospheric pressure changes during the occurrence of seismic events of moderate magnitude for 2001 Bhuj aftershock sequence. We carried out a preliminary study on 274 aftershocks $M_w \geq 4.0$ and detailed study on aftershocks $M_w \geq 4.7$ recorded during the period from Jan 2001 to Dec 2011 for two meteorological observatories namely Bhuj and Naliya of India Meteorological Department network situated in Kachchh region. Atmospheric pressure changes during moderate magnitude seismic events recorded at these two observatories are analyzed for 72-hours time window and represented by line charts. We found large variation in atmospheric pressure during few seismic events while slight to moderate changes in atmospheric pressure are observed during most of events. It is observed that atmospheric pressure curves do not follow its normal pattern and change significantly before, after or during occurrence of seismic events. During some seismic events, pressure changes observed are small but they show more than one anomaly. Similar kind of pressure changes are observed for both observatories. From our preliminary study we found quite visible changes in atmospheric pressure during occurrence of seismic events and a detailed study in this regard may prove atmospheric pressure a good precursor for earthquake prediction in future.

Keywords: Atmospheric pressure, seismic events, lithosphere-atmosphere interaction processes, Kachchh region.

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1. Introduction

In order to understand the seismic potential of tectonic plates, it is extremely necessary to identify all the possible factors that caused plate motion to change in the past. In this regard, climate change could be one possible factor as atmosphere and atmospheric parameters are found to show complementary nature and provide evidences for the existence of strong coupling associated with some damaging earthquakes like Bhuj earthquake (Dey and Singh, 2003; Saraf and Choudhury 2005) and Tronin (1996) for Chinese earthquakes. However, researchers are puzzled by the observations that weather parameters and seismic activity have close proximity. In history, Aristotle (384-322 BC) believed that earthquakes were caused by winds trapped in subterranean caves, there have been a thought that warm, calm, cloudy weather was a sign of an impending earthquake. Since then there is a great debate among researchers that- *'is there any relation between an earthquake and weather'*. Nevertheless, earthquakes can occur in all types of weather, in all climate zones, in all seasons and at any time of the day; in modern times, some researchers do believe in a connection between weather and earthquakes. Some researchers have claimed to accurately predict earthquake occurrences by observing clouds and other meteorological parameters and others claim to have observed clouds associated with earthquake (Morozova, 1997; Shou, 1999).

A sensitive seismograph indicates that there are always some vibrations that shake the ground. Some of these vibrations are man-made like vehicular traffic; operating machinery etc. and natural vibrations such as the strong wind shaking the ground surface, waves hitting shores and the movement of water in rivers and oceans. In seismology, such natural background vibrations are known as microseisms or microtremors. Microseisms are observed at low frequencies on seismograms, although there are some frequencies at which they are especially strong. Microseisms at frequencies above about 1 Hz are generally associated with local weather conditions, while below 1 Hz they reflect regional weather and ocean conditions (John Ebel, 2002). Since microseisms are caused primarily by meteorological conditions, an analysis of microseismic patterns on seismograms provides information about how weather patterns are changing. High-pressure systems generally bring fair skies and light winds and these are often reflected on seismograms by low levels of background microseismic noise. Low-pressure systems are typically accompanied by stronger winds, clouds and precipitation and reflect as microseisms on the seismogram. Microseisms on seismograms are greater in amplitude at many times when low-pressure systems are near a seismic station (John Ebel, 2002). John Ebel (2002) found that during *'nor'easters'* the microseisms on seismograms can be quite large. The *'nor'easters'* are low pressure centers that travel from southwest to northeast along the coast and bring cold wind, rain and higher than normal tides over North American coast and New Englanders call them *'nor'easters',* some of them can be quite strong, with gusty winds and occasionally even exceeding hurricane force. Nor'easters studies of the microseismic signals during passage of Nor'easters at seismic stations show that the pattern is quite unexpected and the strongest amplitudes for the microseisms may occur when the low-pressure center is closest to the seismic stations but it occurs many hours later (John Ebel, 2002). Similar observations are found along the Himalayan range in Northeast India. During the pre-monsoon period, it is observed that during the passage of storms namely '*Nor'westerers,*' microseisms are obvious on the seismogram. These '*Nor'westerers'* are low-pressure centers that travel from Northwest to Northeast India. The Kachchh region in Gujarat state of India is seismically very active (Rastogi, 2012). The region has witnessed three large damaging earthquakes, 1819 Allah Bund earthquake (M 7.9), 1956 Anjar earthquake (M 6.0) and 2001 Bhuj earthquake (M 7.7) (Rastogi et al., 2011). Aftershocks activity is still continuing in the region (Mandal et al., 2012). In recent years, many researchers have studied the 2001 Bhuj earthquake and its long ongoing aftershock sequence to understand the seismicity over the region with different approaches (Rastogi et al., 2001, Bendick et al., 2001; Hurton et al., 2001; Hough et al., 2002; Antolik et al., 2003; Mandal et al., 2004; Dey et al., 2004; Saraf et al, 2005; Kayal et al., 2006; Rastogi et al., 2012). Here we studied anomalous atmospheric pressure changes during occurrence of seismic event ($M \geq 4.7$) in the Kachchh region to examine any possible correlation between atmospheric pressure and local seismicity. The results of this study are highlighted here.

2. Data and Methodology

2.1 Data

We carried out a preliminary study on 274 aftershocks $M_w \geq 4.0$ and detailed study on aftershocks $M_w \geq 4.7$ for the period from Jan 2001 to Dec 2011 over Kachchh region. We used atmospheric pressure data recorded by two meteorological observatories of India Meteorological department in the Kachchh region namely Bhuj and Naliya and earthquake data from the catalogue of India Meteorological Department (IMD) and Institute of Seismological Research (ISR).

2.2 Basic formulation for atmospheric pressure changes

Atmospheric pressure changes over any station, basically depends on air temperatures prevailing over the station and time. Changes in atmospheric pressure during 24-hours a day is known as diurnal variation of atmospheric pressure. Daily atmospheric pressure pattern exhibits 12-hours semi diurnal variation at any station over the tropical region as shown in Figure 1 (Kumar et al., 2006). There are two maximum and two minimum pressures every day and they occur at a constant local time during normal atmospheric conditions over any inland station. The pressure maxima occur around 10 a.m. and 10 p.m. with the minima at about 4 a.m. and 4 p.m. at local time.

It was a great surprise for researchers that why these maxima and minima occur at fixed local time. In the late 1960s, the theory proposed that these atmospheric pressure variations results from waves called solar tides that one generated by the sun's heating of the upper atmosphere. The diurnal variation of atmospheric pressure occurs due to solar heating and cooling (Harris, 1962). The amplitude of semi diurnal variation decreases with height of the station and also found that it changes with season and latitude. It is also related to air temperatures and winds. The diurnal variations of pressure and wind suggested by Wilkes (1949) can be given by following linearized equations,

$$\frac{\partial u}{\partial t} - 2\omega \sin\phi v + \frac{1}{\rho_0 \alpha \cos\phi}\frac{\partial p}{\partial \theta} = 0 \quad (1)$$

$$\frac{\partial v}{\partial t} + 2\omega \sin\phi u + \frac{1}{\rho_0 \alpha}\frac{\partial p}{\partial \phi} = 0 \quad (2)$$

Where, p is the atmospheric pressure, ρ_0 is density of the air, u and v are the eastward and northward components of velocity respectively, ϕ is latitude, θ is longitude, *t* is time and α and ω are radius and angular velocity of the earth. Now, variation of the atmospheric pressure p′ from its daily mean value at a given time can be expressed by the formula proposed by Harris (1955, 1959) and Harris et al. (1962) as follow,

$$p'_{0,t} = \frac{\rho g^2 H'^2}{2 f^2 T_0}\nabla^2 T_{0,t} \quad (3)$$

Where, ρ is air density, *g* is gravitational force, H′ is height of mercury column, ƒ is wind velocity, T_0 is air temperature and ∇ is Laplace operator.

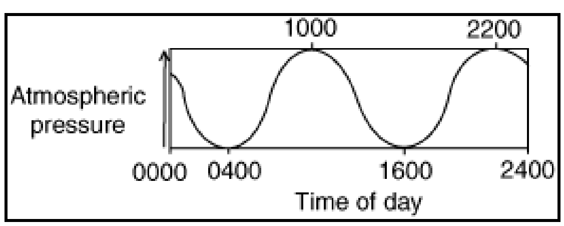

Figure 1. **Normal pattern of atmospheric pressure during a day for any inland station over tropics.**

2.3 Methodology

Figure 2 describes the methodology for the present analysis. During our preliminary study, we have first analyzed *'pressure changes called P_{24}'* at the time of occurrence of seismic event corresponding to all 274-seismic events ($M_w \geq 4.0$). The P_{24} represents the difference in atmospheric pressure from its previous value before 24-hours and it is an important parameter to understand dynamic behavior of weather. We found significant changes in atmospheric pressure trend i.e. rise or fall during the occurrence of seismic event in our preliminary study. Then we carried out a detailed analysis on seismic events of $M_w \geq 4.7$ for atmospheric pressure changes for 72-hours time window. We studied atmospheric pressure changes during the seismic event at the station in 72-hours time window i.e., atmospheric pressure data collected for one day before the seismic event denoted as 'Day:-1', on the day of seismic event and for one day after the seismic event denoted as 'Day:+1'. We considered only those seismic events when special pressure systems like low pressure, depression, deep depression or cyclonic storms were absent. In addition, we ignore the seismic events when some special weather was prevailing and consider those events when normal atmospheric conditions were prevailing.

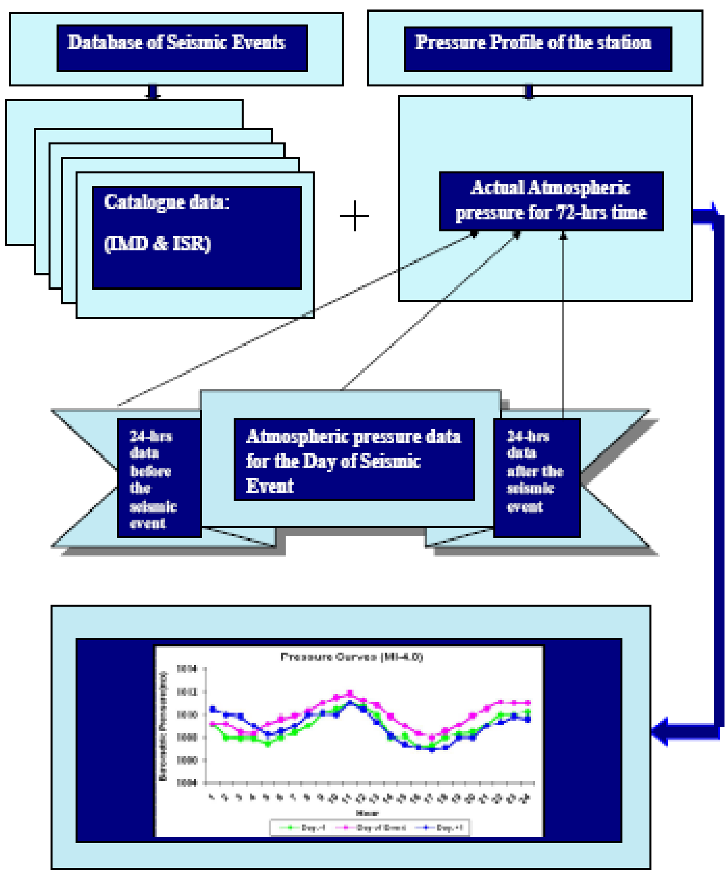

Figure 2. Flow chart for analysis of atmospheric pressure changes during the seismic event.

3. Results and Discussion

Results of our analysis are displayed in Figure 3(i) to (viii) and Figure 4(i) to (viii). Figure 3(i) to (viii) and Figure 4(i) to (viii) shows pressure curves for 72-hours time window during occurrence of seismic event for the observatory Bhuj and Naliya respectively. As displayed in figures (Figure 3(i) to (viii) and Figure 4(i) to (viii)) atmospheric pressure curves for 72-hours time window within the seismic event shows slight, moderate and large variation in different cases. Normally, as discussed above in basic formulation, section 2.1 and as shown in Figure 1 (Kumar et al., 2006), pressure curve showing diurnal variation exhibits two maxima and two minima per day and they occur at a constant local time of 10a.m. and 10p.m. and at 4a.m. and 4p.m. of local time respectively during a day for any station over tropics. There may little changes in this trend depending upon the geography of the location. When we compare pressure curves for Bhuj (Figure 3(i) to (viii)) and for Naliya (Figure 4(i) to (viii)) with Figure 1 of normal pressure curve pattern during a day, it is obvious that - (a) During the occurrence of seismic event, pressure curves got disturbed from its normal pattern and do not follow its normal trend of rising to maxima or falling to minima. Fairly, it remains constant or falls during rise time or vice verse. It is very much clear from Figure 3 (i) to (viii) and Figure 4(i) to (viii). (b) We do not find two clear maxima and two clear minima in the atmospheric pressure curve. We can see in Figure 3(i), (v), (vii) and (viii) and Figure 4(i), (ii), (vii) and (viii) and they do not exhibit pressure maxima and minima mostly on the day of occurrence of seismic event and in some cases next day or previous day of occurrence of seismic event. (c) In some cases, maxima or minima of pressure occurred earlier or later than earthquakes. Figure 3(iii), (iv), (vi) and Figure 4(ii) represent such cases. We found that pressure maxima occur 3 to 4 hours earlier or pressure minima occur 2 to 3 hours later as compared to occurrence of seismic events in these cases. (d) During some seismic events, pressure changes observed are small but they show one or another kind of anomaly like constant pressure curve for some hours or increasing pressure during fall time and vice verse. (e) It is observed from Figure 3(i), (iii), (v), (viii) and Figure 4(i), (vii) and (viii) that pressure curves fluctuate frequently, twice or thrice during 24-hours and again this fluctuation is abrupt by 1mb in an hour. We found mostly similar kind of results for both of observatories. The pressure changes are lower at Naliya compared to Bhuj but still significant. The reasons for lower changes in atmospheric pressure at Naliya are not discussed in this paper as they are beyond the scope of the present study.

Atmospheric pressure changes observed during seismic events are so complex in nature that it is very difficult to understand their behavior. Changes and fluctuation in atmospheric pressure discussed above are extremely hazardous particularly for aviation services where change of 1mb in atmospheric pressure treated as 30feet change in altitude.

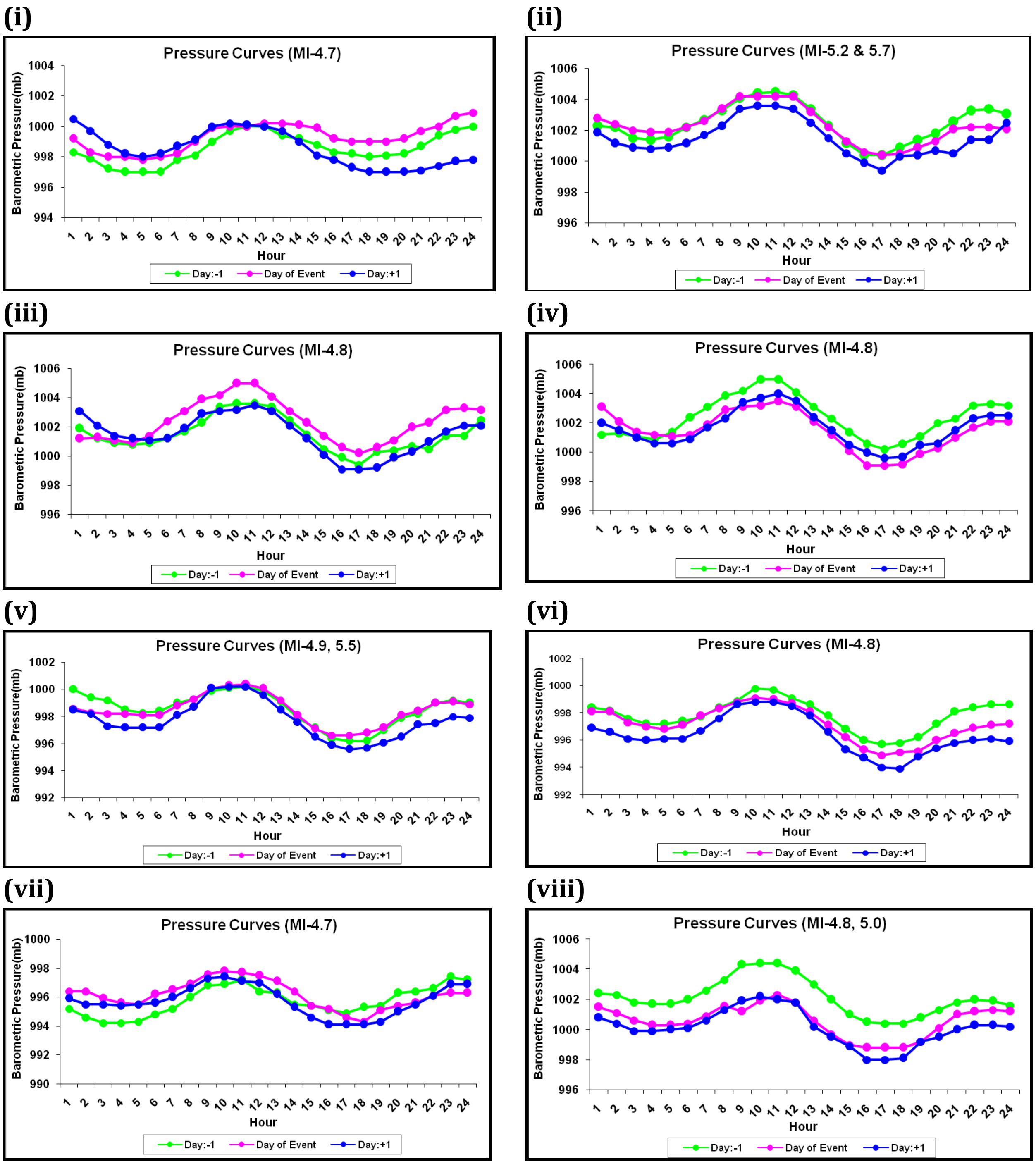

Figure 3. Pressure curves for 72-hours time window during seismic event for the observatory Bhuj.

So far as inter-diurnal pressure changes are concerned, the theory may perhaps reveal the pattern but not the scale of the actual changes. The pressure changes after large earthquake have been studied by Watada et al. (2006, 2006a) for 2003 Tokachi-Oki, Japan earthquake (M 8.3) and by Mikumo et al. (1968) for 1964 Alaskan earthquake (M 9.2). Seasonal variations of earthquakes ($M \geq 7$) are reported in Japan (Heki, 2003). He observed that in snow loaded regions, earthquakes of $M \geq 7$ occur more in spring and summer than in autumn and winter. Ohtake & Nakahara (1999) found a significant seasonality in the occurrence time of past great earthquakes (M >7.9) in the northwestern margin of the Philippine Sea plate. They found that change in the atmospheric pressure can trigger an earthquake of light to moderate magnitude. Similar connection have been found by Gao et al. (2000) in the distribution of earthquakes (mostly M>3) and the yearly fluctuation of atmospheric pressures in southern California. Again, Dey and Singh (2003) found anomalous concentration of water vapor in the atmosphere; Saraf and Choudhary (2005) detected thermal anomaly by NOAA-AVHRR and Genzano et al (2007) detected the thermal anomalies within the area and also at the border of Eurasian and Indian tectonic plates by analyzing the Meteosat 5 satellite IR images for the time period close to the Gujarat earthquake (M 7.7) on 26 Jan, 2001. They concluded that satellite infrared images demonstrate the increased temperature over the structure of active tectonic faults and its dynamics with time. As stated above, atmospheric pressure changes are directly associated with temperature changes and anomalous changes in temperatures lead to changes in atmospheric pressure during occurrence of seismic event. These studies provide strong support to our analysis that during occurrence of seismic activity atmospheric pressure behaves abnormally as a result of hidden lithosphere-atmosphere interaction processes.

4. Conclusion

During our preliminary study, we found noticeable changes of light to moderate level in atmospheric pressure during occurrence of seismic events. The degree of the changes in the normalized pressure are likely to be associated with the prevailing meteorological parameters in the earthquake regions, location of earthquakes, proximity of the epicenters and also season in which the earthquake occurred. These may to be governed by numerous parameters prevailing in the earthquake epicenters and surrounding regions. Processes of stress accumulation, release of stress prior to the earthquake and energy exchange between earth's crust and atmosphere after an earthquake in the epicentral region is likely to be responsible for anomalous atmospheric pressure changes during seismic activity. The exchange of water vapor in the atmosphere during earthquake occurrence is also one important factor responsible for atmospheric pressure changes. The nature of such changes and the hidden physical processes is yet to be explored. Even though pressure changes with respect to seismic event found during our preliminary study are quite visible,

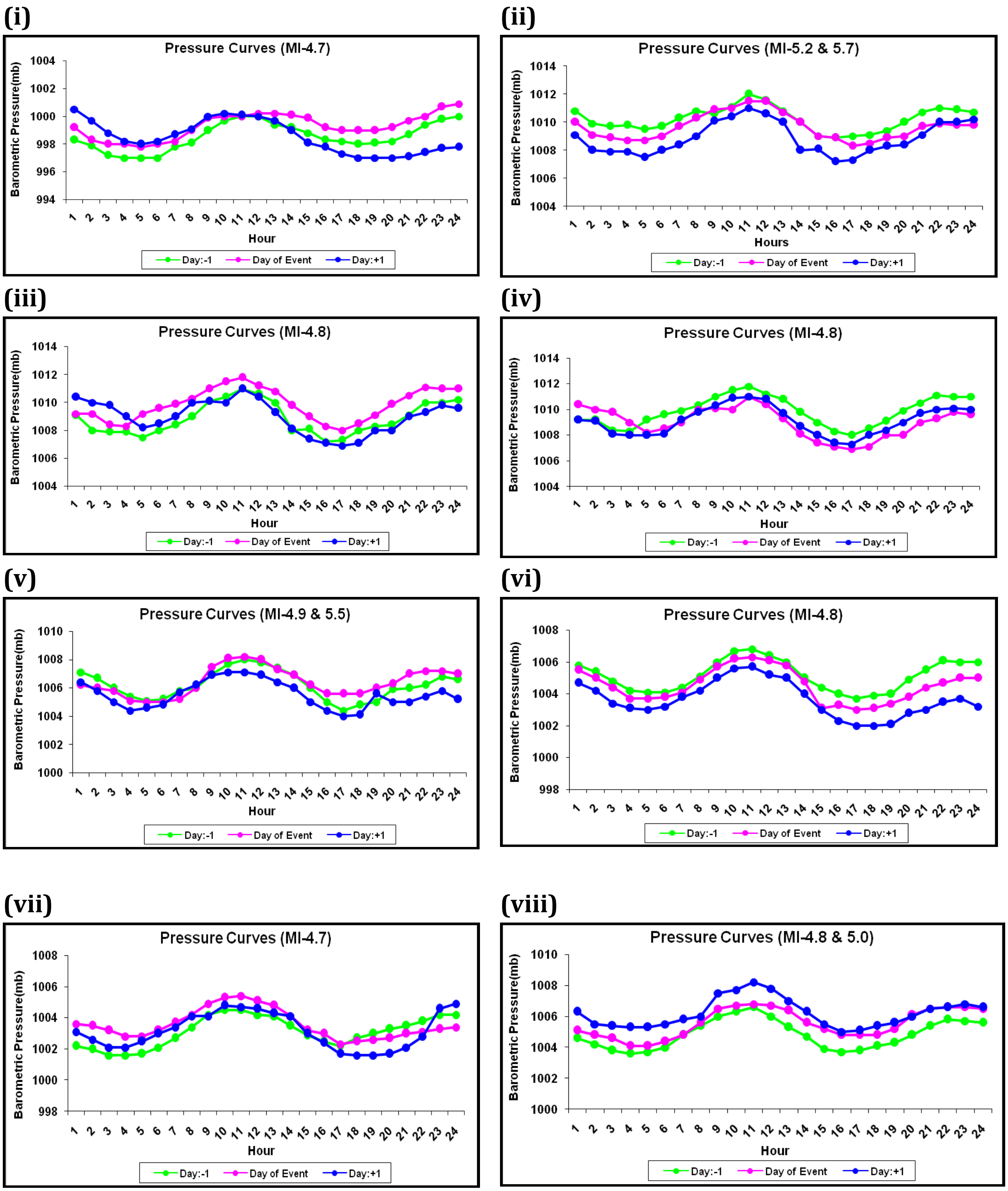

Figure 4. Pressure curves for 72-hours time window during seismic event for the observatory Naliya

it is very difficult to establish direct relation between these two parameters. In-depth study is required in this regard and atmospheric pressure may prove a good precursor for earthquake prediction in future. The theory presented here attempts to explain the pressure changes as a natural consequence of the seismic activity in absence of other controlling parameters on atmospheric pressure. At the conclusion, it is suggested that we should develop a method that will help to establish direct relation between these two parameters. It can be achieved by designing a specific chamber where very sensitive microbarometers and microseismometers both together installed in all four directions in a seismogenic region where other meteorological and geological parameters are silent and only these two parameters can be observed for their mutual effect. By this, we will be able to remove the noise signal in both the parameters or to fix a minimum average noise level and obtain clear signals and later, we can apply this method to moderate and large earthquakes. It is an invitation for further investigation to meet up earthquake challenges.

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