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Atmospheric surface layer responses to the extreme lightning day in plateau region in India

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ABSTRACT

This paper discusses the observations of the atmospheric surface layer (ASL) parameters during the lightning event. During this event behaviour of surface layer parameters has been observed. Other derived parameters like Monin–Obukhov stability parameter (z/L), turbulent kinetic energy (TKE), momentum flux (MF) and sensible heat flux (SHF) have also been considered during this stochastic phenomenon. Characteristics of these surface layer parameters have been analysed during lightning period and compared with the clear weather day. During the peak period of the lightning, the incoming solar irradiance was reduced by one third of its normal value, resulting in an air-temperature decrement near the surface in the range of 4 °C to 6 °C. In addition to that a significant reduction in energy exchanges between surface and lower lying atmosphere (viz. TKE, MF and SHF), has also been observed. The rate of instantaneous decay in solar irradiance and SHF from the first strike to its peak strike time was larger than that seen during clear day hours. The normalized standard deviations of wind components during clear day were studied using Monin–Obukhov similarity theory (MOST) and the results have been compared with earlier studies reported in the literature.

1. Introduction

The atmospheric surface layer is an active link between the atmosphere and the surface of the earth. Thus, its ability to transport momentum, sensible heat, water vapour and other constituents is of fundamental importance in all studies related to surface–atmosphere exchange process (Stull, 1988). The characteristics of this layer are highly influenced by convection, turbulence, thunderstorm, lightning and its interaction with the free atmosphere. In addition, incoming solar radiation plays an important role in various surface layer processes. As the solar radiation is the primary source of energy for living being on the earth and plays an important role for the exchange processes between earth surface and overlying atmosphere due to radiative heating and hence affects the variation in atmospheric temperatures. As the day progressed surface gets heated due to the intensification of solar radiation incident over the surface. The maximum heating is observed during mid-noon when the turbulent exchange processes are well mixed by that period. Lightning has been considered as a phenomenon in which solar irradiance becomes very less due to cloud cover and it develops to the usual value. Later it becomes very less and eventually follows the usual curve. This situation has been taken as a required condition to study the response of ASL in the absence and the availability of solar radiation in a very small time span.

The event of lightning associated with thunderstorm has always been very useful to meteorologists for studying the response of the atmosphere. Lightning is a flash of light in the atmosphere which consists of thunder and is caused by a discharge of electricity. It has been estimated that lightning strikes on the earth surface about 100 times every second (Srinivasan and Gu, 2006). The sudden heating effect and the expansion of heated air give rise to a supersonic shock wave in the surrounding air, which is heard as thunder (Rakov and Uman, 2003). Lightning is generated in electrically charged storm systems; however the method of cloud charging still remains elusive. When the electric field becomes strong enough, an electrical discharge occurs within the clouds or between clouds and the ground. In this analysis, we

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have investigated the impact of this high electric field on the characteristics of the ASL over the Chota Nagpur Plateau area (Ranchi). Results obtained might facilitate in understanding the decay and growth of turbulence process during lightning period additionally showing the response of ASL parameters. The plateau region has a strategic location from the point of view of pre-monsoon thunderstorm evolution. Lightning is a common phenomenon during pre-monsoon thunderstorm and also during active monsoon phases. Every year a lot of casualties have been observed over the region due to lightning and therefore state government agencies have also started working to understand this phenomenon over the region. Looking at the importance of this phenomenon, it has been tried to understand the surface layer processes during pre-monsoon lightning period in this paper. This paper also presents the influence of lightning on turbulent and fluxes parameters. Therefore, objectives of the paper are to study (1) the variations in the ASL parameters during lightning and clear day, (2) the turbulent characteristics of wind components for clear day according to Monin–Obukhov similarity relations.

2. Data and methods of analysis

In order to analyse the impact of lightning on general characteristics of the atmospheric surface layer over Ranchi, the time series measurement of different meteorological parameters (i. e. incoming solar radiation, air temperature, relative humidity, pressure, wind speed, etc.), were made. Wind direction was operated in affiliation with 3-D fast response sonic anemometer (fixed at 10 m above ground level) for measuring wind speed in three different axes and temperature at high frequency. Surface layer micrometeorological observations were obtained from the automatic weather station (AWS) at 8.5 m level which were averaged for one hour interval. The fast response measurements of wind speed and temperature were recorded from the sonic anemometer at a frequency of 10 Hz for the determination of TKE, MF, and SHF. For the collection of Atmospheric Electric Field (AEF) data, an electric field meter (EFM) has been installed. It measures at one second interval which is averaged for one minute duration. The AEF has been measured for decades by EFM usually known as “field mills”. Traditional field mills employ a spinning metal rotor (vane) electrically connected to Earth ground, placed between the external field and stationary metal sense electrodes. Details of instruments used on the lightning day as well clear day are given in Table 1.

The surface layer characteristics are defined in terms of stability, and the vertical variation of temperature, relative humidity, wind speed, fluxes and turbulence. The magnitude of turbulence within the surface layer is estimated through the magnitudes of TKE, while the turbulent exchange of momentum and heat from the basic surface are measured through the vertical momentum flux (τ) and sensible heat flux (H_S). These parameters are determined by (Stull, 1988):

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

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

$$H_S = \rho C_P(\overline{w'\theta'}) \quad (3)$$

In the above equations ρ and C_P are the air density and specific heat of air. u', v', w' and θ' are the fluctuations from the mean of zonal, meridional, vertical winds and the potential temperature respectively. The bar over the equation indicates the value averaged in 30 min.

Table 1
Details of instruments used on the lightning day as well as clear day.

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Name of the sensor (measured parameter)	Range	Response time	Accuracy
(a) Automatic weather station (Make: Campbell Scientific, Canada)			
CM3 pyranometer (solar radiation)	305–2800 nm (50% points) (spectral range)	< 1 min	± 10%
Pt100RTD (air temperature)	−40–60 °C	< 5s	± 0.1 °C
Hygroclip-S3 (Relative humidity)	0–100%	12–15 s	± 1.5%
Electronic barometer (atmospheric pressure)	600–1100 hPa	2 s	± 0.5 hPa
Anemometer (wind speed)	0–100 m/s	< 5 s	± 0.3 m/s
Wind vane (wind direction)	0–360°	< 5 s	± 3°
(b) Sonic anemometer (Make: Campbell Scientific parameter, Canada)			
Name of the sensor (measured parameter)	**Range**		**Sampling rate**
Ultra-sonic anemometer (u, v and w)	0–100 m/s (0–224 mph)		0.1–10 Hz
Air temperature (T)	−40 to 60 °C		0.1–10 Hz
(c) Electric field meter (Make: Campbell Scientific, Canada)			
Name of the sensor (measured parameter)	**Range**		**Accuracy**
Electric field meter AEF	± (0–21,000)		± 1%