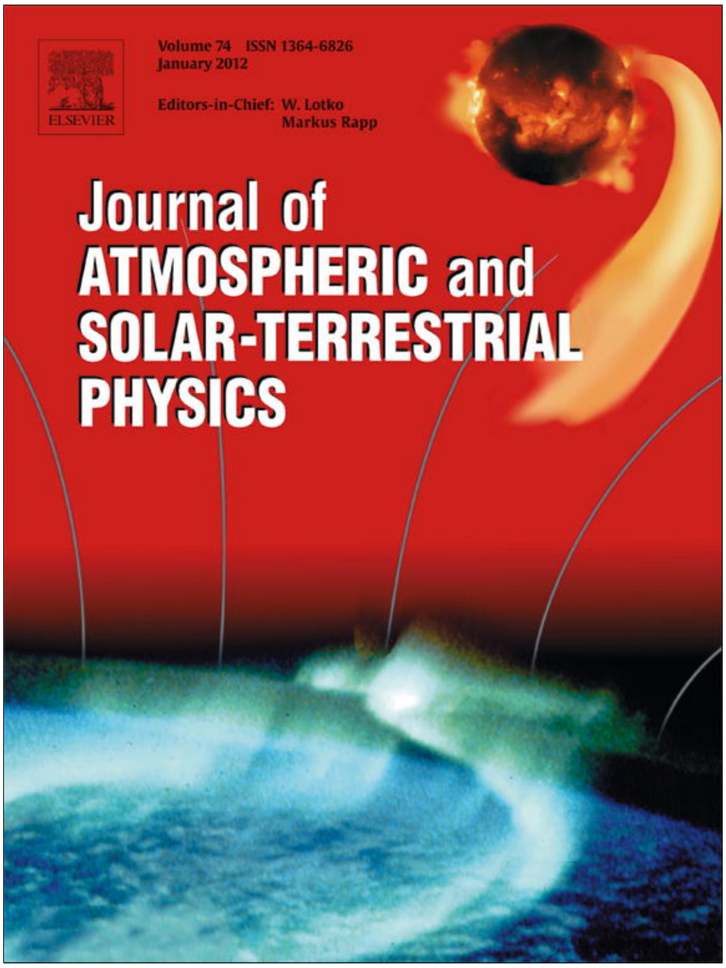
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Drastic variation in the surface boundary layer parameters over Cochin during the annular solar eclipse: Analysis using sonic anemometer data

P.R. Jayakrishnan *, C.A. Babu, P. Sivaprasad

Department of Atmospheric Sciences, Cochin University of Science and Technology, Cochin682 016, India

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ABSTRACT

Atmospheric surface boundary layer parameters vary anomalously in response to the occurrence of annular solar eclipse on 15th January 2010 over Cochin. It was the longest annular solar eclipse occurred over South India with high intensity. As it occurred during the noon hours, it is considered to be much more significant because of its effects in all the regions of atmosphere including ionosphere. Since the insolation is the main driving factor responsible for the anomalous changes occurred in the surface layer due to annular solar eclipse, occurred on 15th January 2010, that played very important role in understanding dynamics of the atmosphere during the eclipse period because of its coincidence with the noon time. The Sonic anemometer is able to give data of zonal, meridional and vertical wind as well as the air temperature at a temporal resolution of 1 s. Different surface boundary layer parameters and turbulent fluxes were computed by the application of eddy correlation technique using the high resolution station data. The surface boundary layer parameters that are computed using the sonic anemometer data during the period are momentum flux, sensible heat flux, turbulent kinetic energy, frictional velocity (u_*), variance of temperature, variances of u, v and w wind. In order to compare the results, a control run has been done using the data of previous day as well as next day. It is noted that over the specified time period of annular solar eclipse, all the above stated surface boundary layer parameters vary anomalously when compared with the control run. From the observations we could note that momentum flux was 0.1 Nm^{-2} instead of the mean value 0.2 Nm^{-2} when there was eclipse. Sensible heat flux anomalously decreases to 50 Nm^{-2} instead of the mean value 200 Nm^{-2} at the time of solar eclipse. The turbulent kinetic energy decreases to 0.2 m^{2}s^{-2} from the mean value 1 m^{2}s^{-2}. The frictional velocity value decreases to 0.05 ms^{-1} instead of the mean value 0.2 ms^{-1}. The present study aimed at understanding the dynamics of surface layer in response to the annular solar eclipse over a tropical coastal station, occurred during the noon hours. Key words: annular solar eclipse, surface boundary layer, sonic anemometer

1. Introduction

Solar eclipse is a celestial phenomenon in which the moon passes between the Sun and Earth, and then it makes a shadow on the Earth, which can be viewed as a blocking of sunlight partially or fully. When the Sun is fully covered by the Moon it is known as total solar eclipse and when it is partially covered it is known as partial solar eclipse. It could occur at any time of the day. During the day time, due to the solar heating the Earth's surface gets heated up and thermals begin to rise. There is a regular diurnal variation for every surface atmospheric boundary layer (ABL) parameters. The maximum air temperature is noted at a time of about 14.00 IST over the tropical stations. Corresponding to this maximum in temperature most of the surface ABL parameters are found to be maximum during the time. The total solar eclipse is a situation in which there is a blocking of solar radiation for a small interval of time. So the changes that occur for surface ABL is purely a micro meteorological phenomenon since the process has the time scale of the order of a few hours (Stull ,1988). It is very interesting to note how these surface boundary layer parameters vary in response to the celestial phenomenon such as solar eclipse.

Several studies were carried out over different parts of India to quantify the changes in the surface atmospheric boundary layer in response to the total annular solar eclipse of 15th January 2010. Venkat Ratnam et al. (2010) analyzed the changes in lower atmospheric boundary layer over the site Gadanki using a set of

* Corresponding author. Tel.: +91 9496026547; fax: +91 484 2353662.
E-mail addresses: prjayakrishnan@gmail.com, jkprdas@gmail.com (P.R. Jayakrishnan).

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instruments including automatic weather station, Doppler SODAR and GPS sonde. They found that the effect of soil temperature is seen clearly up to 20 cm depth and at all the levels up to 15 m. They could obtain strong eclipse induced variations in meteorological parameters of the surface layer over Gadanki. Subrahamanyam et al. (2010) studied the impact of 15th January 2010 solar eclipse over Thumba, a south Indian coastal station. They investigated the variations in surface ABL using AWS, sonic anemometer and GPS radiosonde. Associated with the decrease in radiation intensity, they could obtain significant changes in boundary layer parameters as well as thermodynamic parameters. Bala Subrahamanyam and Anurose (2011) analyzed the impacts on sea/land breeze circulation characteristics over Thumba in response to the annular eclipse of January 15, 2010. They observed that the vertical thickness of the sea breeze cell was confined to 300 m on the eclipse day whereas it was extending to about 610 m on the control run day. Muraleedharan et al. (2011) also studied the impact of annular solar eclipse on the meteorological parameters over Goa. They observed a strong inversion at 13 km and an abnormal warming in the upper troposphere noticed on the eclipse day.

The Space physics Laboratory (SPL), Thiruvananthapuram carried out extensive and collocated experiments over different regions of the atmosphere in the field experiment named 'Suryagrahan-2010', which was organized by Vikram Sarabhai Space Centre (VSSC). The outcome of the field campaign has been published as proceedings of the National Workshop: Results on Solar Eclipse (NaWRoSE, 2011). It discusses the effects of annular solar eclipse over different regions of the atmosphere such as boundary layer, troposphere, stratosphere and ionosphere.

The solar eclipse induced variations have been extensively analyzed over different parts of the globe by several researchers (Sethu Raman, 1982; Aplin and Harrison, 2003; Foken et al., 2001; Sethu raman et al., 1990; Altadilla et al., 2001; Afraimovich et al., 2002; Founda et al., 2007; Stoev et al., 2008). They reported that the boundary layer responded to the eclipse induced changes in surface layer rapidly. The variations are found to be in association with the sharp drop in the direct solar radiation. In this study we investigate the micro meteorological variations of surface layer parameters during the occurrence of the annular solar eclipse of 15th January 2010, over the coastal station Cochin (10°02'41'' N, 76°19'34'' E, 38 m ASL).

2. Data and methodology

The sonic anemometer USA-1 (make: METEK, GmbH, Germany) was installed at Kalamassery (10°02′41″ N, 76°19′34″ E, 38 m ASL) in Cochin University campus in January, 2008. It provides zonal, meridional and vertical components of wind as well as air temperature at a temporal resolution of one second. With the availability of this fast response instrument installed at a height of 7 m above ground level we are able to get continuous observation of wind and temperature at the station. The raw data sets were archived after quality check. The different statistical parameters and surface boundary layer parameters as well as surface fluxes were computed using the eddy correlation method as described in Arya (2001). The parameters investigated in this study are momentum flux, sensible heat flux, turbulent kinetic energy, frictional velocity, and variance of u, v, w, t.

Using the Eddy correlation method different parameters are computed using the following formulae:

$$\text{MomentumFlux} = \rho {u_*}^2 \ (\text{N m}^{-2}) \tag{1}$$

$$\text{SensibleHeatFlux} = -\rho C_p u_* \theta_* \ (\text{W m}^{-2}) \tag{2}$$

where frictional velocity $u_* = (u'w'^2 + v'w'^2)^{1/4}$ (3)

$$\theta_* = -w'\theta'/u_* \tag{4}$$

$$\text{Turbulent kinetic energy (TKE)} = 1/2(u'^2 + v'^2 + w'^2)(m^2\ s^{-2}) \tag{5}$$

where ρ is the air density which is taken as 1.2 kg m^{-3}, C_p is the specific heat capacity of dry air at constant pressure which can be taken as 1004 J K^{-1} kg^{-1}, u′, v′ and w′ are the fluctuations of wind components from the mean, as described in Stull (1988).

The different variances can be computed as

$$\text{Variance } u = \overline{u}^2 \tag{6}$$

$$\text{Variance } v = \overline{v}^2 \tag{7}$$

$$\text{Variance } w = \overline{w}^2 \tag{8}$$

$$\text{Variance } t = \overline{t}^2 \tag{9}$$

For the computation of fluxes and statistical parameters the averaging time taken is 10 min, since it is suitable for the eddy correlation method (Stull, 1988).

2.1. Details of annular solar eclipse of 15th January 2010

Annular solar eclipse took place over India on 15th January 2010. The eclipse had a magnitude of 0.9190 and it was the longest solar eclipse with a duration of about 11 min and 7.8 s. The other peculiarity of the eclipse is that its peak period was in the noon hours, when we receive maximum insolation from the sun. The time of the occurrence of the eclipse is from 11.25 AM to 15.15 PM IST. This solar eclipse was also visible in Singapore, Dubai, Qatar, Bahrain, Kuwait, Oman, Pakistan, Sri Lanka, Malaysia, Africa, Europe, and parts of China. In India, the path of eclipse was through Palk straight among South Kerala, South Tamil Nadu and North Sri Lanka.

3. Results and discussions

In this paper we present the anomalous variation of different surface boundary layer parameters over the coastal station, Cochin in association with the occurrence of annular solar eclipse. The parameters studied are momentum flux, sensible heat flux, frictional velocity, turbulent kinetic energy and variances of u, v, w, t. For the sake of comparison, a control run was made for all the parameters in the days before and after the solar eclipse day. The control run days were taken as 14th January 2010, which was the day prior to solar eclipse and 16th January 2010, which was the day after solar eclipse over Cochin. In the discussion part, the figure of the control run for 16th January 2010 was taken into consideration for comparison. The variation of surface boundary layer parameters associated with the annular solar eclipse is summarized below.

Fig. 1 gives the diurnal variation of momentum flux and sensible heat flux on the control run day, 16th January 2010 as well as on the annular eclipse day. On the eclipse day ie. on 15th January 2010, the momentum flux shows anomalous decrease in the noon hours. It decreases up to 0.01 Nm^{-2} at the time 14:00 IST (Fig. 1(a)). This anomalous decrease is attributed to the occurrence of annular solar eclipse. Due to the solar radiation cut off for a short period, boundary layer wind and temperature vary in a micro scale of the order of a few hours. So this is typically a micro meteorological phenomenon. Fig. 1(b) shows the diurnal variation of momentum flux on the control run day, 16th January 2010. In response to the evolution of convective boundary layer, momentum flux also shows a diurnal maximum and minimum. The maximum flux of 0.4 Nm^{-2}

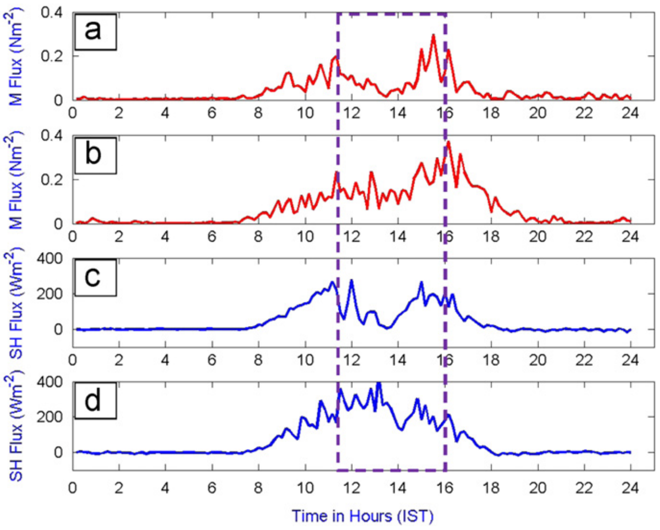

Fig. 1. Diurnal variation of surface boundary layer parameters on the annular eclipse day as well as on the control run day (a) Momentum Flux on eclipse day (b) Momentum flux on control run day (c) Sensible heat flux on eclipse day and (d) Sensible heat flux on control run day. The portions inside the dotted lines indicate the time period of solar eclipse.

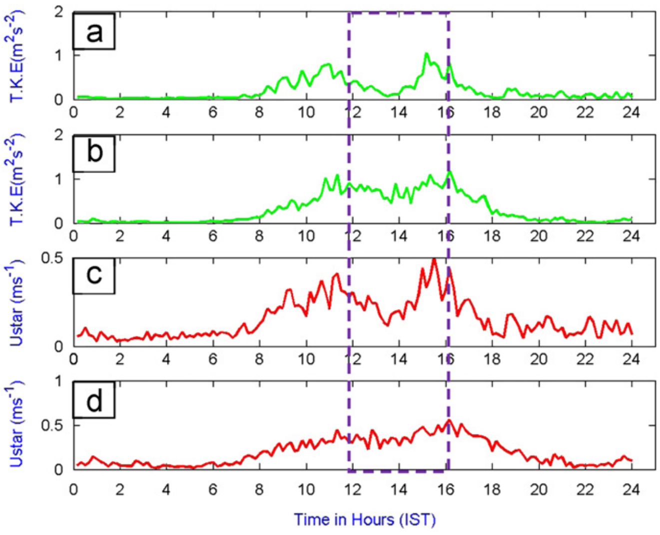

Fig. 2. Diurnal variation of surface ABL parameters on eclipse day as well as the control run day (a) Turbulent Kinetic Energy on eclipse day (b) Turbulent kinetic energy on control run day (c) Frictional velocity on eclipse day and (d) Frictional velocity on control run day. The portions inside the dotted lines indicate the time period of solar eclipse.

occurred at 16:00 IST. Mitsuta (1958) presented the results of direct measurements of momentum flux in the surface ABL using sonic anemometer. In his experiment at a height of 2 m level he could obtain a momentum flux value of 0.53 Nm^{-2}, which agrees with the flux value in our analysis. Chehbouni et al. (2000) obtained a momentum flux value of 0.6 Nm^{-2} over a grassland patch using scintillometer based and eddy correlation based experiments that also agree with our observations. In the study reported by Bala Subrahamanyam et al. (2011), the impact of annular solar eclipse on the boundary layer over Thumba is discussed. They could observe significant reduction in momentum flux from 0.4 Nm^{-2} on the control run day to 0.05 Nm^{-2} on the solar eclipse day. This agrees with our observations.

Fig. 1(d) gives the diurnal variation of sensible heat flux on the control run day 16th January 2010. The sensible heat flux has a maximum value of 300 Wm^2 during the noon hours at the time 15:00 IST. On the solar eclipse day from Fig. 1(c), the sensible heat flux decreases anomalously in the noon hours with minimum value of −10 Wm^{-2} at the time 14:00 IST. This anomalous decrease is attributed to the annular solar eclipse occurred in the noon hours. In the next control run day i.e 16th January (figure not attached), we could observe normal sensible heat flux values in the noon hours with value 400 Wm^{-2}. Chehbouni et al. (2000) got a sensible heat flux value of 300 Wm^{-2} based on the eddy correlation method which agrees with the observations we got on the control run day. Bala Subrahamanyam et al. (2011) observed a reduction of sensible heat from 300 Wm^{-2} to 20 Wm^{-2} during the annular solar eclipse period. This also agrees well with our observations. Krishnan et al. (2004) obtained the value of sensible heat flux as −10 Wm^{-2} during the occurrence of solar eclipse of 11th August 1999 over a semi arid region Ahammadabad.

Diurnal variation of turbulent kinetic energy on the control run day 16th January is shown in Fig. 2(b). Associated with the convective boundary layer growth, T.K.E also increases and becomes a maximum in the noon hours. The maximum value is 1 m^{2}s^{-2} at about 15:00 IST. On the day of solar eclipse, between time 11:30 to 15:00 IST the T.K.E sharply decreases to very low value of about 0.1 m^{2}s^{-2} and approaches zero (Fig. 2(a)). This sharp decrease is due to the suppression of turbulence due to the cut off radiation in the noon hours and this is in response to the annular solar eclipse. In the analysis by Krishnan et al. (2004) the obtained T.K.E during solar eclipse was 0.2 m^{2}s^{-2} and this agrees well with our results. Rajeev et al. (2011) estimated the reduction in T.K.E during the eclipse period as 0.025 m^{2}s^{-2}, while frictional velocity decreased to as low as 0.05 ms^{-1}, which are attributed to the decrease in turbulence fluctuations of wind components during solar eclipse.

The diurnal variation of frictional velocity on the control run day (16th January 2010) is given in Fig. 2(d). As evidenced from the figure, during the noon hours maximum variation for u_* takes place and it has a maximum value of 0.5 ms^{-1} at the time 15:00 IST in response to the convection. But on the solar eclipse day, u_* decreases and reaches a minimum of 0.1 ms^{-1} at the time 13:00 IST, due to the influence of annular solar eclipse (Fig. 2 (c)). After the solar eclipse it recovers to normal values. On the control run day 14th January 2010, u_* again shows normal diurnal behavior with maximum value 0.5 ms^{-1} (figure not attached). In the work by Krishnan et al. (2004), they got a frictional velocity of 0.3 ms^{-1} and it is found to decrease to 0.05 ms^{-1} during the eclipse period. Namboodiri et al. (2011) observed a reduction of frictional velocity value from 0.3 ms^{-1} to 0.1 ms^{-1} which agrees with our observation. Also Rajeev et al. (2011) estimated the frictional velocity using sonic anemometer during annular solar eclipse found to be 0.05 ms^{-1} from 0.3 ms^{-1}. These previous studies were compared with our results and obtained good matching of the observations.

The variances *u*, *v*, *w* and *t* are shown in the Figs. 3 and 4 on the control run day 16th January 2010 as well as on the annular solar eclipse day. As evident from the figure, maximum value for all the variances occur in the noon hours corresponding to time 17: 00 IST. The variances in u and v have maximum value 1 m^2 s^{-2} at the time 17:00 IST, variance w has maximum value of 0.5 m^{2}s^{-2} at the time 15:00 IST and variance t shows maximum value of 0.8 m^{2}s^{-2} at the time 15:00 IST on the control run day 16th January. Corresponding to the annular solar eclipse, there is sharp decrease of variances as evidenced by the figure. Variances *u* and *v* show minimum value of about 0.1 m^{2}s^{-2} at the time 14:00 IST due to the solar eclipse. Variance *w* has minimum value of 0.1 m^{2}s^{-2} at the time 14:00 IST and variance *t* decreases to value 0.1 K^2 s^{-2} at the time 14:00 IST in response to the solar eclipse. The statistical parameters such as variances decrease due to the

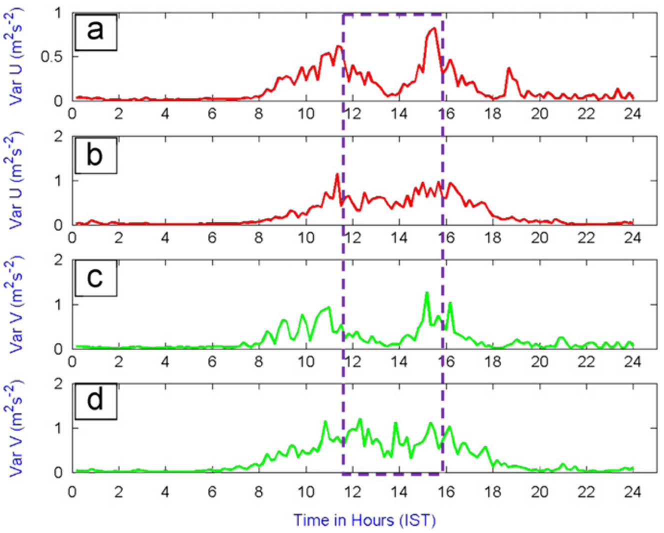

Fig. 3. Diurnal variation of variances on the annular solar eclipse day as well as on the control run day (a) Variance *U* on eclipse day (b) Variance *U* on control run day (c) Variance *V* on solar eclipse day and (d) Variance *V* on control run day. The portions inside the dotted lines indicate the time period of solar eclipse.

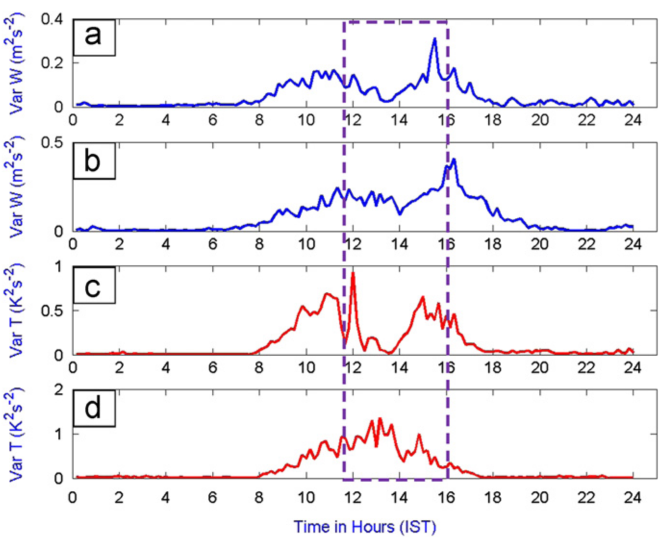

Fig. 4. Diurnal variation of variances on the annular eclipse day as well as on the control run day (a) Variance *W* on eclipse day (b) Variance *W* on control run day (c) Variance *T* on solar eclipse day (d) Variance *T* on control run day. The portions inside the dotted lines indicate the time period of solar eclipse.

fact that, wind and temperature fluctuations are found to decrease due to the sudden ceasing of solar irradiance. This is indeed reflected in the decreasing of variances of wind and temperature.

4. Conclusions

It is observed that the surface boundary layer parameters are varying sharply in response to the solar eclipse, which is attributed to the depletion of the solar radiation for a short interval of time. This situation is similar to that of total overcasting of cloud and decrease in radiation. Since solar energy is the primary source of energy for atmospheric boundary layer, its cut off for a short period has significant effect on surface ABL parameters. On the eclipse day, momentum flux decreases anomalously from 0.5 Nm^{-2} to 0.01 Nm^{-2}. Sensible heat flux decreases from its normal value 300 Wm^{-2} to -10 Wm^{-2} due to the effect of solar eclipse. Turbulent kinetic energy also decreases sharply from its normal value 1 m^{2}s^{-2} to 0.1 m^{2}s^{-2} on the eclipse day. Frictional velocity has a normal value 0.5 m s^{-1} in the control run day and it decreases anomalously to 0.1 m s^{-1}. The corresponding variances of *u*, *v*, *w* and *t* are also found to decrease anomalously. Generally during noon hours, the convective boundary layer grows in response to the convective thermals. Due to the occurrence of annular solar eclipse, this growth of convective boundary layer is blocked and hence the anomalous changes in surface ABL occur.

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