MAUSAM, **60**, 1 (January 2009), 1-10

551.511.3 : 551.515.4

Pattern of meteorological parameters during severe thunderstorms – A frequency domain analysis

SUTAPA CHAUDHURI* and MOUMITA BISWAS

Department of Atmospheric Sciences, University of Calcutta, Kolkata, India

(*Received 16 October 2007, Modified 24 October 2008*)

e mail : *chaudhuri_sutapa@yahoo.com;moumita_mailme@yahoo.co.in

सार – गर्ज के साथ तूफान कपासी अथवा मेघ माप के अत्यधिक रूप से आने की मौसम परिघटना है जो मेसोस्केल में होने वाली अस्थिरताओं के कारण उत्पन्न होती है। इनके उत्पन्न होने में धरातल के प्राचलों का महत्वपूर्ण योगदान है जबकि गर्ज के साथ तूफान के विकसित होने का निरूपण करने के लिए उपरितन वायु मूें दबाव के बनने की आवश्यकता है। जो तूफान ओला वृष्टि, हवा के तेज झोकों अथवा बंवडर के साथ आते हैं वे उस स्थान विशेष के लिए आपदा लाते हैं। इसीलिए गर्ज के साथ तूफानों का सटीक पूर्वानुमान देना आवश्यक हो जाता हे । इस शोध पत्र का उद्देश्य तूफान के आने की बारम्बारता वाले क्षेत्रों में समय श्रृखला विश्लेषण का उपयोग करते हुए भीषण तूफानों के दौरान मौसम वैज्ञानिक प्राचलों के पैटर्नों को देखते हुए भीषण तूफानों की पूर्वानुमानता का मूल्यांकन करना है। बारम्बारता वाले क्षेत्र के विश्लेषण में विभिन्न समय श्रंखला में सहायक विषयों के आँकड़ा श्रंखला का निरूपण निहित है। फुरिए विश्लेषण से समय श्रंखला में उतार चढ़ाव अथवा परिवर्तनशीलता का पता चलता है क्योंकि ये साइन और कोसाइन क्रियाओं की श्रृखलाओं को एक साथ जोड़नें से उत्पन्न होते हैं। समग्र समय श्रृखला विभिन्न आवृत्तियों पर साइन और कोसाइन तरंगों के दोलन के संचयन के संयुक्त प्रभाव से उत्पन्न होती मानी जाती है। इस शोध पत्र में एस. टी. ओ. आर. एम. (स्टॉर्म) पाइलट फेज़ प्रयोग 2006 के अन्तरर्गत कोलकत्ता (22°32′ उ., 88°20′ पू.) में तूफान वाले दिनों से विश्लेषण किया गया है तथा इसे पिछले छह वर्षों के सिनॉप्टिक प्रेक्षणों के निष्कर्षों से प्रमाणित किया गया है। इस अध्ययन से यह पता चलता है कि तूफान वाले दिनों में समय के साथ– साथ तापमान धीरे बढ़ता है और 1400 बजे (स्थानीय समय) 32° सेल्सियस के अधिकतम मान तक पहुँच जाता है। जैसा कि प्रादेशिक मौसम केन्द्र ने सूचित किया है कि तूफानों के आने का समय 1550 से 1610 बजे (स्थानीय समय) के बीच है। इस प्रकार सापेक्षिक आर्द्रता, पवन गति पवन दिशा और सौर विकिरण जैसे अन्य प्राचलन तूफान वाले दिनों में अलग किस्म का पैटर्न दर्शाते हैं। मौसम वैज्ञानिक प्राचलों के पैटर्न संभवत ऐसे तूफानों की पूर्वानुमानता का मूल्याकंन कर सकते हैं।

ABSTRACT. Thunderstorm is a high frequency cumulus or cloud scale weather phenomenon and is generated due to instabilities created in the meso-scale. The surface parameters play a significant role in the genesis whereas the strength of the upper air pull is required to assess the growth of the thunderstorms. The thunderstorms associated with hail, high wind gust or tornadoes lead to catastrophe over the particular location. The accurate prediction of the occurrence of thunderstorms is thus, becomes a necessity. The purpose of the present paper is to assess the predictability of severe thunderstorms by viewing the pattern of the meteorological parameters during severe thunderstorms using time series analysis in frequency domain. Analysis in frequency domain involves representation of the data series in terms of the contributions made at different time scales. Fourier analysis represents the fluctuations or variations in a time series as having been arisen from the adding together of a series of sine and cosine functions. The overall time series is regarded to have generated from the combined effects of the collection of sine & cosine waves oscillating at different frequencies. In the present study the thunderstorm days of STORM Pilot Experiment – 2006 are analysed over Kolkata (22°32′, 88°20′) and validated the findings with past six year synoptic observations. The study reveals that on the thunderstorm days, temperature gradually increases with time and reaches the maximum value of 32° C at 1400 hours (local time). The time of occurrence of thunderstorms as reported by the Regional Meteorological office is between 1550 to 1610 hours (local time). Similarly the other parameters like relative humidity, wind speed, wind direction and solar radiation show a distinctly different pattern on thunderstorm days. The patterns of meteorological parameters might lead to assess the predictability of such thunderstorms.

Key words – Oscillations, High frequency, Fourier analysis, Qualitative, Timescales.

1. Introduction

Severe thunderstorms of pre-monsoon season (April – May) over northeastern part (20° N to 28° N Latitude; 84° E to 93° E Longitude) of India are of great concern for the meteorologists of India because of its devastating effect on life and property on the ground and aviation aloft. Research on pre-monsoon thunderstorms has been conducted since nine decades by Indian and foreign scientists Humphreys, 1920; Normand, 1938; IMD, 1941; Byers & Braham, 1949; Desai & Mull, 1938; Dauglas 1947; Mull & Rao, 1948; Desai & Rao 1954; Cornford & Spavins, 1973; Mukherjee & Chowdhury, 1979; Kalsi & Bhatia, 1992; Holton, 1992; Chaudhuri, 2006. Thunderstorm being a meso-scale weather phenomenon associated with cumulus convection, closer network of observatories is required to understand it. To cope with the devastation due to such thunderstorms a National Programme, Severe Thunderstorm: Observational and Regional Modeling (STORM) has been launched by the Department of Science & Technology, Government of India in 2006. The purpose of the national research programme is to set up a closer network of observatory over the thunderstorm prone location. Automatic Weather Stations (AWS) are installed over different part of West Bengal during the Pilot phase experiment under this Programme. AWS receives the continuous record of basic meteorological parameters at a pre-assigned time intervals. The parameters recorded are; temperature, humidity, dew point temperature, wind speed, wind direction, solar radiation, rainfall, soil moisture temperature, etc.

The purpose of the present paper is to identify the pattern of some meteorological parameters to observe whether any definite pattern prevails during severe thunderstorms using Fourier analysis. The pattern of the meteorological parameters might lead to assess the predictability of the severe thunderstorms.

2. Data

The surface data of meteorological parameters has been collected at 30 minutes time interval from Automatic Weather Station (AWS) during the month of May 2006 over Kolkata (22° 32′, 88° 20′) during the STORM Pilot Experiment 2006. In the present study, the synoptic observations of the surface parameters has also been collected from India Meteorological Department and National Data Centre during the pre-monsoon season of six years (2001 to 2006) and the record of the occurrence of thunderstorms is collected from the Regional Meteorological Office, Kolkata. The quality of the AWS data of Kolkata is checked with the Dumdum synoptic observation and found to be comparable.

3. Methodology

Fourier analysis represents data series in terms of different frequencies. The overall time series is regarded as the combined effects of sine & cosine waves oscillating at different frequencies. Fourier analysis represents the fluctuations or variations in a time series (Wilks, 1995).

In the method of Fourier analysis the data points represent a collection of Fourier coefficients as a function of time scales.

A given data series consisting of exactly *n* points can be represented, meaning that a harmonic function can be obtained, that passes through each of the points, by adding together a series of $\frac{n}{2}$ harmonic functions;

$$y_t = \bar{y} + \sum_{K=1}^{n/2} C_K \cos\left[\frac{2\pi kt}{n} - \phi_K\right] \tag{1a}$$

$$= \bar{y} + \sum_{K=1}^{n/2} \left\{ A_K \cos\left[\frac{2\pi kt}{n}\right] + B_K \sin\left[\frac{2\pi kt}{n}\right] \right\} \tag{1b}$$

The cosine wave, constituting $k = 1$ term in equation (1a) is the fundamental and represents the first harmonic. The other $\left[\frac{n}{2} - 1\right]$ terms in the summation of equation (1a) and (1b) are higher order harmonics, or cosine waves with frequencies

$$\omega_K = \frac{2\pi k}{n} \tag{2}$$

These are integer multiples of the fundamental frequency ω_1.

Equation (1b) shows that the coefficients A_K and B_K corresponding to the data series y_t can be obtained by using multiple regression methods;

$$x_1 = \cos\left(\frac{2\pi t}{n}\right),\ x_2 = \sin\left(\frac{2\pi t}{n}\right),\ x_3 = \cos\left(\frac{2\pi 2t}{n}\right),$$

$$x_4 = \sin\left(\frac{2\pi kt}{n}\right),\ x_5 = \cos\left(\frac{2\pi 3t}{n}\right) \text{ and so on.} \tag{3}$$

This, in fact, is the case in general, but if the data series is equally spaced in time and contains no missing values, the coefficients can be expressed as;

$$A_K = \frac{2}{n} \sum_{t=1}^{n} y_t \cos\left(\frac{2\pi kt}{n}\right) \tag{4a}$$

and

$$B_K = \frac{2}{n}\sum_{t=1}^{n} y_t \sin\left(\frac{2\pi kt}{n}\right) \tag{4b}$$

To compute a particular coefficient A_K, an n - term sum is formed consisting of the products of the data series y_t with the values of a cosine function executing k full cycle during the n time units. For relatively short data series these equations can be easily programmed and evaluated. Having computed these coefficients, the amplitude - phase form of equation (1a) can be expressed as,

$$C_K = \left[A_K^2 + B_K^2\right]^{\frac{1}{2}} \tag{5}$$

The phase angle is computed as

$$\phi_k = \begin{cases} \tan^{-1}\dfrac{B_k}{A_k}; A_k > 0 \\ \tan^{-1}\dfrac{B_k}{A_k} \pm \pi; A_k < 0 \\ \dfrac{\pi}{2}; A_k = 0 \end{cases} \tag{6}$$

The spectral density can be obtained as;

$$d_K = \frac{(n/2)C_K^2}{(n-1)s_y^2} \tag{7}$$

Where

$s_y^2 \rightarrow$ The variance of the sample of size "n"

4. Data analysis and implementation procedure

In the present paper all parameters are observed to change with time interval. The variation of the cosine function has been estimated with time because prognostic prediction is compact and useful than diagnostic one. Time series analysis also apparently gives the idea of the pattern of the parameters but in this study Fourier analysis has been done to obtain the idea specifically, to authenticate the results and to predict more accurately with the shift of phase angle.

Initially the meteorological parameters from Automatic Weather Station (AWS) observations at 30 minutes interval are taken. Time series of each parameter has been observed. Those parameters are selected for the calculation with respect to different cosine function which shows sinusoidal nature with time series. The equations (4) to (6) are used to compute the coefficients of the function for different harmonics of temperature, relative humidity, wind speed, wind direction, surface pressure and solar radiation for thunderstorm days during the pre - monsoon month of May.

Computing the time series in a frequency domain helps to overcome the following three small intricacies in order to use a sine or cosine function to represent it:

(*i*) The argument of a trigonometric function is an angle, whereas the data series is a function of time.

(*ii*) Cosine and Sine function fluctuate between +1 and –1, whereas the data will generally fluctuate between different limits.

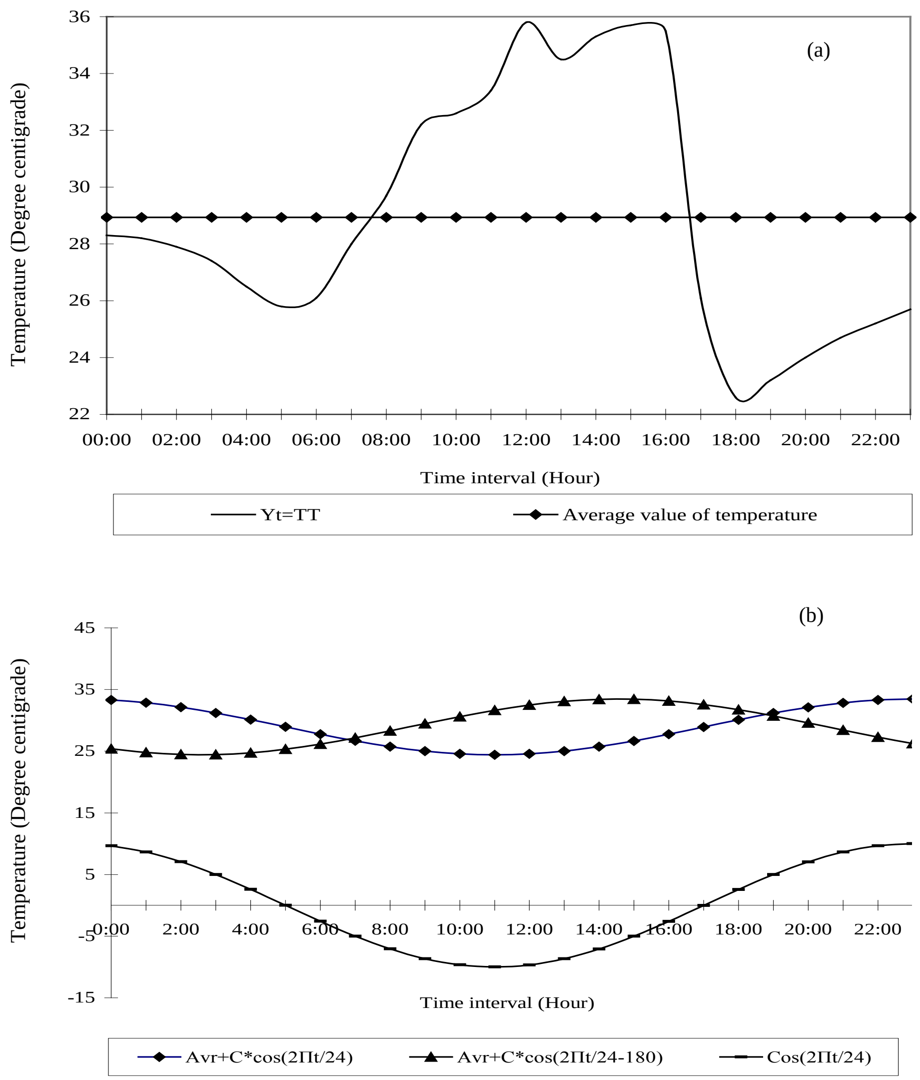
(*iii*) The cosine function is at its maximum value for $\alpha = 0$ and $\alpha = 2\Pi$ and sine function is at its mean value for $\alpha = 0$ and $\alpha = 2\Pi$. Both the sine and cosine may thus be positioned arbitrarily in the horizontal with respect to the data.

The solution to the first problem comes through regarding the length of the data record, as constituting a full cycle or the fundamental period. The full cycle of time series corresponds to 360° or 2Π radians in angular measure. It can be considered that it is located in time between 0 and n frequency.

The second problem is overcome by shifting the cosine or sine function up or down to the general level of the data and then stretching or compressing it vertically until its range corresponds to that of the data. Since the mean of a pure cosine or sine wave is zero, simply adding the mean value of the data series to the cosine function assures that it will fluctuate around that mean value. The stretching or shrinking is accomplished by multiplying the cosine function by a constant function C_1, known as the amplitude. Again the subscript "1" indicates that this is the amplitude of the fundamental harmonic. Since the maximum and minimum values of a cosine function are ± 1, the maximum and minimum values of the function $C_1 \cos(\alpha)$ will be $\pm C_1$.

Combining the solutions to these first two problems for data series yields

$$y_t = \overline{y} + C_1 \cos\left(\frac{2\Pi t}{n}\right)$$



Figs. 1(a&b). Schematic diagram showing (a) the time series of temperature of a thunderstorm day during the pre-monsoon season over Kolkata and (b) three cosine functions illustrating transformation from time to angular measure, vertical positioning & stretching and lateral shifting yielding finally the function matching the data approximately

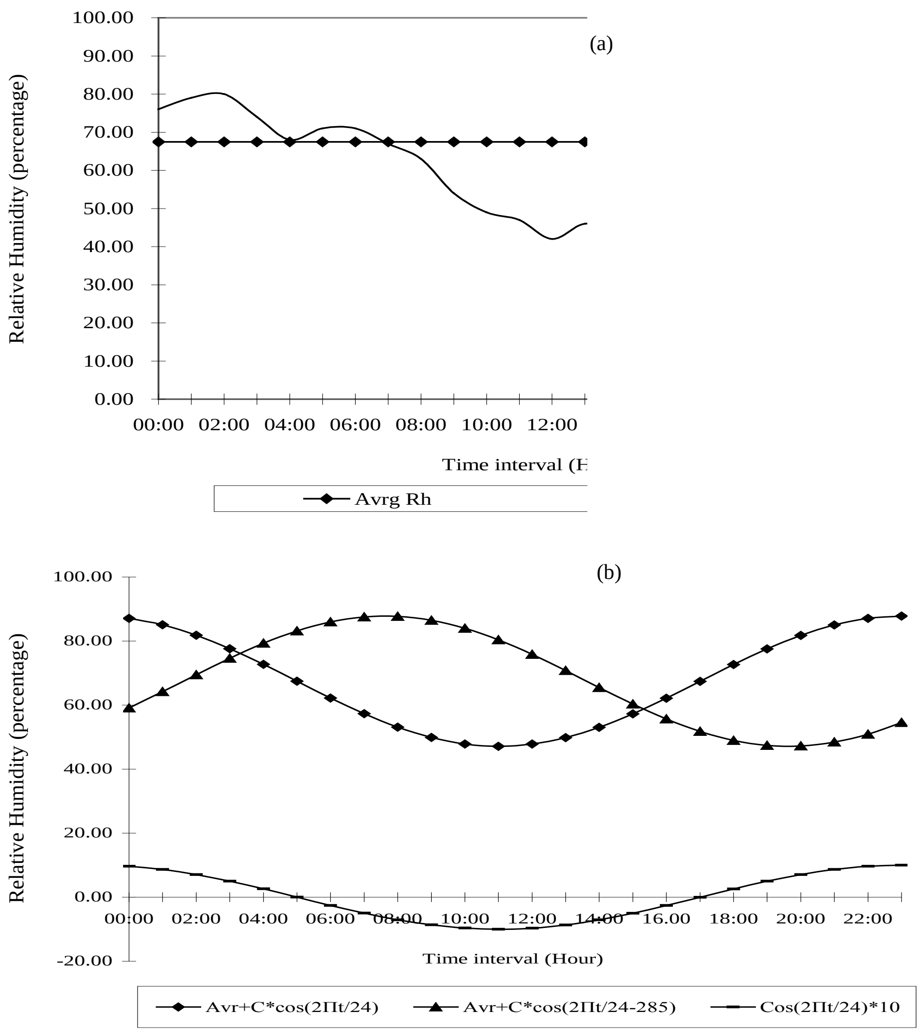
Finally it is usually necessary to shift a harmonic / Fourier function (Jakubauskas *et al*., 2002) laterally in order to have it matches the peaks and troughs of a data series. This is most conveniently accomplished when the cosine function is used, because the function achieves its maximum value when the angle on which it operates is zero. Shifting the cosine function to the right by the angle ϕ_1 results in a new function that is maximized at $\omega_1 \frac{t}{n} = \phi_1$.

$$y_t = \bar{y} + C_1 \cos\left(\frac{2\prod t}{n} - \phi_1\right)$$

The angle ϕ_1 is called the phase angle or phase shift. Shifting the cosine function to the right by this amount requires subtracting ϕ_1 so that the argument of the cosine function is zero when (2Πt/n) = ϕ_1 (Wilks, 1995).

5. Results and discussions

The Harmonic analysis is performed on the meteorological parameters collected during the thunderstorm days. Data points are collected from AWS installed over Kolkata (22°32′ & 88°20′) for the pre-monsoon month of May 2006. In the present study



Figs. 2(a&b). Schematic diagram showing (a) the time series of relative humidity of a thunderstorm day during pre-monsoon season over Kolkata and (b) three cosine functions illustrating transformation from time to angular measure, vertical positioning & stretching and lateral shifting yielding finally the function matching the data approximately

Harmonic Analysis is done on the surface parameters to draw the conclusion. The parameters considered in this study to view the predictability are surface temperature, surface relative humidity, surface wind (speed and direction), solar radiation and surface pressure.

Surface temperature

The temperature on a thunderstorm day shows a sinusoidal pattern against time interval and thus, Fourier analysis has been done on surface temperature. The maximum value of temperature is observed to be 35° C at 12 noon. The day shows the maximum temperature at the frequency of (12*360) / 24 = 180° (The total 24 data series oscillates over total 360 degree). But, the phase angle ϕ shows the frequency of 189 degree. In the present data set 15 degree is equivalent to 1 hour. Phase angle thus, shows 9 degree delay. It indicates that temperature starts to increase nearly 1 hour after 12 noon. Three cosine functions are used to authenticate the position of maximum temperature with phase shift and no shift condition. Thunderstorms are observed to occur at 16 hours (4 pm). It can thus, be predicted that nearly 4 hours before thunderstorms temperature will start to increase and attain the value of 33-34 degree centigrade [Figs. 1(a&b)].

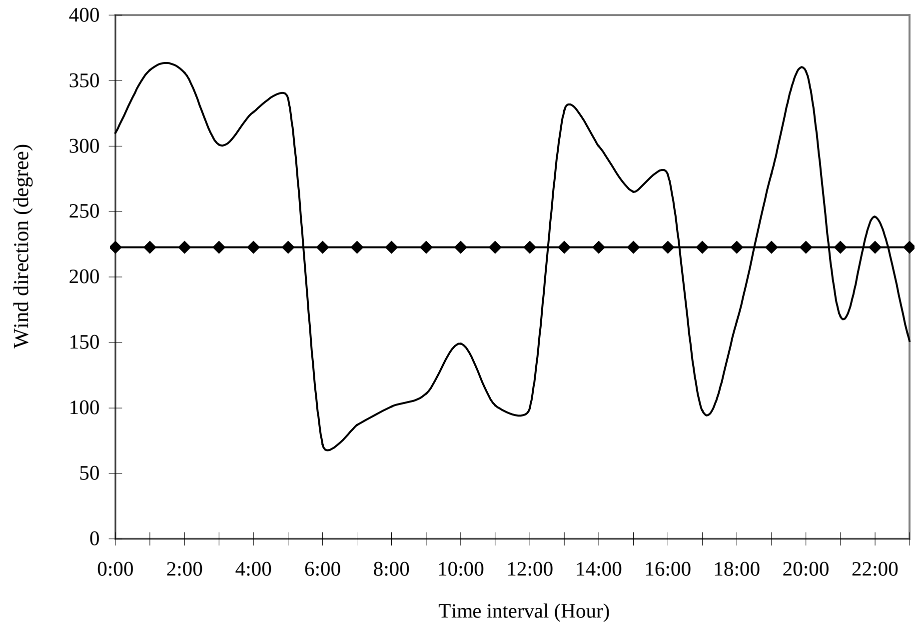


Fig. 3. Schematic diagram showing the time series of wind direction of a thunderstorm day during pre-monsoon season over Kolkata

Surface relative humidity

Relative humidity on a thunderstorm day also shows nearly sinusoidal nature with time series. Three cosine functions are plotted for the time series of relative humidity. Fourier analysis reveals that maximum relative humidity is at frequency of 285 degree at 19 hours, but according to phase angle it is at 182.82 degree. Since phase angle is less than the frequency, it reveals that almost 6 to 7 hours before 19 hours that is from 11 a.m. to 12 noon the relative humidity starts to increase and attains the value above 80 %. It can, thus be predicted that high (above 80%) relative humidity will start to accumulate from 4-5 hours before the occurrence of thunderstorms during the pre-monsoon season over Kolkata [Figs. 2(a&b)].

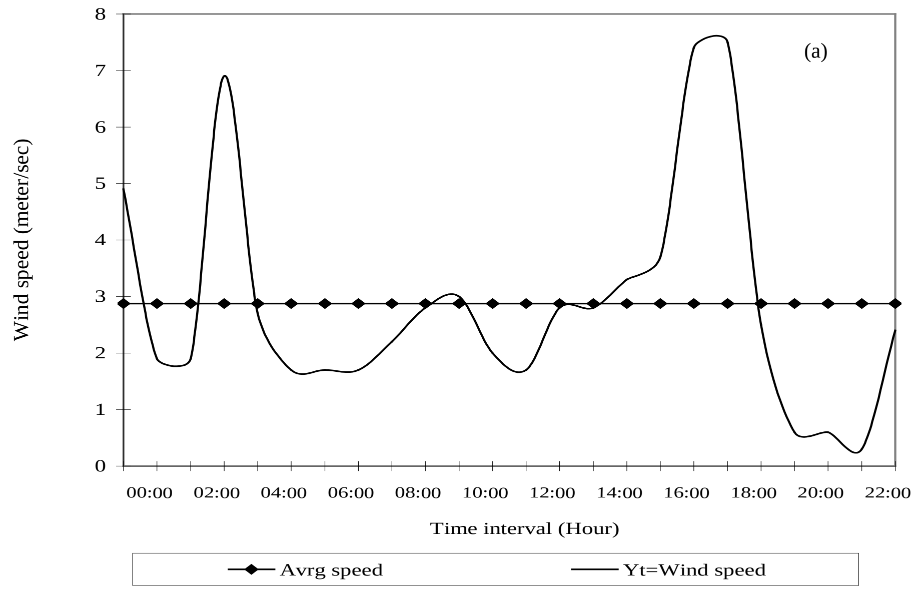
Surface wind (speed & direction)

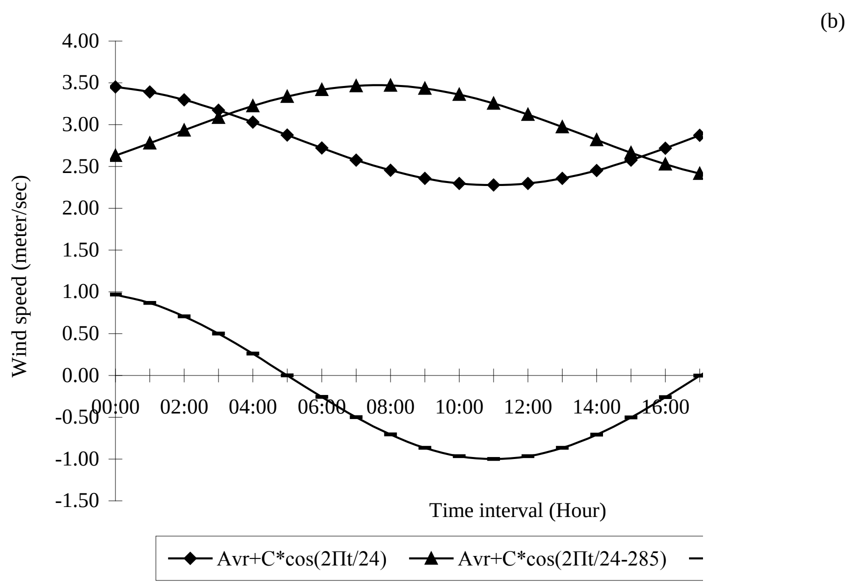
Wind direction on thunderstorm days shows very irregular pattern with the time series so Fourier analysis has not been applied on this parameter (Fig. 3).

Wind speed, on the other hand, shows slightly regular pattern with time series on a thunderstorm day. Wind speed is observed to be maximum at the frequency 285 degree and at 19 hours (7 pm), whereas the phase angle of Fourier analysis shows that the maximum speed will be at 268.58 degree, so it can be predicted that the wind will attain its maximum speed around 1 hour before 19 hours. It is thus, apparent that just before or at the time of occurrence of thunderstorms very light wind will prevail which gradually increases after the occurrence of thunderstorm [Figs. 4(a&b)].

Solar radiation

Solar radiation also shows nearly oscillating pattern on a thunderstorm day. Fourier analysis, on the other hand, does not show any significant finding about the parameter as three cosine functions shows their peak and trough at same position [Figs. 5(a&b)]. Therefore no accurate prediction is possible with this parameter.

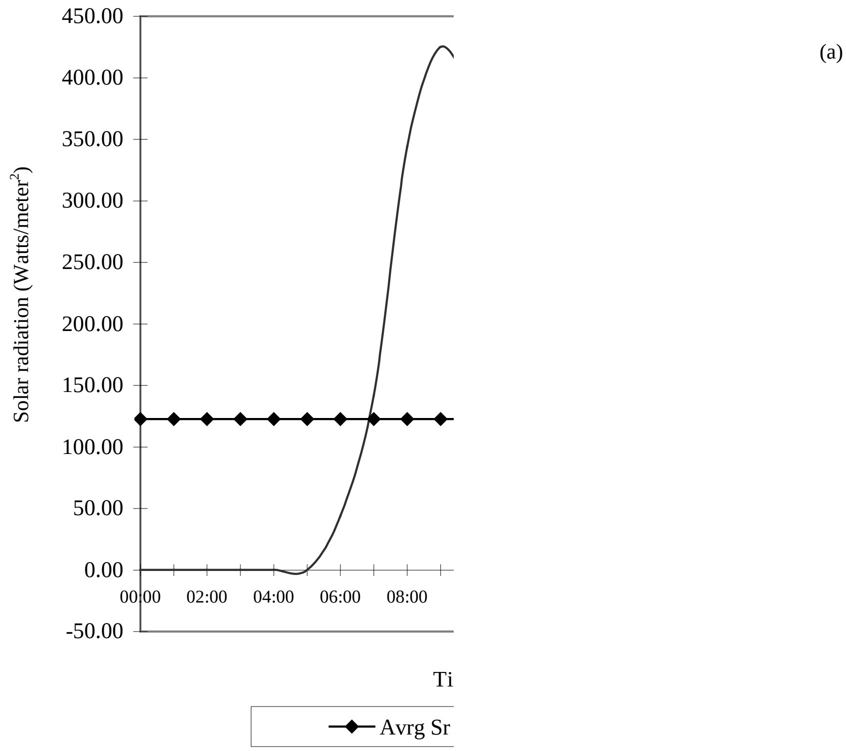


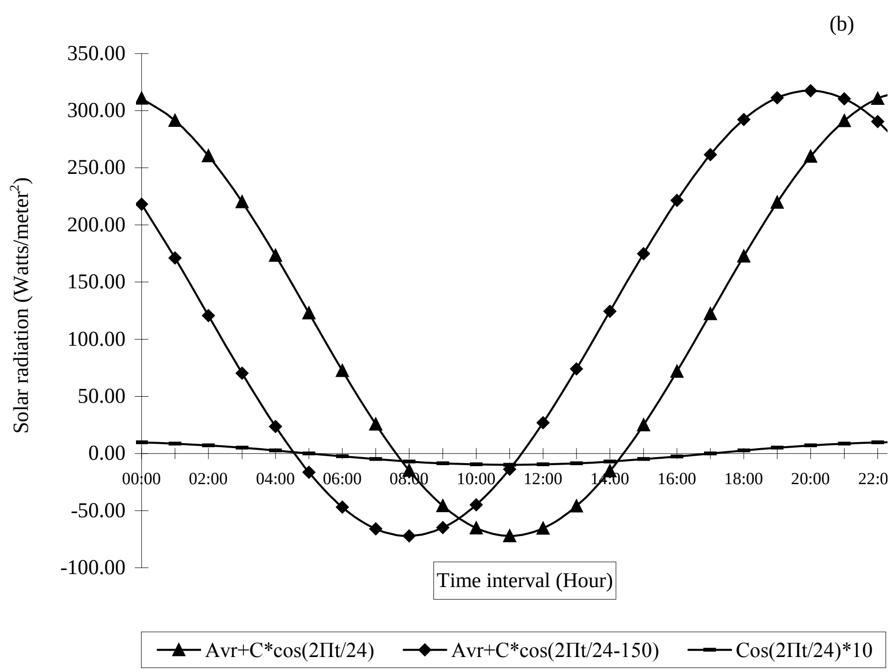


Figs. 4(a&b). Schematic diagram showing (a) the time series of wind speed of a thunderstorm day during pre-monsoon season over Kolkata and (b) three cosine functions illustrating transformation from time to angular measure, vertical positioning & stretching and lateral shifting yielding finally the function matching the data approximately

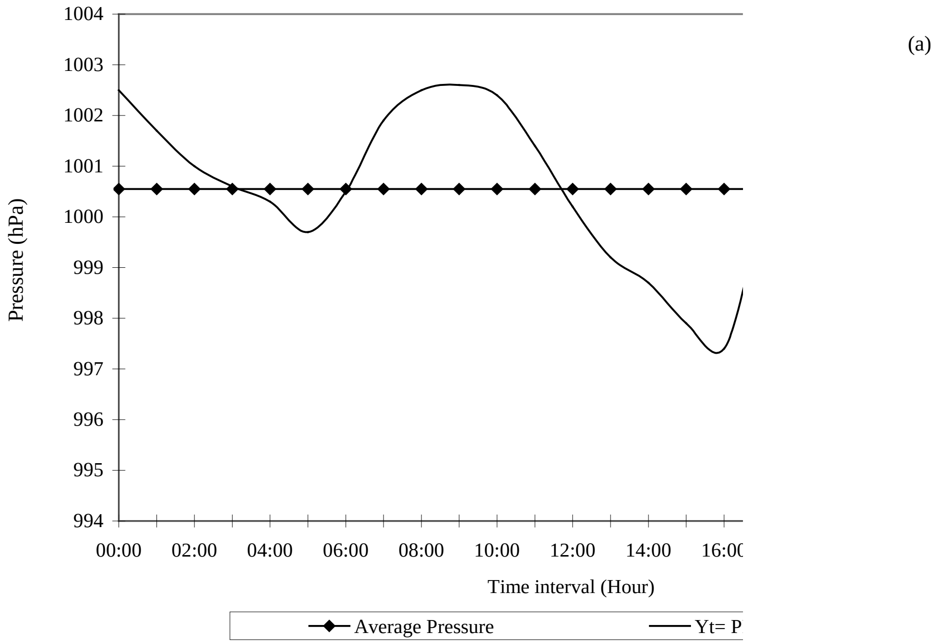
Surface pressure

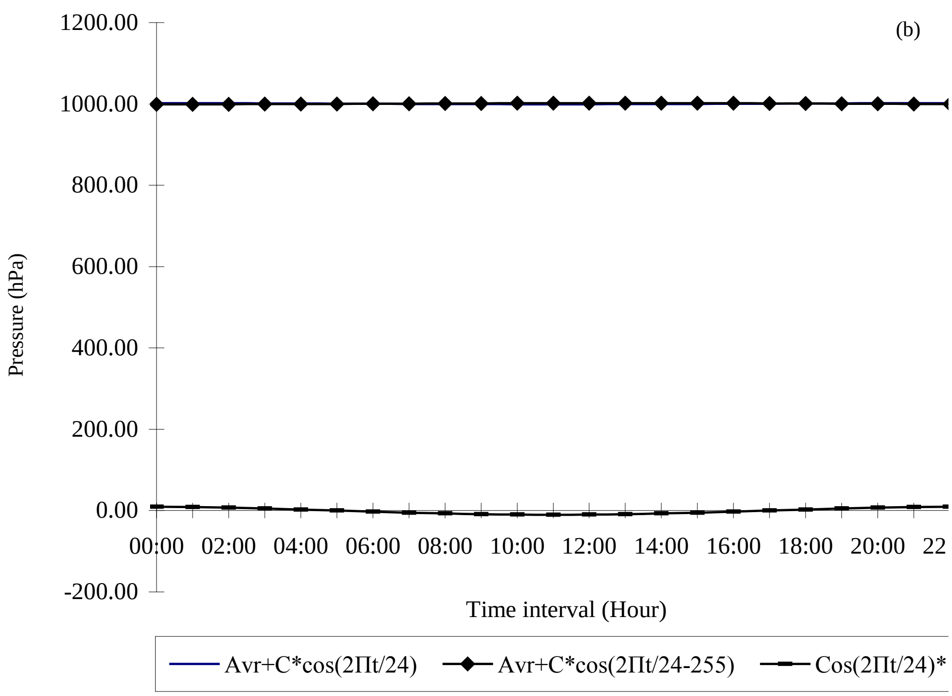
Surface pressure does not show a regular oscillating pattern with time interval on a thunderstorm day. Fourier analysis does not show any significant finding as well. However, low pressure appears at the frequency of 255 degree at 16 hours whereas the phase angle of low pressure is 141.66 degree. It can thus be stated that almost 7 hours before 16 hours *i.e.*, from 11 am onwards pressure maintains to be minimum. It can be stated that 4 -5 hours





Figs. 5(a&b). Schematic diagram showing (a) the time series of solar radiation of a thunderstorm day during pre-monsoon thunderstorms over Kolkata and (b) three cosine functions illustrating transformation from time to angular measure, vertical positioning & stretching and lateral shifting yielding finally the function matching the data approximately





Figs. 6(a&b). Schematic diagram showing (a) the time series of pressure on a thunderstorms day during pre-monsoon season over Kolkata and (b) three cosine functions illustrating transformation from time to angular measure, vertical positioning & stretching and lateral shifting yielding finally the function matching the data approximately before the occurrence of pre-monsoon thunderstorms a low pressure will be generated over the place [Figs. 6(a&b)].

6. Conclusion

It can thus, be concluded from the study that few basic surface meteorological parameters (temperature, relative humidity & wind speed) show a regular oscillating pattern on the day of thunderstorm during the pre monsoon season. The study also brings in some important information which can be the necessary conditions for the genesis of severe thunderstorms over Kolkata during the pre-monsoon season. The study reveals that high surface temperature (above 30° C), moderate to high relative humidity (above 80%), a low pressure (below 1000 hPa) and a highly low wind provides an indicator for the genesis of thunderstorm during the pre-monsoon season in the afternoon/evening over Kolkata.

As the study is based on only a month of AWS data, therefore in future, if the record of thunderstorms at regular interval for a longer period during the pre-monsoon season is available then the extension of this paper can be made to establish the results and more accurate prediction can be possible .

Acknowledgement

The first author thanks the Department of Science & Technology, Govt. of India, for the financial assistance in conducting the research under STORM Programme.

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