

Effect of January 15, 2010 Annular Solar Eclipse on Meteorological Parameters over Goa, India

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Abstract

Atmospheric perturbations due to the annular solar eclipse were monitored to understand its influence on the meteorological parameters from surface to the lower stratosphere. A strong inversion at 13km and an abnormal warming in the upper troposphere noticed on the eclipse day. A decrease in tropopause height associated with increase in temperature caused anomalous warming. Considerable attenuation of incoming solar radiation resulted in abrupt increase of air temperature during the next 24 hours followed by sharp decrease in relative humidity. The time lag is attributed to the distance from the totality and the response time between tropopause and surface layer.

Keywords: Solar Eclipse, Tropopause, Vaisala Radio Sonde, Humidity, AWS, India

1. Introduction

An eclipse occurs when an astronomical body completely or partially masks another. During a solar eclipse the apparent diameter of the Moon resembles the apparent diameter of the Sun. As a result an occultation of the solar disc takes place regularly every 223 lunar revolutions when the Moon is interposed between the Earth and the Sun. This process leads to sudden cut off of radiation for few minutes that can cause disturbance on the thermal balance of the atmosphere. Radiative changes during a partial eclipse was measured by Abbot (1958) and found that the fractional decrease in net radiation was much greater than the fractional obscuration of the Sun's disc and suggested phenomenal decrease was due to the penumbra in the atmosphere. Such an eventuality would lead to intense meteorological events propagating down to the atmospheric boundary layer (ABL). Several investigations were carried out to understand the effect of eclipse on the dynamics of the ABL over various geographical locations and different terrains (Antonia et al., 1979; Sethu Raman, 1982; Anderson, 1999; Krishnan et al., 2004; Founda et al., 2007; Venkat Ratnam et al., 2010, Bala Subrahmanyam and Anurose, 2011).

The solar eclipse gives a rare opportunity to study the influence of solar intensity on the surface meteorological parameters. Variations of different surface meteorological parameters and the behavior of troposphere and stratosphere during solar eclipses have been the most challenging problems in recent years. Mohanakumar and Devanarayanan (1982) made a detailed study of the surface meteorological parameters over Trivandrum, India, during the February 16, 1980 total solar eclipse, where the totality of the path was 80%. Later Szalowski (2002) had reported immediate decrease in air temperature while a delayed response was reported elsewhere (Narasimha et al., 1982). Although an upsurge in wind speed was noticed before the eclipse by some of the investigators (Anderson and Keefer, 1975; Eaton et al., 1997, Nymphas et al., 2009), decrease of wind speed during the eclipse was noticed by (Aplin and Harrison, 2003; Krishnan et al., 2004; Stove et al., 2005). The upsurge of wind speed was attributed to a cold front in the penumbra and deceleration of wind speed was attributed to stabilization of surface layer following the temperature drop and suppression of turbulent process (Aplin and Harrison, 2003). However, Nymphas et al. (2009) had noticed an upsurge of wind speed just before the first contact of the eclipse followed by a sharp decrease in wind speed due to the cooling and stabilization of the atmospheric boundary layer. A study on the variations in the solar ultraviolet radiation and the meteorological parameters at the ground level before, during and after the total solar eclipse of 29 March

2006 at four stations located in the greater Athens basin in Greece showed that the reduction of the solar ultraviolet radiation at 312 and 365 nm reached 97% and 93% respectively (Founda et al., 2007). The near-ground air temperature dropped to $\sim 0.7^{\circ}\text{C}$ during the eclipse event at the center of Athens while the relative humidity increased reaching a maximum at the end of the solar eclipse. The wind speed decreased after the solar eclipse maximum without any significant change in direction. Investigations on the 15th January 2010 solar eclipse by Nishanth et al. (2011) revealed evidence for the reduction of surface air temperature, relative humidity and wind speed from a location close to the southwest coast of India (11.9 N, 75.4 E). Further south, very close to the path of totality (8.5 N; 76.9 E) Bala Subrahmanyam and Anurose (2011) had reported significant reduction in the intensity of sea breeze during the period of recent annular eclipse and its vertical extent was reduced from 610 m to 300 m when compared to the control day. The nearly total solar eclipse of 15th January 2010 at Thiruvananthapuram, India (near equatorial station) caused a reduction in ambient temperature and wind speed, whereas, an increase in relative humidity was recorded during the eclipse period (Sharma et al., 2010).

The objective of this investigation is to understand the effect of the longest annular solar eclipse, a rare and unique phenomenon occurred on January 15, 2010, on the upper atmosphere and at the atmospheric boundary layer by setting up the experiments at the coastal station of Goa ($15^{\circ} 30' \text{N}$, $73^{\circ} 50' \text{E}$) situated far away ($> 1000 \text{ km}$) from the path of totality. The state of the art Vaisala radio sonde system and well established automatic weather station were used to monitor the evolution of the eclipse and its effect felt at the entire atmospheric column.

A detailed picture of 15 January 2010 annular solar eclipse is given in the next session. Instrumentation set up and methodology is described in the following session. Fourth section deals with the results obtained from both surface and upper air observations. The results are discussed in the 5th session and the final conclusions are given towards the end of the paper.

2. Annular Solar Eclipse of 15 January 2010.

The solar eclipse of January 15, 2010 was an annular eclipse of the Sun. An annular solar eclipse occurs when the Moon's diameter is smaller than the Sun, causing the Sun to look like a ring, blocking most of the Sun's light. An annular eclipse normally appears as partial eclipse over a region thousands of kilometers wide. On 2010 January 15th, we witnessed the longest annular solar eclipse of the Third Millennium. It will not be possible to witness a longer annular eclipse before the year 3043. The path of the moon's umbral shadow started in Central Africa, continued further its long journey – almost circumnavigating half of our planet – over East Africa and the Indian Ocean, where annularity was the longest with just over 11 minutes (see Fig. 1). The long duration implies that the Moon appears considerably smaller than the Sun. Indeed, the lunar diameter is only 0.912 of the Sun's disk, obscuring just 0.832 of the Sun's disk. It then continued further to Southern Asia, touching the southern edge of India and the northern shores of Sri Lanka at about 1.15 pm local time (LT), and then to Myanmar (2.03 pm L.T) and finally ending in Southern China. The annular eclipse was visible in south Kerala, south Tamil Nadu and southern parts of Mizoram. It appeared as a partial eclipse in the rest of the places in India. The annular eclipse of January 15, 2010 over Goa, India was only partial and was visible for 3 hours and 55 minutes between 11.11 am and 3.06 pm LT, which is 05.30 hrs + UTC. The distance of the path of totality from the point of observations is greater than 1000 km at the closest point.

3. Data and methodology

In order to study the effect of annular partial solar eclipse on the atmospheric parameters over Goa (15° 30'N, 73° 50' E), special upper air observations were planned at the peak of the eclipse on 15th January 2010 (2 hours flight time commence at 6 UTC), 24 hours after the eclipse (same flight schedule maintained) and 42 hours before the eclipse (routine measurement schedule at 12 UTC) using state of the art Vaisala DigiCORA sounding system. The ascends were carried out using all-digital Vaisala Radiosonde RS92-SGP that offers the world's highest level of pressure, temperature and relative humidity measurement performance, and continuous wind data availability (Instrument details at <http://www.vaisala.com/en/meteorology/products/Pages/default.aspx>).

Sensor specifications of RS92-SGP radiosonde are given in Table 1. Wind data is computed from radiosonde movements during ascent. The movement is measured utilizing either navigation signals such as GPS or radio direction finding. On an average the permissible radiosonde ascend rate is 6 ms⁻¹

and RS92 series sonde can achieve 10 m vertical resolution right up to the lower stratosphere height of more than 25 kilometers.

Supporting surface meteorological parameters were obtained from the real time internet accessible Automatic Weather Station (AWS) designed at National Institute of Oceanography, Goa installed very close to the balloon launching platform. AWS measures surface meteorological parameters, such as air temperature, relative humidity, pressure, solar radiation, rainfall rate, wind speed and direction at every 10 minutes to address the minute diurnal variability. Specifications of the factory calibrated sensors of the weather station and their respective web sites were given in Table 2. AWS data from 13th to 17th January 2010 had been analyzed to capture the effect of the eclipse in the preceding and following days (other than eclipse day) so that the causative factors for such variability could be investigated.

4. Results

Vertical profiles of temperature, wind speed and humidity were measured using the high resolution Vaisala sonde observations from Dona Paula, Goa, for 3 days, viz., January 13, 2010 (42 hrs prior to eclipse), January 15, 2010 (peak-time of the eclipse day) and January 16, 2010 (24 hrs after the peak-time of the eclipse day) so as to understand the changes occurring due to the solar eclipse on atmospheric parameters. Observations taken on January 13th and 16th 2010 were referred to as control days as it represents the situation of the atmosphere before and after the eclipse.

The eclipse over Goa was partial and visible between 11.11 hrs and 15.06 hrs (local time), with duration of 3 hours and 55 minutes. The totality of the eclipse path was over Kanyakumari, the southern tip of India with total obscuration of 10 minutes and 18 seconds. The Vaisala observations started at 12.00 hrs (local time) and completed by 14.00 hrs, in order to capture the atmospheric perturbation at the peak time of the eclipse.

The vertical profiles of temperature were taken on January 13, 15 and 16, 2010 from surface to 23 km altitude are presented in Fig. 2. Temperature profile on the eclipse day showed two distinct inversion layers in the troposphere. The first inversion was seen around 1 km height, just above the atmospheric boundary layer and a strong secondary inversion was observed in the upper troposphere at about 13 km

altitude. The temperature inversion indicated strong stability which inhibits vertical movement of air just above the atmospheric boundary layer and in the upper troposphere. The lapse rates between these two inversion layers were very sharp and steady without any disturbances. The upper troposphere above the inversion layer was quite warm during the eclipse day. Tropopause height was observed at 17.15 km altitude. Slight decrease in temperature seen in the stratosphere (22 km) was quite unique on the eclipse day. Since the profile was limited to 23 km altitude, it was not possible to understand the extension of the positive lapse rate in temperature in the lower stratosphere.

The temperature profile on January 13th was quite different from that of the eclipse day. Higher lapse rate was noticed above 10 km that extended to the height of tropopause (~18 km). The small scale disturbances observed in the lower 6 km during 16th January (control day) could probably be due to convective activity and effect of clouds in this region. Positive lapse rate was observed in the middle troposphere, between 8 and 11 km beyond which the warming continued up to the tropopause level. Warming seen in the upper troposphere on 16th extended further down when compared to the eclipse day at the same time. It is interesting to note that the tropopause height became very sharp during the day after the eclipse and was occurring at a lower level of 16.8 km.

In the month of January 2010, five Vaisala sonde observations were made and the vertical profiles were analyzed including eclipse day in order to highlight the variation of tropopause temperature with height. Tropopause temperatures and heights were plotted against time in Fig 3. The tropopause temperature was 192.7° K two days prior to the eclipse. On the eclipse day, the temperature decreased by 1.8° K, and the tendency continued in the next 24 hours. Thereafter the temperature appeared to be increasing. Similarly the tropopause height was 17.75 km before the eclipse that rapidly decreased to 17.41 km on the eclipse day. The lowest tropopause height of 16.90 km was observed on 16th January 2010, 24 hrs after the eclipse. Thereafter, the height of the tropopause returned to its initial position of 17.75 km.

Decrease in tropopause height during the annular eclipse had prompted us to further examine the vertical motions at the tropopause height. Vertical velocity at the tropopause height over the grid point at Goa (15° 30'N, 73 ° 50' E) had been taken from ERA – Interim ECMWF (European Center for Medium-range Weather Forecasting) data for the entire days of January 2010. The daily values of the vertical velocity at the tropopause level in isobaric co-ordinates during January 2010 were plotted against time

and illustrated in Fig 4. The vertical velocity at the tropopause height appeared to be fluctuating in the sub zero zone implying inconsistent vertical updrafts. The variability up to the eclipse day was not very significant as it hardly crosses the one standard deviation mark. But immediately after the eclipse the vertical motion dramatically changes direction to witness an abnormal downdraft with magnitude crossing 0.05 Pa s^{-1} well ahead of 2 standard deviation mark. The enhanced vertical motion during the post eclipse day is therefore statistically significant.

The fluctuations of tropopause height were often associated with vertical movements of air mass in the troposphere and stratosphere. Lowering of the tropopause height was therefore associated with downward forcing of the stratospheric air mass to the denser troposphere and this process would warm the tropopause and the upper tropospheric region. This was exactly what happened during the eclipse time. Since the temperature at this height was below zero, reduction in temperature would mean warming at this height. During eclipse time the downward thrust bring the tropopause to lower height that cause an increase in temperature below zero. The trend appeared to be extending to the following day even after the eclipse had subsided.

Zonal wind observations from the Vaisala sonde on 13th, 15th and 16th of January were depicted in Fig 5. During eclipse and the following days, zonal winds near to the ground up to 3 km height were easterlies peaking at about 1.25 km height. Easterlies were replaced by westerly winds above 3 km extending to 21 km level in the stratosphere. On the eclipse day, westerly wind reached its peak ($> 25 \text{ m s}^{-1}$) at about 10 km and gradually weakens with height. Just below the tropopause, the westerly component abruptly decreased and regained its strength above the tropopause height. The day after the eclipse, the strength of the westerly component picks up with height to reach 15 m s^{-1} .

The static stability parameter computed in the entire height ranges from surface to 23 km altitude during the two control days (January 13th & 16th) and the eclipse day (January 15th) were displayed in fig 6. The magnitude of the static stability suddenly increased around 1.2 km height from surface on the eclipse day, which was also seen after 24 hours. Unstable conditions were also seen between 0.5 km and 2.5 km height range. The stability parameter did not show much variation in the entire troposphere above this height. High stable conditions were seen in the upper troposphere and lower stratosphere during both eclipse and post eclipse days.

Vertical profiles of relative humidity (RH) during the time of eclipse (15th Jan), 42 hrs prior to the eclipse (13th Jan) and 24 hrs after the eclipse (16th Jan) were displayed in Fig 7. Observations taken on eclipse day and the post eclipse control day (January 16th) at the same local time indicated three distinct peaks in the profile. The lowest dominant peak in relative humidity was observed around 2.5 km altitude with values exceeding 90%. This marks the highest RH value compared to the control day of 16th January 2010. Even though Goa is a coastal station, the surface level RH was only 60%, from where the RH increased with height and attained the peak around 2.5 km. On the eclipse day, severe dry conditions were observed at 5 km where RH reduced to zero percent. Larger fluctuations in RH occurred between 6 and 8 km. A secondary peak was noticed at 12.5 km that appeared to be more prominent and sharper on 13th January (> 50%) and the peak degraded on eclipse day. The sharpness of the peak further eroded on 16th January. Interestingly, the building of RH (30%) below the tropopause (~ 17.5 km) during 13th January appeared to be degrading during eclipse day and started reappearing once the effect of the eclipse disappeared on 16th January. This episode could be attributed to the tropopause warming and the subsequent gradual building up of RH after the eclipse.

In order to understand the effect of eclipse on surface meteorological parameters, we had analyzed the diurnal variation of near surface parameters (from AWS) such as solar radiation, atmospheric pressure, wind speed, air temperature and relative humidity. Diurnal variation of solar radiation observed every 10 minutes intervals at Goa during the eclipse day and the two control days before and after the eclipse were reproduced in Fig. 8. On the eclipse day, slight cloudiness in the morning hours obscured the sky and reduced the sun shine by 9.00 hrs LT. Subsequently the radiation showed a gradual increase in the clear sky condition until an abrupt cut off occurred after the commencement of the eclipse at about 1300 hrs. It could be seen from Fig 8 that the solar radiation considerably reduced from about 1000 W m^{-2} to 150 W m^{-2} during the peak hours of the eclipse noticed at a place far from the path of totality.

January 17th 2010 was considered to be a perfect clear sky day as the fluctuations due to atmospheric disturbance was minimal and hence was taken as a model case. The attenuation of solar radiation falling on earth surface was minimal on this day. Therefore the difference of solar radiation observed between the eclipse day and model day was estimated and plotted in Fig. 9. By this approach the amount of solar flux attenuated due to the effect of annular solar eclipse at Goa could be emphasized.

The depletion of solar radiation due to eclipse was highlighted as a peak in Fig. 8 and the depletion was because of the cloudiness during the morning hours between 06.40 hrs and 10.50 hrs. The solar radiation received at the surface, since the commencement of eclipse, got gradually cut off to reach the maximum solar influx difference at 1330 hrs LT. The solar eclipse was visible over Goa, between 11.11 hrs and 15.06 hrs LT, which could also be interpreted by the depletion of radiation from Fig 9.

The attenuation of solar radiation reached its peak at 13:20 hrs LT to mark the maximum obscurrence due to the eclipse. The solar radiation flux was reduced by of 842 Wm^{-2} during this process. Normal day exhibits a high influx of solar radiation during these hours, but the eclipse reduced the incoming solar radiation considerably. Since there was no cloudiness reported during the time of the eclipse over Goa, it was evident that the decrease in solar radiation during this period was due to the effect of annular solar eclipse. The amount of solar radiation attenuated due to the solar eclipse was computed as 9765 Wm^{-2} , which was capable of altering the thermal balance of the atmosphere. Direct heating of the Earth by the incoming solar radiation and its emission by the Earth's surface that could modify the variations in surface air temperature and humidity are the natural process in the absence of the solar eclipse. Solar eclipse prohibits radiation falling on the earth's atmosphere and the subsequent changes in the long wave radiation that could severely influence the air temperature and humidity distribution are the causative effects of the eclipse.

Figure 10 illustrates the diurnal variation of atmospheric pressure measured at every 10 minutes during the eclipse day and other control days before and after the eclipse. The surface pressure during the eclipse day fell between the pressure values of two control days and the trend continued till the end of the day. In the early morning hours of the eclipse day, the surface pressure was much lower than those of the control days, and by 9 hrs LT the surface pressure gradually increased to overtake the pre-eclipse control days and with time it occupied the position almost equidistant from both pre and post eclipse control days. During the eclipse, the surface pressure showed a slight enhancement to its normal changes, though significant changes were not observed. Since the 15th January 2010 Annular eclipse was partially visible over Goa, its direct effect might have been reduced.

Time evolution of air temperature at Goa during the eclipse day and the control days were displayed in Figure 11 as recorded by the AWS. The air temperature during the early morning hours were relatively

high on the eclipse day and the next 24 hours, compared to other control days. On the eclipse day, the temperature recorded a steep increase after 08.00 hrs and attained the peak value soon after mid-day. The effect of solar eclipse was instrumental in controlling further increase in surface air temperature and instead decreased slightly by 16.00 hrs LT in the evening. Even though the magnitude was quite low the effect of solar eclipse on the air temperature near to the ground was worth noticing. However, the rate of decrease in temperature during the eclipse period was much less than expected from the solar radiation cut off associated with solar eclipse,

The temperature change in the next day of the eclipse was quite noteworthy, because the atmosphere in this region after 23 hours of eclipse had a similar effect to that of the eclipse day. But an abnormal increase of air temperature was noticed in the next day with the peak touched 34 °C at about 14.30 hrs LT. An abrupt cooling was also seen soon after attaining the daily maximum temperature within a time span of 70 minutes.

Diurnal variations of wind speed during the eclipse day and the control days were displayed in Fig 12. Relatively high wind speeds observed prior to the eclipse was suddenly reduced and became calm during the peak hours of the annular eclipse. After eclipse, the wind speed showed some revival before the sunset over Goa. On the previous day, the wind over Goa was very calm especially in the forenoon hours, and the sea breeze became active in the afternoon. On the next day, strong winds were noticed in the early hours and the strength more or less persisted throughout the day with slight weakening in the afternoon hours.

Diurnal variations of relative humidity over Goa obtained from AWS were presented in figure 13 to understand the effect of solar eclipse on RH. Lowest RH values of the day could be seen during the beginning of the solar eclipse. In the later part of the eclipse, the RH value was found to be gradually increasing. Surprisingly the RH of the following day exhibited a gradual decrease right from the early hours to reach an all-time low of 40% at about 14.30 hrs LT when the air temperature recorded the highest values on that day. The RH values then picked up rapidly to reach 70% level within a short span of 30 minutes. On 17th January, a clear sunny day, the RH attained the lowest value at mid-day, associated with the time of maximum incoming solar radiation.

5. Discussion

The perturbation due to the annular eclipse of 15th January 2010 was closely monitored both in the upper atmosphere and in the near surface layer using high resolution Vaisala Radiosonde and Automatic Weather Station (AWS) respectively. Meteorological parameters of the troposphere and lower stratosphere were taken during the eclipse, 24 hrs after the eclipse and 42 hrs prior to the eclipse. Simultaneous surface observations were taken every 10 minutes continuously from 13th to 17th January 2010 to understand the relative changes in near surface pressure, solar radiation, temperature, wind, and relative humidity.

The decreasing trend of the tropopause height was seen from the fag end of December 2009 to the middle of (16th) January 2010 where the tropopause was lowered by more than 1000 m (from Vaisala radiosonde data). This abnormal fluctuation of tropopause could be attributed to the influence of annular eclipse and such fluctuation can cause warming in the upper troposphere. A downdraft at the tropopause height in tune with the fluctuation in tropopause could support the movement of stratospheric ozone from the lower stratosphere that can cause warming of upper troposphere (see Fig. 2), in the event of a shutdown of incoming solar radiation due to the annular eclipse. The tropopause height and temperature noticed during the eclipse day and the two control days exhibited observational evidence of warming of the upper tropopause due to the decrease in tropopause height (Fig. 3). It is worth noticing that the warming continued further to the next 24 hrs even after the effect of eclipse subsided.

The vertical velocity in isobaric surface at the tropopause over Goa (from ECMWF interim data) provides evidential proof for the heating in the upper troposphere due to the fluctuation in tropopause height (see Fig.4). And the peak of the fluctuations observed in the vertical velocity in the following days further support the persistence of such disturbance even after the culmination of the eclipse at these altitudes. The subdued humidity profiles during the eclipse day compared to two control days also support the warming of the upper tropopause (Fig. 7). Such decrease of tropopause height and a subsequent increase of temperature were noticed by Bhattacharya et al. (2010) during the eclipse observed on 22nd July 2009 at Kalyani in West Bengal. A 399 m decrease of the tropopause height on an eclipse day caused the temperature to raise 0.2 °C. Previously, Dutta et al., (1999) had reported similar changes in the tropopause during the eclipse day of October 22, 1995. Inversion layers observed

just above the atmospheric boundary layer and in the upper troposphere are unique events during the present eclipse episode.

Observations on the surface meteorological parameters during the annular solar eclipse over Goa revealed that surface pressure was not significantly affected by the solar eclipse. The solar radiation recorded at the surface indicated considerable reduction (from 1000 to 150 W m⁻²) during the peak hours of the eclipse of January 2010. The solar radiation difference between the eclipse day and the model day highlighted the reduction of solar flux in the order of 850 Wm⁻² due to eclipse as this could alter the thermal balance of the atmosphere. However the fluctuation in solar radiation flux noticed in the local noon hours of the following day indicated its persistence even after the annular eclipse episode. The remarkable fluctuations in air temperature and the abrupt rise in relative humidity after a steep fall coexisting with the time of the residual of the annular eclipse recurred in the following day explains the inter relationship and its implications in regional climate. Similar trends in air temperature and relative humidity were observed by Bhattacharya et al.,(2010) during the solar eclipse occurred on 22nd July 2009 at Kalyani in West Bengal (maximum phase 90.2 %). In the present case the totality was about 900 km away from the point of observation which could be one of the reasons for the extended phase lag.

From the uninterrupted time series of Vaisala radio sonde observation during 2009 it has been observed that the surface and tropopause pressure was more or less in phase during the summer months and out of phase during the rest of the year (unpublished manuscript). Therefore an increase in pressure at the tropopause height would lead to a decrease in pressure (convection) at the surface levels during winter months with certain phase lag in accordance with the study we carried out. In the event of an enhanced convection a decrease in air temperature (increase in temperature gradient) and relative humidity (increase in humidity gradient) in the surface layer is essential to support sustained evaporation (convection). The surface convection is linked to the low level convergence and at the center of convergence the wind speed is normally low (Neelin and Held 1987; Liu 1988). Therefore the surface level observations support convection in the lower troposphere in response to the warming in the upper troposphere and subsequent deepening of tropopause.

According to Svensmark (1998), the cosmic ray flux produces during the period of solar eclipse may have some effect on meteorological parameters in the lower atmosphere. Bhattacharya (2010) suggested

that the local change in temperature, pressure and relative humidity during the solar eclipse act as an indicator to investigate the effect of weather on cosmic rays. The limb darkening effect induces the changes in temperature and relative humidity. They further mentioned that the reduction in cosmic ray intensity caused by local climate change is interpreted though no apparent relation is exhibited between cosmic ray intensity and geomagnetic disturbances.

6. Conclusion

A study pertaining to the influence of January 15, 2010 annular eclipse at Dona Paula Goa, on the temperature, humidity and wind changes in the troposphere and lower stratosphere using the high resolution Vaisala radiosonde observations and surface meteorological parameters based on automatic weather station revealed that the solar eclipse showed considerable influence in Goa, which is located far away from the path of totality. A decrease in tropopause height and an increase in tropopause temperature were noticed during the eclipse time. A strong inversion at 13 km height and strange warming in the upper troposphere was seen on the eclipse day. Considerable attenuation of incoming solar radiation seemed to cause an unprecedented increase and then a sharp decrease in near-surface air temperature during the next 24 hours. Relative humidity also indicated an abnormal increase after a steep fall in the lower part of the atmosphere with similar time lag. On the contrary, there was no response time reported during the solar eclipse occurred on 22nd July 2009 at Kalyani in West Bengal that left similar variability on air temperature and humidity (maximum phase 90.2 %). Therefore there are reasons to believe that the response time depends largely on the distance between the point of observation and the path of totality. Time lag can also be partially attributed to the response time between the tropopause and the surface layer. More work is to be carried out to ascertain this aspect. Solar eclipse did not leave any appreciable changes in surface pressure, but the surface wind speed became calm. The features observed at the surface layer collectively support the concept of convection in the lower layer in response to the high pressure formation at the tropopause height.

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CAPTIONS

- Figure 1 Study location and trajectory of Annular Solar Eclipse of 15th January 2010 over peninsular India. (NASA 2010 eclipse bulletin, source : <http://eclipse.gsfc.nasa.gov/SEmono/ASE2010/ASE2010fig/ASE2010-fig206.pdf>)
- Figure 2. Vertical profiles of temperature during the eclipse day and two control days.
- Figure 3. Tropopause temperature and height plotted against time.
- Figure 4. Vertical velocity (ω) in isobaric surface at the tropopause height plotted with time. Mean (dashed line), mean \pm standard deviation (dotted line) and $2 \times$ (mean \pm standard deviation) (dash and dot line) are denoted by $\overline{\omega}$, σ_1 and σ_2 respectively.
- Figure 5. Zonal wind profile during eclipse day and two control days.
- Figure 6. Static Stability variation with height in the troposphere and lower Stratosphere during eclipse day and two control days.
- Figure 7. Zonal Relative Humidity profile during eclipse day and two control days.
- Figure 8. Attenuation of solar radiation during, before and after the partial annular solar eclipse over Goa, India.
- Figure 9. Solar radiation difference -Solar flux of Jan15th subtracted from that of Jan17th (from AWS data).
- Figure 10 Surface level pressure changes over Goa during the eclipse day and days before and after the eclipse.
- Figure 11. Diurnal variation of air temperature associated with solar eclipse and days before and after the eclipse.
- Figure 12. Diurnal variation of wind speed on the eclipse day and days before and after the eclipse.
- Figure 13. Diurnal variation of Relative Humidity in the surface level on the eclipse day and days before and after the eclipse.

TABLE 1

Parameter	Sensor	Range	Resolution	Uncertainty
Temperature	F-THERMOCAP	60 to -90 °C	0.1 °C	0.5 °C
Humidity	Heating HUMICAP	0 to 100 % RH	1 %	5 %
Pressure	Silicon BAROCAP	1080 to 3 hPa	0.1 hPa	~ 1 hPa
Wind (m/s)	GPS	0 to 180 m/s	0.2 m/s	----

Table 1. . Improved Vaisala Radio Sonde RS92-SGP specifications.
(<http://www.vaisala.com/en/meteorology/products/Pages/default.aspx>)

TABLE 2

Sensor	Make (web site)	Range	Accuracy
Wind Speed	RM Young (www.youngusa.com)	0 – 60 m/s	0.2 m/s
Air Temperature	YSI (www.ysi.com)	0 – 45 °C	± 0.15 °C
Pressure	Honeywell (www.honeywell.com)	800 – 1060 mb	0.4 mb
Humidity	Rotronic (www.rotronic.com)	0 – 100% RH	3 %
Solar Radiation	Licor (www.licor.com)	0 – 300 mW/cm ²	5 %
Rain	RM Young (www.youngusa.com)	--	3 %

Table 2. Real time reporting internet accessible AWS Sensor Specifications.
Respective web sites of the sensor manufacturer are given in brackets.

FIGURE 1

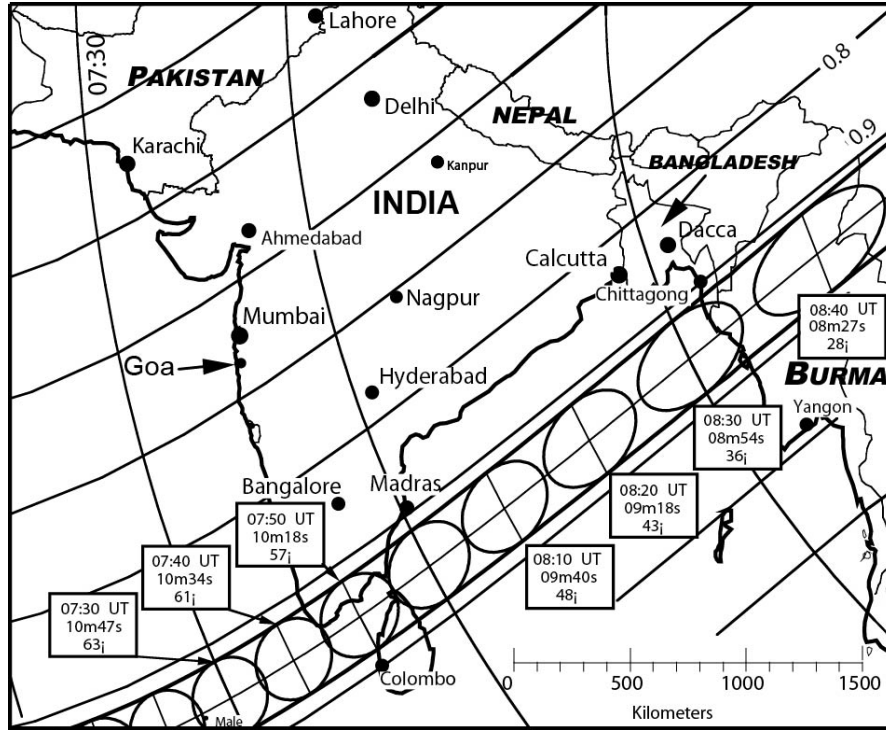


FIGURE 2

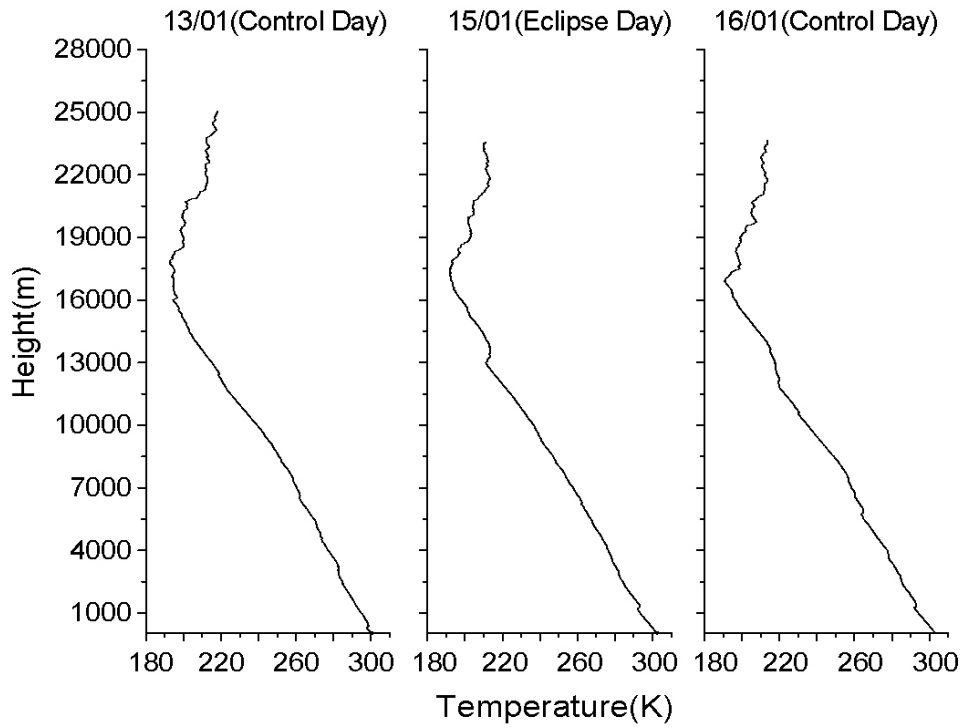


FIGURE 3

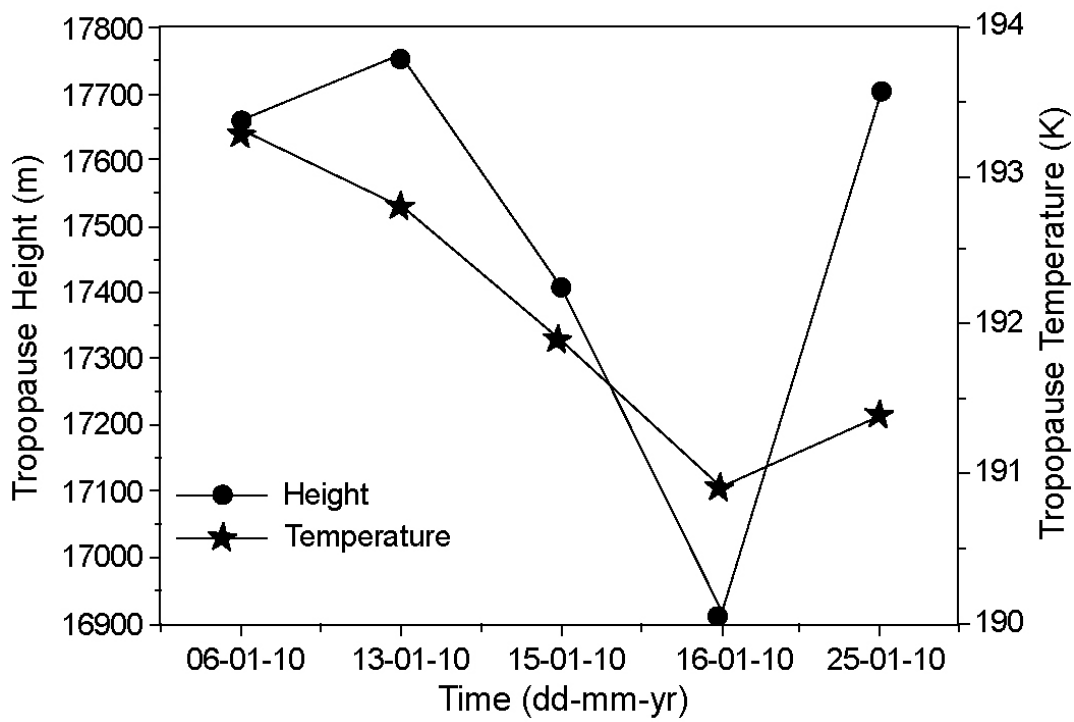


FIGURE 4

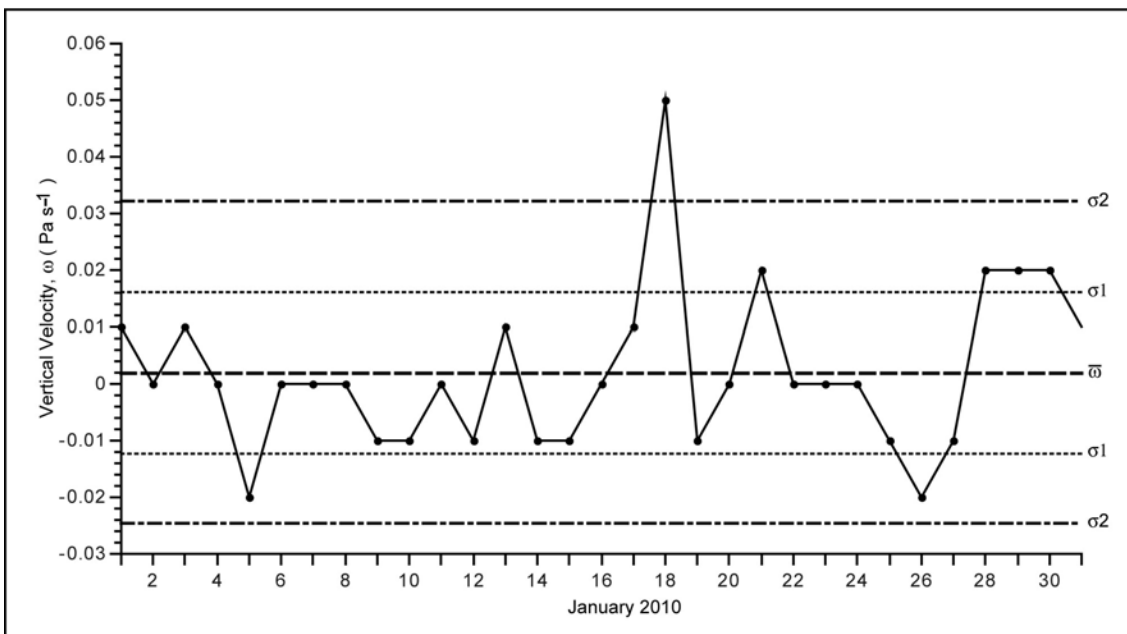


FIGURE 5

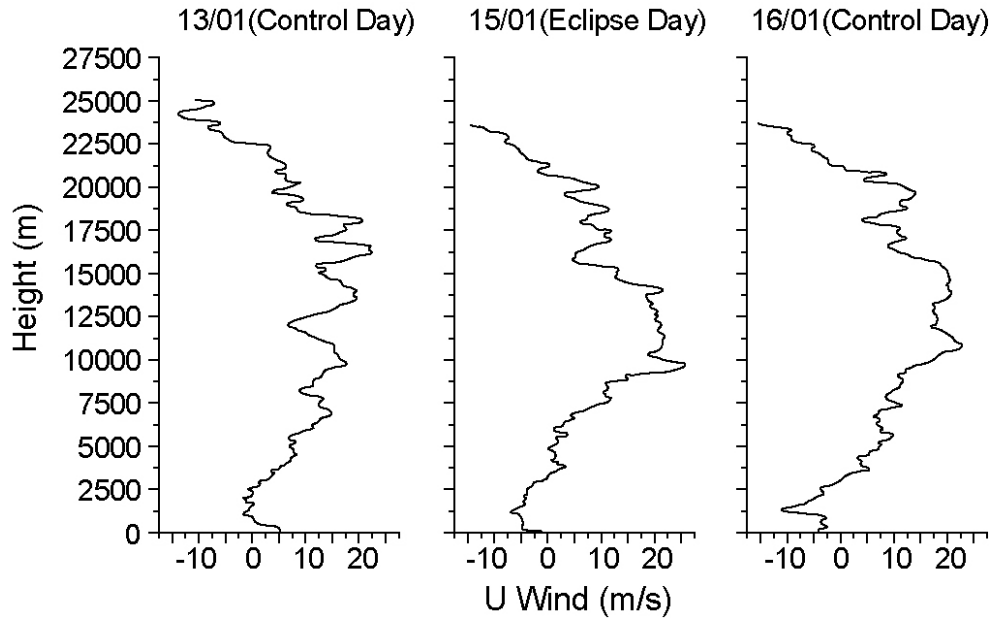


FIGURE 6

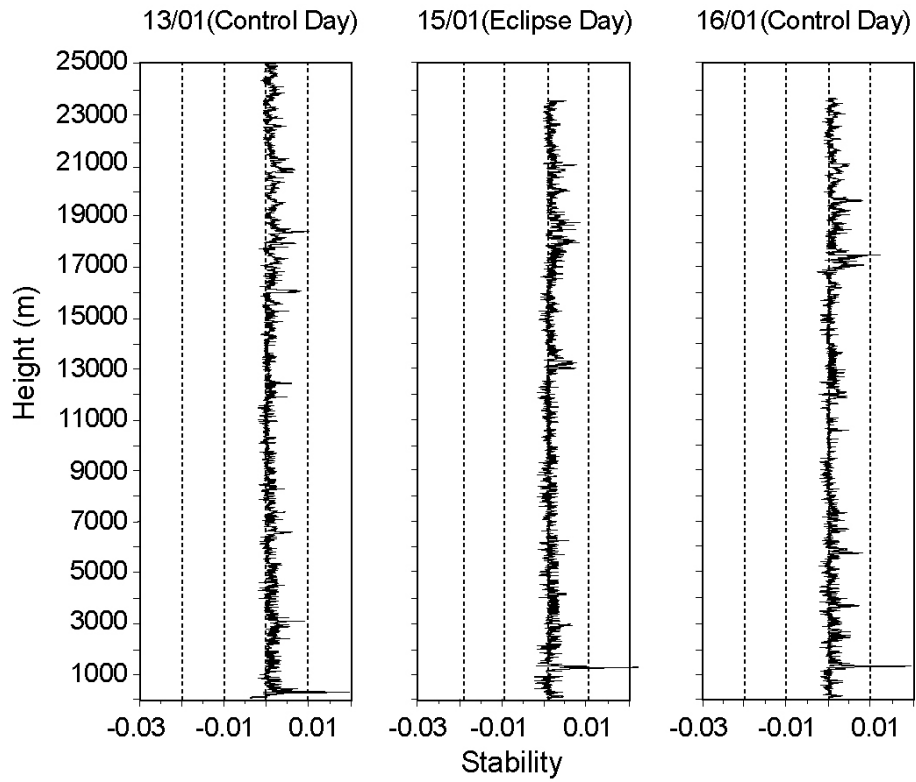


FIGURE 7

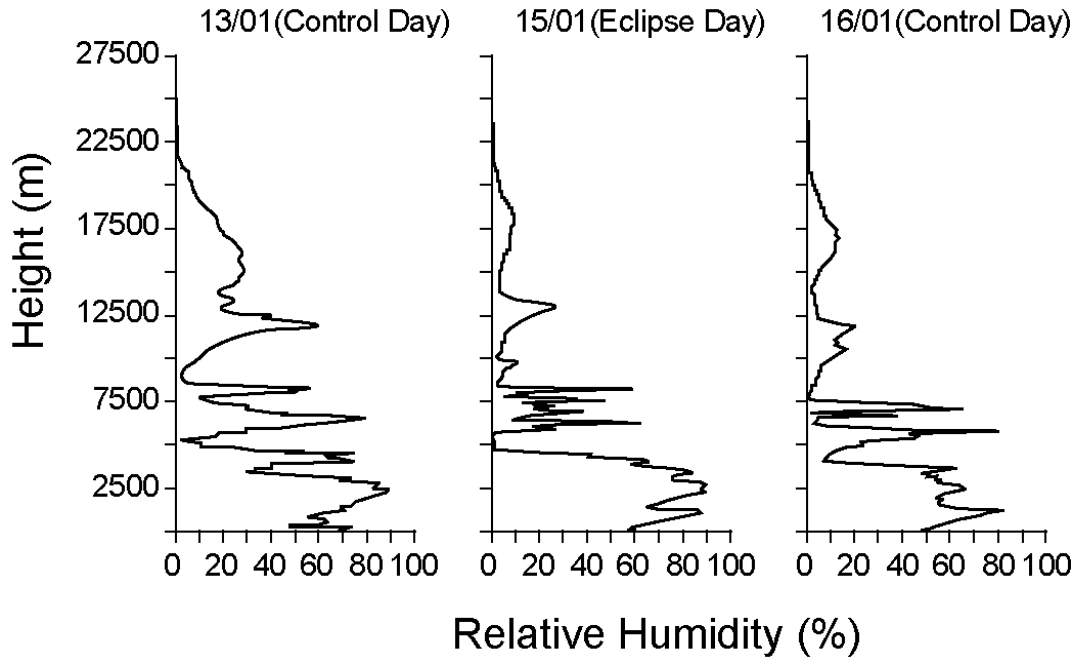


FIGURE 8

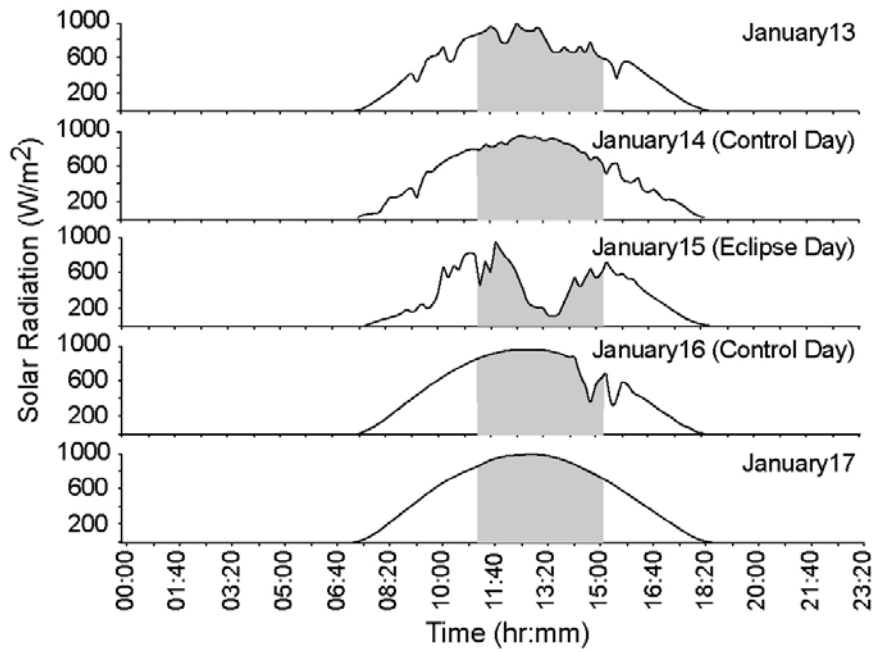


FIGURE 9

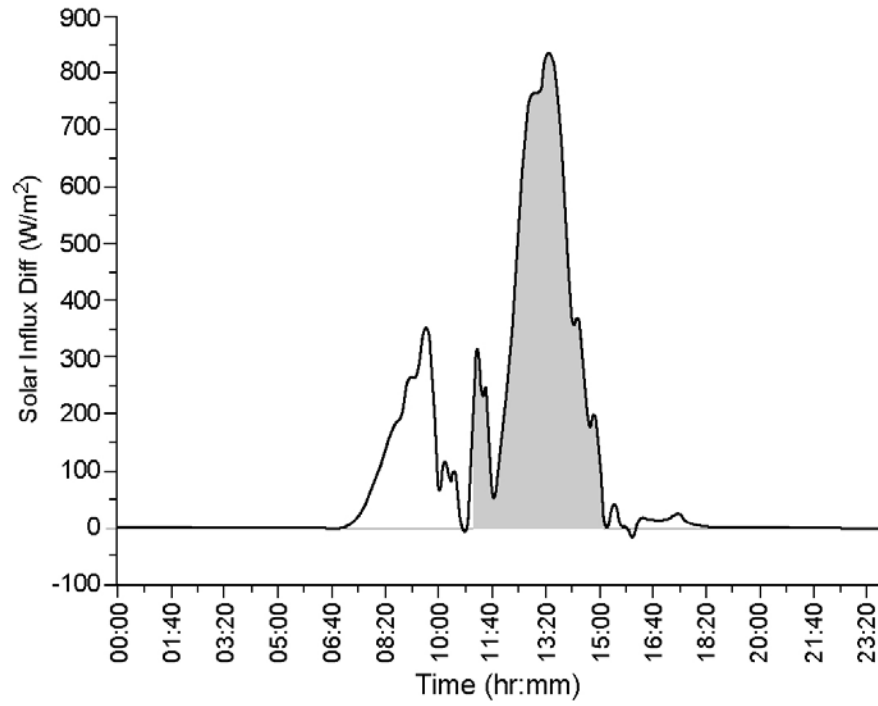


FIGURE 10

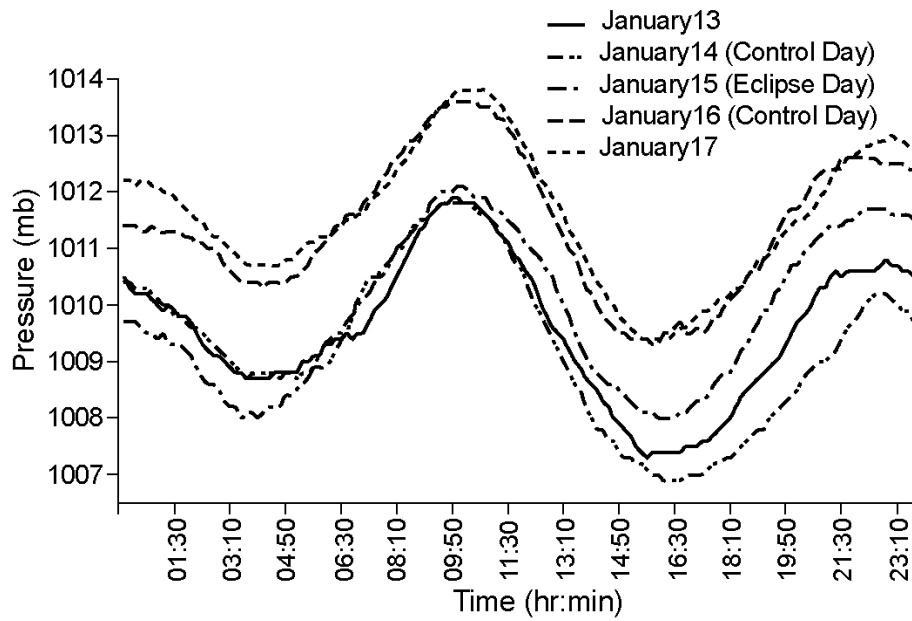


FIGURE 11

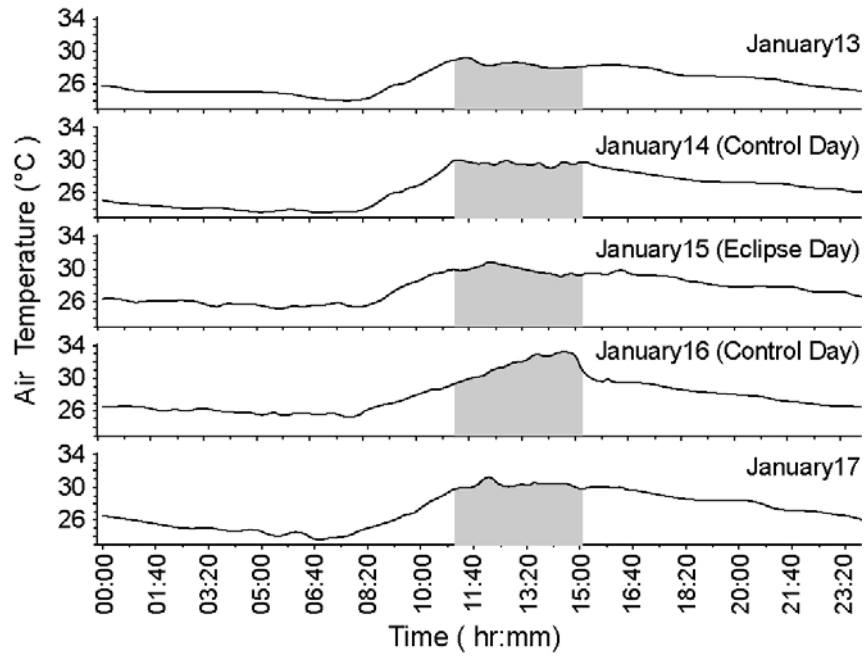


FIGURE 12

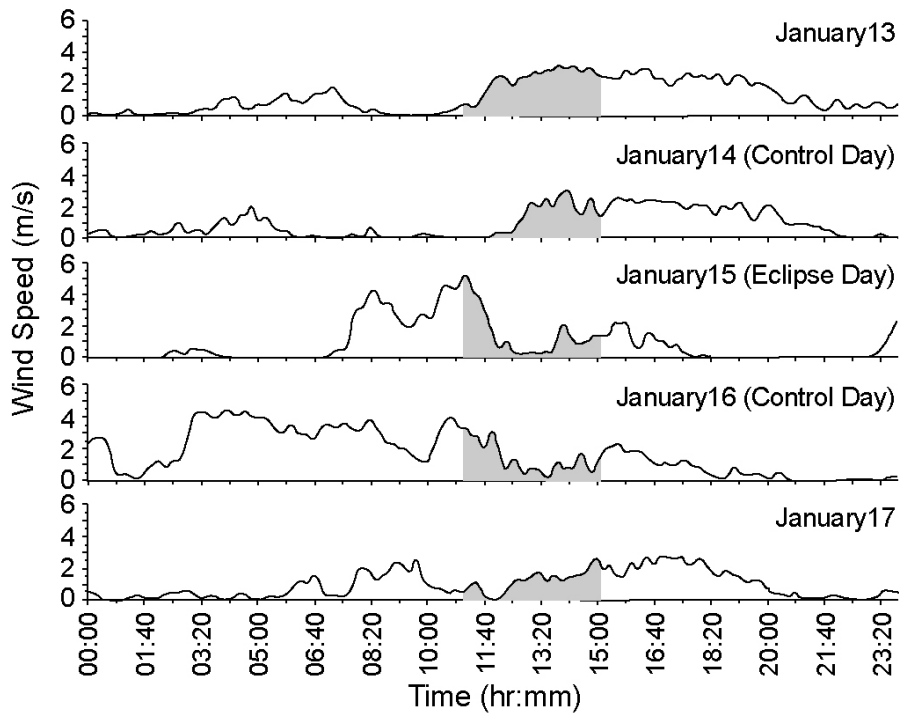


FIGURE 13

