International Journal on Emerging Technologies 11(2): 763-769(2020)
ISSN No. (Print): 0975-8364
ISSN No. (Online): 2249-3255

Spectral Studies of Ground-based Observations of Wind Components, Temperature & Analysis of Flux Parameters during Pre-Monsoon Thunderstorms Period at Ranchi

Poulomi Chakravarty[1] and Manoj Kumar[2]
[1]Research Scholar, Department of Environmental Sciences, Central University of Jharkhand, India.
[2]Professor, Department of Environmental Sciences, Central University of Jharkhand, India.

(Corresponding author: Poulomi Chakravarty)
(Received 04 January 2020, Revised 02 March 2020, Accepted 05 March 2020)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Genesis and distribution of thunderstorms are still an enigma and their frequency and intensity have increased in the Eastern India over the years. Ranchi, India is known to experience frequent thunderstorms during the pre-monsoon months. The strong squalls and lightning have a detrimental impact on lives and materials of this region. There is a lack of ground based observational studies on land surface processes in this region. The challenges regarding this aspect includes lack of micrometeorological towers and automated weather stations in locations frequented by thunderstorms. The study was aimed at bridging the knowledge gap by analyzing the parameters such as turbulent kinetic energy (TKE), sensible heat flux (Hs), momentum flux (MF), wind speed (Ws), temperature (Ts) during days of storm, cloudy and clear days to compare the differences and analyze the energetics of the storm period of Ranchi, India. Spectral analysis of temperature and wind components (u, v and w dimensions) were also carried out for 3 days (4th May, 8th May and 17th May,2010) during pre-monsoon period to study the spectral density using different kernels. The observational data was obtained from the micrometerological tower set up at BIT Mesra, Ranchi, India. Sudden changes in wind speed and momentum flux and turbulent kinetic energy was also observed on clear days with sudden gusts of wind without rainfall. The highest TKE value on 4th May was 7.64 m^2s^{-2}at 8 pm during second storm of the day and lowest was 0.04 m^2s^{-2}at 4 am. On 8th May the maximum wind speed was 7.81 ms^{-1} at 12 pm. The maximum momentum flux was1.09 Nm^{-2}on 4th May at 8 pm and lowest 0.002 Nm^{-2} at 4.30 am.The maximum Hs value recorded was 223.65 Wm^{-2} on 4th May just after thunderstorm at 5pm and before the start of second storm the lowest value of all three days recorded was -59.22 Wm^{-2}. The results of the study indicated major changes in energy components, temperature and wind during onset of storms and on cloudy and clear days. The spectral analysis of the average temperature recorded by the sensor (Ts_avg1), (Ts_avg2) and (Ts _avg3) for 4th, 8th and 17th May depicted smoothed spectral density graphs when user defined kernel weighting was applied. The Temperature graphs 1, 2 and 3 were observed to have appeared smoothed when the fixed kernel weighting. Similarly, for wind in all dimensions same observations were recorded. Spectral analysis of the wind and temperature component depicts the components in terms of energy and smoother the curve the depiction is considered better. This study used two user defined kernels to smooth the graphs and found them to be effective. More Ground based observational studies need to be carried out in this region to garner information regarding the storm genesis as local thunderstorm are dependent on land surface parameters.

Keywords: thunderstorms, spectral analysis, energy fluxes.

Abbreviations: Hs, Sensible Heat flux; TKE, Turbulent kinetic energy; MF, momentum flux; Ws, Wind speed; Ts, Sensor Temperature; LULC, land use land cover.

I. INTRODUCTION

Thunderstorms accompanied by lightening is a characteristic feature of tropical areas. The frequency of thunderstorms has risen over the years [1]. Thunderstorm which is a stochastic event occurs during pre-monsoon and monsoon season, but the majority of severe thunderstorms are known to occur during March to May months (pre-monsoon period) in Eastern part of India [2]. The term stochastic has been associated with thunderstorms because stochastic events can be analyzed statistically but are difficult to predict. Although thunderstorm prediction has advanced significantly over the years the accuracy is uncertain in some cases. The thunderstorms occurring in the Eastern India and the Indo Gangetic plains have been named as Nor'westers as the stormy winds come from North west direction; "Kal Baisakhi" is the local name given to the thunderstorms as they occur in the Baisakh months [3]. In Jharkhand, India every year thunderstorm and lightening pose a threat to lives of people and property [4]. India is predominantly an agrarian country where 70% of the citizens reside in rural region out of which 60% population is dependent on agriculture [5]. Thunderstorm with rain and hail prove to be a mixed blessing in this case where rainwater provides moisture to dry soil whereas hailstorms destroy standing crops. A Thunderstorm can be defined as an extreme weather event which is usually accompanied by rainfall, lightning, thunder and occasionally hail and squall lines. CTCZ Report: During the summer months from March to May, India gets heated up due to intense solar heating. As a result, the pressure on the surface decreases and a trough is observed over the heated area. The trough created by heating is called a heat trough and is only 2-3 km in height above this height the air descends. Thunderstorms are generated because of the surface heating during summer days which further leads to development of convective cells. These convective cells generate thunderstorms accompanied by rain in the afternoons and evenings [4]. The tropics are frequented by single cell thunderstorms [6]. The air mass thunderstorms are driven by the wind shear and convective cells occurring locally. When the heating of land surface is high the air is lifted in the form of eddies or air parcels towards the levels of free convection in the atmosphere [7]. After reaching this level the air parcel converts to a self-buoyant system by utilizing the convective potential energy that is available and rises higher. These types of thunderstorm last for a maximum of half hour and is a big contributor of convective rainfall in the tropical regions [8]. There is an outflow of cold air with changes in wind speed and direction during the final dissipative stages of the thunderstorm.

The gaseous atmosphere and the solid Earth surface are linked by the atmospheric surface layer. In case of studies related to land-atmosphere transfer process the ability of atmospheric surface layer to transport matter, energy and momentum is very crucial [9]. Convection, thunderstorm and turbulence influence the atmospheric boundary layer. The surface layer processes are primarily influenced by solar radiation which is the main source of energy for all the biotic and abiotic processes on Earth. Atmospheric temperature is affected by the radiative heating by the sun. The intensity of radiation of sun increases gradually from early morning towards afternoon, thus the surface gets heated when the Earth emits the long wave radiation. The heating is the highest in the middle of the noon due to mixing of turbulent exchange processes. The presence of cloud cover during thunderstorm and lightening reduces solar irradiance [10]. The responses of the atmosphere can be studied using surface data collected during thunderstorm and lightening period.

II. METHODOLOGY

A. Study Area Background

The site of the study is BIT Mesra, Ranchi, India (coordinates: 23˚25' N, 85 ˚25' E) with elevation 609 m above mean sea level. The site is situated over region of wet convection at the Eastern end of the monsoon trough. The climate of the site is humid subtropical monsoon type (Cwa). There are four distinct seasons 1) summer or pre-monsoon (March-May) 2) Monsoon (June- September) 3) Post monsoon (October-November) 4) Winter (December- February).

B. Comparative study of energy fluxes during extreme weather and fair-weather conditions

The analysis of flux parameters and their relation to thunderstorm activity was carried out by utilizing time series data of meteorological parameters meteorological parameters (radiation, air temperature, pressure, wind speed and relative humidity). The measurement of wind speed at 3 axes and temperature at 10 Hz frequency was done by 3-D fast response sonic anemometer situated at 10 m height. The automatic weather station (8.5 m height) gave the micrometeorological observations at surface layer. The turbulent kinetic energy (TKE), momentum flux (MF) and sensible heat flux (SHF) were determined by the values recorded by the sonic anemometer. TKE can be defined as the measure of turbulence intensity that is affected or caused by thermal generation, vertical transport and dissipation. It is attributed to wind shear, buoyant force, level wise redistribution of TKE and forces of pressure. Dissipation by molecular forces is considered as the most important sink and sources apart from wind shear can also be considered as such [11].

The characteristics of atmospheric surface layer are defined in terms of temperature variation vertically, stability, wind speed, relative humidity, turbulence and fluxes. Within the atmospheric surface layer, the extent of turbulence is estimated by the turbulent kinetic energy magnitude and from the surface the momentum and heat turbulent exchange is measured through sensible heat flux (SHF) and the momentum flux (τ);[4, 8] determined the formulas for the parameters:

$$TKE = \frac{1}{2}\left(\bar{u}'^2 + \bar{v}'^2 + \bar{w}'^2\right) \quad (1)$$

$$\tau = \rho(\sqrt{\overline{u'w'}^2 + \overline{v'w'}^2} \quad (2)$$

$$H_s = \rho c_p(\overline{w'\theta'} \quad (3)$$

In the equations given above the u', v', w' are the deviations from the mean of wind in zonal, meridional and vertical forms and θ' is the deviation from mean for the potential temperature. Air density is depicted by ρ and specific heat of air is C_P. The values were averaged over a period of 30 minutes depicted by the bar given over the equation.

C. Weather Conditions

The analysis of flux parameters was done by comparing two days one with thunderstorm activity and another without any storm within the same month. 4th May 2010 was chosen because of the occurrence of thunderstorm at 4.20 PM to 4.30 PM again 5.25 to 5.40 PM and finally 7.40 to 8 PM. Early morning had 6 octa of cloud coverage, afternoon had 4 octa at 2 PM and by 4 the sky as overcast, and thunderstorm initiated by 4.20 PM at the study site. 8th May 2010 was the next day chosen as it had medium wind speed and bright sunshine at 7 am with 3 octa cloud coverage and 4 octa cloud coverage with medium wind speed.

D. Spectral Analysis

Spectral analysis is carried out for transformation of real space time series into frequency space co-ordinates. The frequency co-ordinates help in extraction of magnitude, phase and the representations of spectral density and periodogram along with verification of stationarity of the series. The seasonal components can be identified, and the extent of noise filtration can be decided on its basis. The time series spectral representation (X_t) is decomposed into summation of sinusoidal components and the uncorrelated random coefficients. The autocovariance and autocorrelation functions into sinusoids can be obtained after that. The periodogram is used along with a smoothing function so that a better estimate of spectral density can be estimated which in turn depicts a better spectrum. XLSTAT 2018.1 Premium (license: student version) was used to run the spectral analysis for this study. The software computed the sine and cosine transforms of the series for every individual Fourier frequency and derived functions from these computed transforms.

The sample size was considered as 'n' and [i] was the highest integer value, the Fourier frequencies can be written as

$$w_k = \frac{2\pi k}{n}, k = \left(\frac{n-1}{2}\right), \dots, \frac{n}{2} \quad (4)$$

The Fourier cos written as

$$a_k = \frac{2}{n}\sum_{t-1}^{n} X_t \cos\left(w_k (t-1)\right) \quad (5)$$

Fourier sine can be expressed as

$$b_k = \frac{2}{n}\sum_{t-1}^{n} X_t \sin\left(w_k (t-1)\right) \quad (6)$$

The periodogram of the series can be expressed as

$$l_k = \frac{2}{n}\sum_{t-1}^{n} X_t \left(a_k^2 + b_k^2\right) \quad (7)$$

The estimation of spectral density of the time series (X_t) can be written as

$$\hat{f} = \sum_{i--p}^{p} w_i J_{k+i} \quad (8)$$

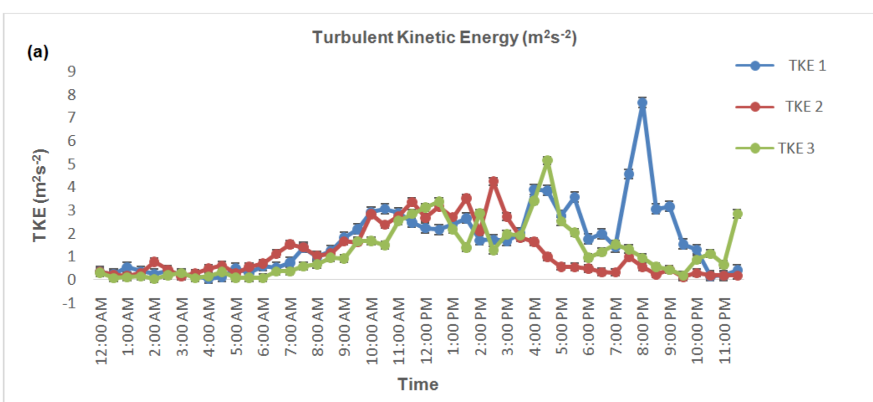
with
$$\begin{cases} J_{k+1} = I_{k+i,} & 0 \leq k+i \leq n \\ J_{k+1} = I_{-k+i,} & k+i < 0 \\ J_{k+1} = I_{n-(k+i),} & k+i > n \end{cases}$$

In this case p is the bandwidth of the spectrum and w_i is the weight which are user defined or fixed by the software. When the kernel is not user defined the analysis is done by fixed kernels, Bartlett kernel was used for this study. If $p = c.q^e$ and $\lambda_i = i/p$

Bartlett:
$$\begin{cases} c = 1/2, & e = 1/3 \\ w_i = 1 - |\lambda_i| & if\ |\lambda_i| \leq 1 \\ w_i = 0 & \end{cases}$$

III. RESULTS

The maximum TKE value on the thunderstorm day was 7.64 $\mathrm{m^2s^{-2}}$at 8 pm during the second thunderstorm and 3.90 $\mathrm{m^2s^{-2}}$ during the first thunderstorm at 4 pm. The lowest TKE recorded on 4th May was at 4 am and the value recorded was 0.04 $\mathrm{m^2s^{-2}}$. On the 8th May the highest TKE was 4.24 $\mathrm{m^2s^{-2}}$recorded at 2.30 pm and the lowest value was 0.16$\mathrm{m^2s^{-2}}$ recorded at 1 am. On 17th May the highest recorded TKE was at 4.30 pm and the value was 5.14$\mathrm{m^2s^{-2}}$ and the lowest value recorded was 0.07$\mathrm{m^2s^{-2}}$. The onset of storms depicted high values of TKE. Similarly, when there was a squall on 17th may despite having clear skies the TKE rose to a higher level. The TKE value has been depicted in Fig. 1 (a) as TKE 1 (4th may- storm day), TKE 2 (8th May- cloudy day) and TKE 3 (17th may- clear, windy day). The highest wind speed on 4th May was at 10 am the value being 7.61 $\mathrm{ms^{-1}}$and the lowest wind speed was 1.52 $\mathrm{ms^{-1}}$ at 10.30 pmduring initiation of the first storm at 4 pm the wind speed rose to 5.64$\mathrm{ms^{-1}}$ and 3.71 $\mathrm{ms^{-1}}$ at 7 pm. On the cloudy day of 8th May the highest wind speed was recorded at 12 pm and the value 7.81$\mathrm{ms^{-1}}$ and the lowest value recorded was 0.63 $\mathrm{ms^{-1}}$recorded at 11 pm that night. The highest wind speed on 17th May was 6.30 $\mathrm{ms^{-1}}$ indicating a sudden squall and the lowest value was observed 0.41$\mathrm{ms^{-1}}$ at 12 am. Figure 1 (b) depicts the wind speed on the three chosen days. The momentum flux on 4th May during both the storms rose at 5 pm it was 0.95$\mathrm{Nm^{-2}}$and at 8 pm it was 1.09 $\mathrm{Nm^{-2}}$ and lowest 0.002$\mathrm{Nm^{-2}}$ at 4.30 am, represented in figure 1 (c). On the 8th of May the highest momentum flux recorded was 0.34$\mathrm{Nm^{-2}}$ at 12 pm and 0.013$\mathrm{Nm^{-2}}$ at 12.30 am. On 17th May 1.042 $\mathrm{Nm^{-2}}$ was observed during 5 pm and lowest value was recorded at 12 am and the value recorded was 0.003 $\mathrm{Nm^{-2}}$.The highest peak on sensible heat flux graph was observed on the day of the storm at 5 pm just after the end of first storm the value recorded was 223.65 $\mathrm{Wm^{-2}}$ as shown in figure 1(d). Before the commencement of first storm the sensible heat flux as expected dipped to a value of 17.89 and at 6 pm before the start of second storm the value recorded was -59.22 $\mathrm{Wm^{-2}}$,the lowest of all three days. The 8th of May and 17th of May showed similar values where the sensible heat flux (Hs) rose steadily and peaked in the afternoon hours 12.30 then dipped as the day progressed. The highest sensor temperature recorded on the day of the storm was 34.77˚C at 3 pm just before the storm and lowest recorded temperature was 20.12 ˚C at 9.30 pm after the completion of second storm of that day. There was a sharp fall in the temperature just before the first storm corresponding to the dip in sensible heat flux, the temperature fell directly from 33.11˚C at 4.30 pm to 29.24˚C at 5 pm. The highest temperature recorded on the 8th of May was at 3.30 pm 35.76˚C and the lowest temperature was 23.35˚C at 12 am. On 17th May the maximum temperature recorded by the sensor was 40.38 ˚C at 3.30 pm and the lowest temperature recorded was and lowest recorded temperature for that day was 27.62 ˚C at 5 am.



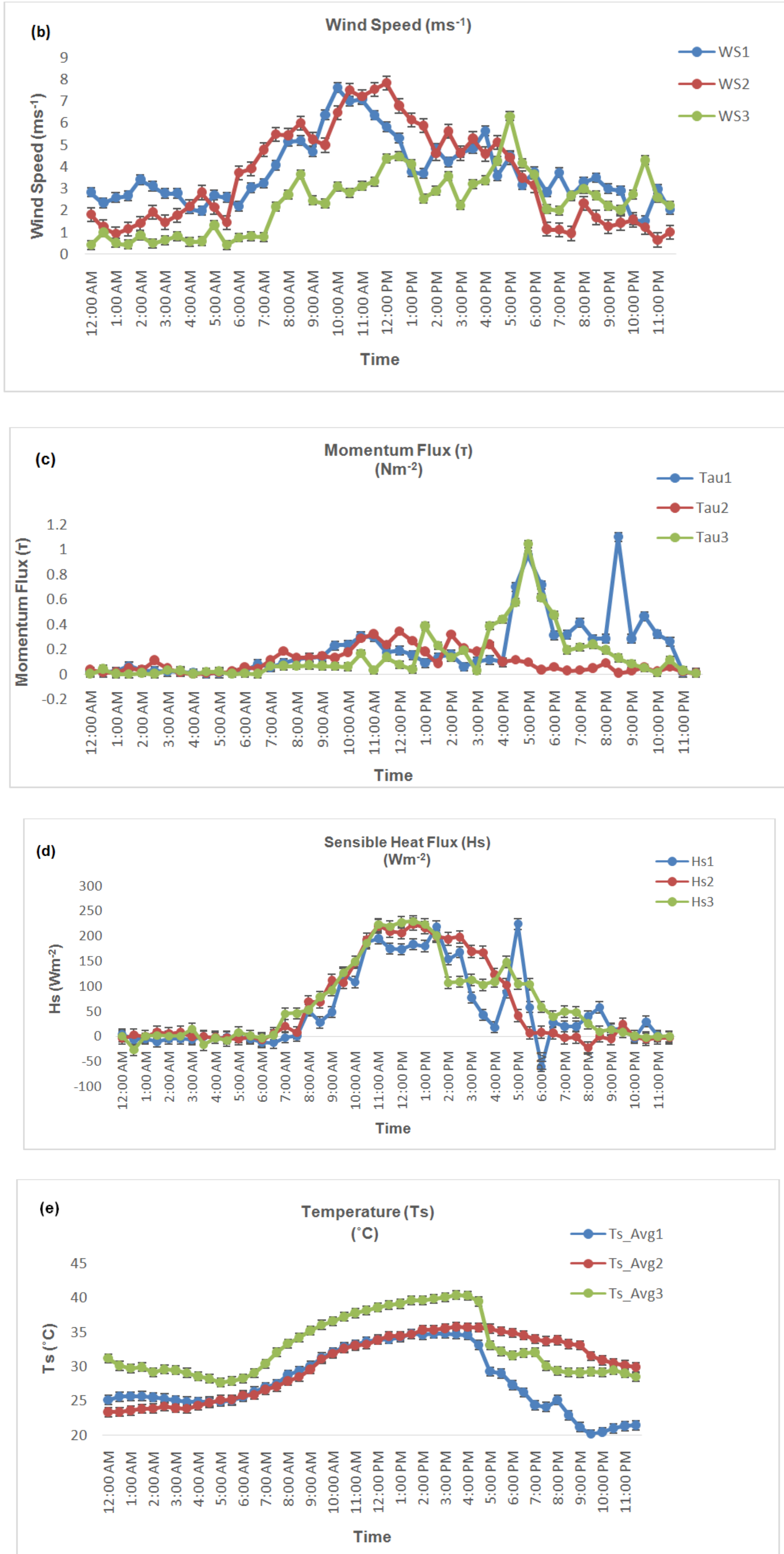


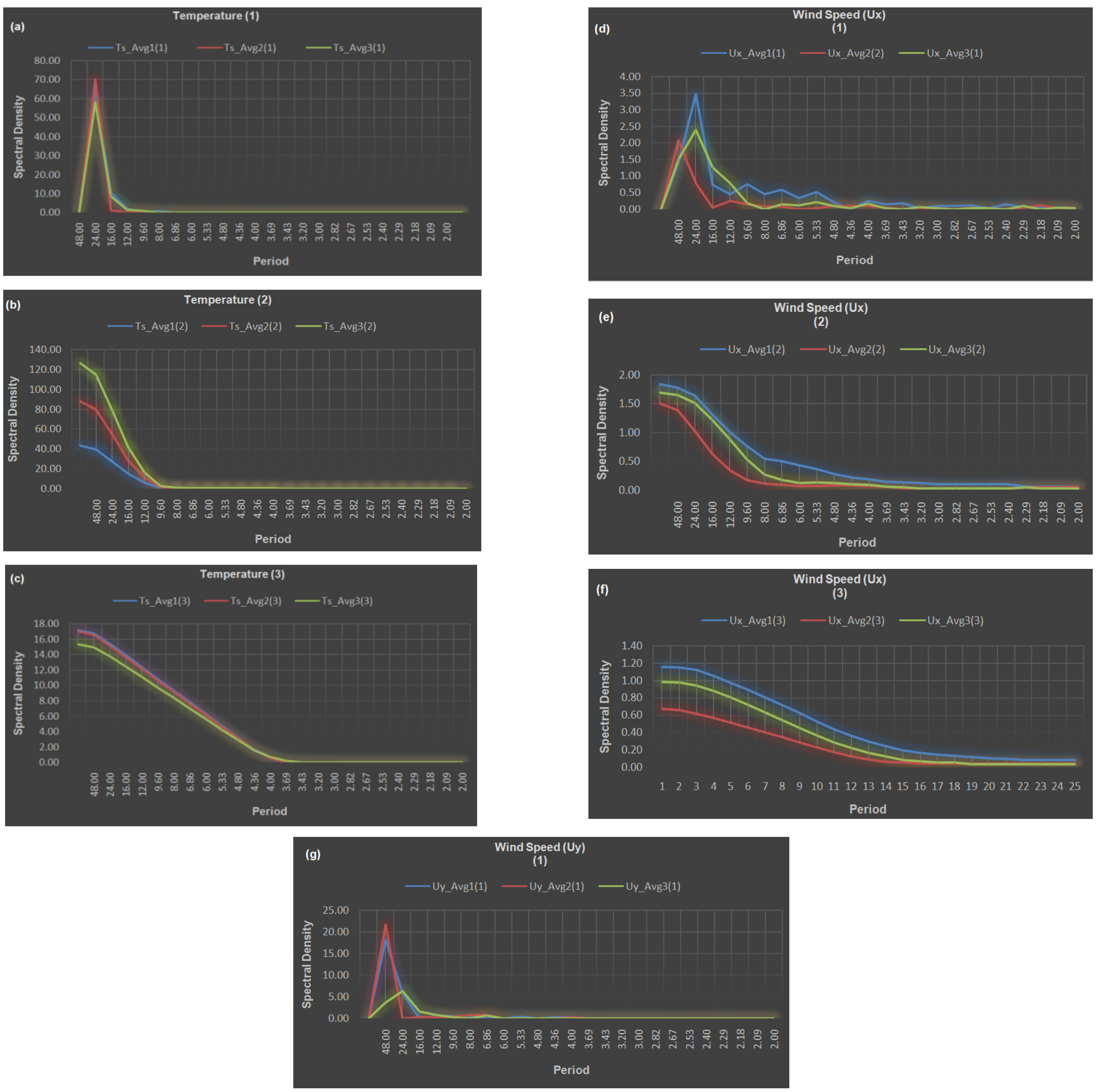
Fig. 1. Comparison of (a)Turbulent Kinetic energy (TKE), (b) Wind speed (WS), (c) Momentum Flux (MF), (d) Sensible heat flux (Hs) and Temperature (Ts) on 4th May, 8th May and 17th May.

A. Spectral Analysis result

Spectral analysis of the temperature recorded by the sensor and the wind speed in different dimensions were carried out. The time series for the wind speed and temperature was converted into spectral series to analyze their behavior in the imaginary space of frequency. Kernel weighting Bartlett was firstly used for the parameters with c = 0.5 and e = 0.33. Secondly two user defined fixed weighting were applied to all the time series and the graphs were plotted to check the smoothness of the spectral density. The fixed weight used for the study were (1,2,3,4,3,2,1) and (1,2,3,4,5,6,7,8,9,10,11,12,11,10,9,8,7,6,5,4,3,2,1) chosen by following the examples given in the study of spectral analysis of solar flare in the XLSTAT demonstration guide. The spectral analysis of the average temperature recorded by the sensor (Ts_avg1), (Ts_avg2) and (Ts _avg3) for 4^{th}, 8^{th} and 17^{th} May depicted smoothed spectral density graphs when user defined kernel weighting was applied. The Temperature graphs 1, 2 and 3 were observed to have appeared smoothed when the fixed kernel weighting like in Fig. 2 (Temperature (2) b) and (Temperature (3) c). In the graph Fig. 2 (Temperature (1) a) software-based kernel was implemented. Similarly, for wind in all dimensions same observations were recorded. The white-noise test Fisher's Kappa and Bartlett's Kolmogorov-Smirnov [12], for the time series of temperature and wind in different dimensions were applied and the values have been represented in Table 1.

Table 1: White-noise test for temperature and wind components.

Tests	Average Temp 1	Average Temp 2	Average Temp 3	Wind Speed Ux(1)	Wind Speed Ux(2)	Wind Speed Ux(3)	Wind Speed Uy(1)	Wind Speed Uy(2)	Wind Speed Uy(3)	Wind Speed Uz(1)	Wind Speed Uz(2)	Wind Speed Uz(3)
Fisher's Kappa	18.830	21.652	18.713	7.755	11.109	7.538	14.952	19.622	9.988	12.374	17.144	9.480
Bartlett's Kolmogorov -Smirnov	0.905	0.941	0.888	0.490	0.624	0.679	0.815	0.855	0.732	0.752	0.745	0.711



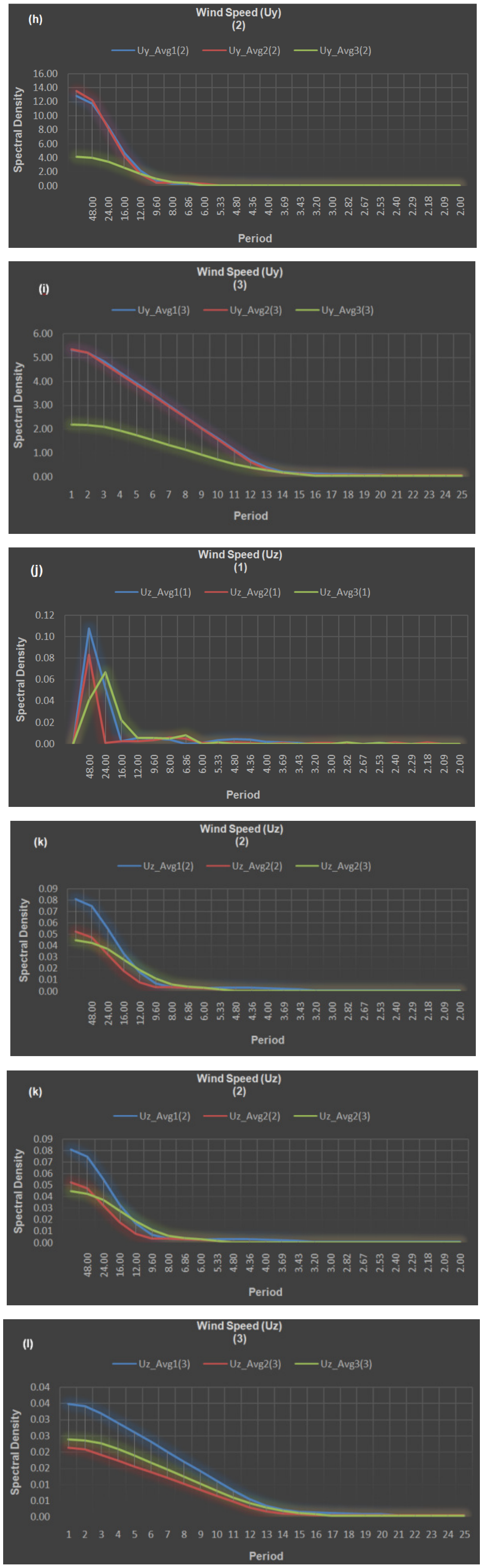


Fig. 2. Spectral density graphs for Temperature and wind components in u, v and z dimensions.

IV. DISCUSSION

The changes in turbulent kinetic energy, sensible heat flux, momentum flux and wind speed were apparent with the onset of storms, this result is in consonance with [13]. The cloudy and clear days witnessed gradual variations in the parameters that were diurnal. The temperature changes were more restricted and followed the diurnal fluctuation pattern on all three days. The spectral analysis of the temperature and wind component using two different user defined kernels were to compare them with the spectral density graphs with fixed weightage. It was observed that the user defined kernels were more efficient in smoothing the spectral density graphs. It is imperative to study the energetics of the storms occurring in Indian subcontinent due to the increased frequency and intensity of the thunderstorm and lightning events. The observational studies help in understating the subtle changes in energy levels near the ground level and their comparison with satellite observations would further help in the study of storm genesis and prediction. In view of the ever-increasing rate of land use land cover changes, especially in areas of increased population it is necessary to have a comprehensive knowledge regarding important issues such as climate change, extreme events, resource management and LULC changes [14].

V. FUTURE SCOPE

With the rise in erratic weather conditions and extreme events across the globe it is imperative to study the causal effects of these phenomenon. Spectral analysis has not been carried out in this area before using different smoothing functions so this study is novel in this aspect. This study will provide baseline observational data for the existing weather and land surface conditions for Ranchi, Jharkhand during pre-monsoon thunderstorms and help in simulation and prediction of changes in land surface dynamics during thunderstorms.

ACKNOWLEDGEMENTS

– The data used for the study was the part of Department of Science and Technology, Government of India, New Delhi funded multi-institutional mega field campaign on "Continental Tropical Convergence Zone (CTCZ) project titled "Observational study of land surface atmosphere interaction in the monsoon trough along its active eastern end" to the Birla Institute of Technology, Ranchi.

– The work was funded by DST INSPIRE fellowship (IF150978) to the Corresponding author by Department of Science and Technology, India.

Conflict of Interest. There is no conflict of interest regarding this study.

REFERENCES

[1]. STORM Science Plan (2005). presented by Department of Science &Technology, Ministry of Science & Technology, Government of India, 'Severe thunderstorms—observations and regional modeling (STORM) programme. http://www.imd.gov.in/SciencePlanofFDPs/STORM%20Science%20Plan.pdf

[2]. Tyagi, B., Satyanarayana, A. N. V., & Vissa, N. K. (2013). Thermodynamical structure of atmosphere during pre-monsoon thunderstorm season over Kharagpur as revealed by STORM data. *Pure and Applied Geophysics*, *170*(4), 675-687.

[3]. Ghosh, A., Lohar, D., & Das, J. (2008). Initiation of Nor'wester in relation to mid-upper and low-level water vapor patterns on METEOSAT-5 images. *Atmospheric Research*, *87*(2), 116-135.

[4]. Dwivedi, A. K., Chandra, S., Kumar, M., Kumar, S., & Kumar, N. K. (2014). Atmospheric surface layer responses to the extreme lightning day in plateau region in India. *Journal of Atmospheric and Solar-Terrestrial Physics*, *120*, 143-149.

[5] Kumar, G., & Duggal, S. (2019). A Micro level Survey on the Role of Women in Climate Resilient Agriculture and Their Economic Status under Rain-fed District of Himachal Pradesh, India. *International Journal on Arts, Management and Humanities, 8*(1), 6-11.

[6]. Tyagi, A. (2007). Thunderstorm climatology over Indian region. *Mausam*, *58*(2), 189-212.

[7]. Whiteman, C. D. (2000). *Mountain meteorology: fundamentals and applications*. Oxford University Press.

[8]. Schumacher, C., & Houze Jr, R. A. (2003). Stratiform rain in the tropics as seen by the TRMM precipitation radar. *Journal of Climate*, *16*(11), 1739-1756.

[9]. Stull, R. B. (1988). Mean boundary layer characteristics. In *An Introduction to Boundary Layer Meteorology* (pp. 1-27). Springer, Dordrecht.

[10]. Dwivedi, A. K., Chandra, S., Kumar, M., Kumar, S., & Kumar, N. K. (2015). Spectral analysis of wind and temperature components during lightning in pre-monsoon season over Ranchi. *Meteorology and Atmospheric Physics*, *127*(1), 95-105.

[11]. Srivastava, M. K., & Sarthi, P. P. (2002). Turbulent kinetic energy in the atmospheric surface layer during the summer monsoon. *Meteorological Applications*, *9*(2), 239-246.

[12]. Bartlett, M. S. (1966). An Introduction to Stochastic Processes, Second Edition. Cambridge University Press, Cambridge.

[13]. Chakravarty, P., & Kumar, M. (2020). Trend Analysis and ARIMA Modeling to Assess Meteorological and Surface Parameters in Ranchi, India During Pre-Monsoon Months. *GIS Business*, *15*(2), 69-87.

[14]. Khan, A. S., & Khan, A. B. (2020). Assessment of Land use and Land Cover Dynamics in Shingla River Basin Using Multi Temporal Satellite Imageries. *International Journal on Emerging Technologies*, *11*(1), 263-269.

How to cite this article: Chakravarty, P. and Kumar, M. (2020). Spectral Studies of Ground-based Observations of Wind Components, Temperature & Analysis of Flux Parameters during Pre-Monsoon Thunderstorms Period at Ranchi. *International Journal on Emerging Technologies*, *11*(2): 763–769.