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Overview of solar eclipse of 21st June 2020 and its impact on solar irradiance, surface ozone and different meteorological parameters over eight cities of India

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Abstract

The present study is aimed to investigate the variation in solar radiance, surface ozone, temperature, relative humidity and wind velocity during the most recent and one of the most significant annular solar eclipses of 21st June 2020. Effects of solar eclipse have been analyzed first time at eight different cities of India located nearly perpendicular to the eclipse axis having an eclipse magnitude from 98.6 % to 77.2 %. Significant reductions in solar irradiance at different stations were found during the maximum phase of the solar eclipse due to the occultation of the Sun by the Moon. With the progression of the solar eclipse, surface ozone concentrations were also found to be decreasing and reached to its minimum value during the maximum phase of eclipse and then after the end of the eclipse started regaining their original behavior. Overall, the change in ozone was found to be proportional to eclipse magnitude. A decrease of ozone levels ranged from 30 % to 65 % over all the stations. In addition to the above, atmospheric cooling from the solar eclipse of 21st June 2020 induced dynamical changes to the meteorological parameters (temperature, relative humidity and wind speed) with the change being most prominent during the maximum phase of the solar eclipse.

Keywords: Solar eclipse; Solar irradiance; Surface ozone; Meteorological parameters

1. Introduction

The phenomena like solar eclipse have always been very interesting to different researchers to assess their impact on our surroundings (Gogosheva et al., 2002; Tzanis, 2005; Varotsos, 2002, 2004, 2005; Tzanis et al., 2008; Peñaloza-Murillo and Pasachoff, 2018). It is found that in a total solar eclipse event the value of solar irradiance decreases to zero whereas in a partial solar eclipse it does not decrease to zero (Aplin et al., 2016). Although a solar eclipse is primarily of astronomical interest, meteorological changes also result from the abrupt change in isolation, causing cooling in the atmospheric surface layers (Aplin and Harrison, 2003). In many studies, transient changes in meteorological parameters (temperature, relative humidity and wind velocity) solar radiance and surface ozone have been reported (Eliot, 1990; Zerefos et al., 2007; Tzanis et al., 2008; Hanna, 2000, 2016, 2018; Subrahmanyam et al., 2013; Dolas et al., 2002). During the partial phases of solar eclipse relatively gradual change in the value of different meteorological parameters is observed but at the time of totality, the changes are quite rapid. Many researchers have reported the effect of the solar eclipse on earth's environment viz. variation in ozone,

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wind speed, relative humidity and short time disturbance in Solar irradiance and in consequence thermal balance of the atmosphere (Srivastava et al., 1982; Fernandez et al., 1993; Zerefos et al., 2001; Tzanis, 2005; Kolev et al., 2005; Gerasopoulos et al., 2008; Chakrabarty et al., 1997; Niranjan et al., 1997; Girach et al., 2012; Dutta, et al., 1999; Naja and Lal, 1997). Eliot (1990) reported the observations of air temperature, barometric pressure, relative humidity, cloud and rainfall at all one hundred and fifty-four meteorological stations in India and solar radiation observations at six stations during the solar eclipse of January 22, 1898. He further reported that the air temperature diminished in proportion to the obscuration and the maximum reduction of temperature was 12 °C at Karwar and there was a steady increase of pressure proceeding at a nearly uniform rate during the eclipse. Chakrabarty et al. (1997) reported a sharp decrease in the ozone column from its normal value 15 min before the maximum obscuration of the Sun, followed by a sharp rise 10 min after the maximum obscuration during the solar eclipse of October 24, 1995 over Ahmedabad. A substantial decrease in ozone concentration is reported by Zerefos et al. (2001) at Thessaloniki, Greece during the solar eclipse event of 11 August 1999. Atmospheric ozone production is a photochemical phenomenon, ozone decreases because of lack of solar irradiation (during the eclipse event) in the UV range (Jain et al., 2020). Decrease in temperature during solar eclipse also causes reduction in ozone formation in the lower atmosphere (Zerefos et al., 2007; Reid et al., 1994; Chimonas and Hines, 1971). Tzanis et al. (2008) reported a reduction of solar irradiance up to 97% over Greece, Athens. They further reported an increase in relative humidity as well as decrease in wind velocity. Several other workers have also reported changes in different meteorological parameters during the solar eclipse period (e.g. Fernandez et al., 1993, 1996; Anderson, 1999; Aplin and Harrison, 2003; Krishnan et al., 2004). Krishnan et al. (2004) reported a decrease of 0.5 °C in temperature and decrease in wind speed also, while the variation in relative humidity was reported within the natural variability of the day during a total solar eclipse effect of August 11, 1999 over Ahmadabad, India.

Despite various studies of the solar eclipse effect on solar irradiance, surface ozone and meteorological parameters at individual places, a complete study of all the above parameters simultaneous at different places having different magnitudes of a solar eclipse is lacking. To complete this gap, the present study has been initiated during the most recent annular solar eclipse of 21st June 2020 at eight different cities of India having different eclipse magnitudes.

The recent solar eclipse of 21st June 2020 provided us a unique opportunity to study changes in solar radiance, surface ozone and different meteorological parameters at different places in India. The annular solar eclipse was seen in the Indian states of Uttarakhand, Rajasthan and Haryana in the morning hours whereas partial solar eclipses were seen in the different other parts of the country. The eclipse magnitude ranged from 77.2% to 98.6% at different stations included in the present study. In the present work, we have selected different cities from the northern part of the country viz. Kurukshetra and Sirsa from Haryana state, Jaipur from Rajasthan, Amritsar and Jalandhar from Punjab, Varanasi from Uttar Pradesh, Chandigarh the union territory and Delhi the capital of India has been taken into consideration to study the environmental effects of the solar eclipse. An overview of variation in different meteorological parameters (temperature, relative humidity and wind speed) and also observed change in solar irradiance and ozone concentrations have been analyzed. The results obtained are compared with previously reported results during the solar eclipse in different parts of the world.

2. Observation and data

2.1. Description of the eclipse

The first solar eclipse of 2020 occurred on 21st June forming an annular ring. This annular solar eclipse started in Africa, crossed over to the Arabian Peninsula and then passed to Asian countries. The path of annularity was about 60 km wide and started from the Democratic Republic of the Congo, passing across the Central African Republic, South Sudan, Ethiopia and Eritrea. It then passed over Yemen, Saudi Arabia, Oman, Pakistan, India, China and Taiwan to end in the Pacific Ocean. This annular solar eclipse started at the eastern part of the Democratic Republic of Congo at 4.48 GMT just at sunrise and ended in the Pacific Ocean at 8.32 GMT, covering an enormous distance of about 14000 km in just 3 h and 45 min. This eclipse is unique in a manner as it took place on June solstice (21st June i.e. the day which brings the longest day of the year).

The solar eclipse started at different stations of the study with a slight difference in time and also ended with the same difference in time (Table 1). Maximum obscuration was observed around 12.00 o'clock at noon at all the places. Fig. 1 presents the umbral and penumbral regions of the annular solar eclipse of 21st June 2020 over India, Pakistan, China and Nepal. Our different observation sites with their magnitude are also indicated in the figure. The observation sites were chosen such that they were located nearly perpendicular to the eclipse axis having an eclipse magnitude from 98.6 % to 77.2 % to provide an impact on the investigation of the eclipse. Since this solar eclipse occurred during monsoon season, on the day of the eclipse some cities showed partial cloud coverage whereas some showed comparatively clear or nearly no clouds cover.

2.2. Data and methodology

In the present study, data measured by Central Pollution Control Board (CPCB), India is used. CPCB was constituted by the Government of India under the Prevention

Table 1
Details about Solar eclipse at different locations with their maximum eclipse magnitude.

Places	Latitude Longitude	Partial eclipse begins (IST)	Greatest eclipse (IST)	Maximum Eclipse Magnitude	Partial eclipse ends (IST)
Amritsar	31.6° N, 74.8° E	10.20	11.57	91.5%	13.41
Chandigarh	30.7° N, 76.7° E	10.24	12.04	95.4%	13.48
Delhi	28.7° N, 77.1° E	10.20	12.01	93.7%	13.48
Jalandhar	31.3° N, 75.5° E	10.22	12.01	91.0%	13.44
Jaipur	26.9° N, 75.7° E	10.14	11.55	88.1%	13.44
Kurukshetra	29.9° N, 76.8° E	10.21	12.01	98.6%	13.47
Sirsa	29.5° N, 75.0° E	10.16	11.56	98.6%	13.42
Varanasi	25.3° N, 82.9° E	10.31	12.17	77.2%	14.04

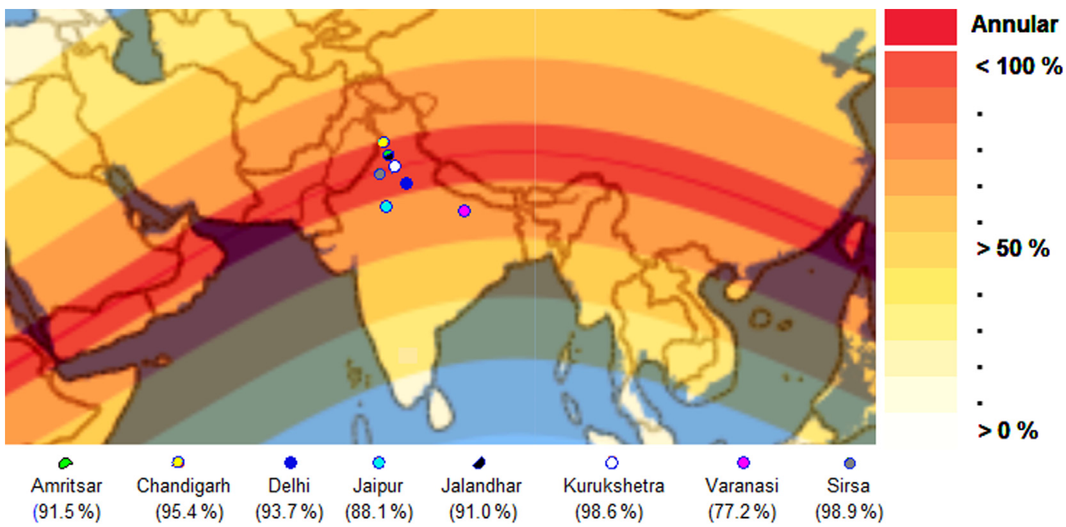

Fig. 1. The umbral and penumbral regions of the annular solar eclipse of 21st June 2020 over India, Pakistan, China and Nepal. Our different observation sites showing their eclipse magnitudes are also indicated on the map.

and Control of Pollution Act, 1974 which is a statutory organization. It was established to improve air quality in the whole country by controlling air pollution. CPCB provides Respirable Suspended Particulate Matter (RSPM), Carbon Monoxide (CO), Ozone (O_3), Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2) and Suspended Particulate Matter (SPM), solar radiance, temperature, wind speed, wind direction and relative humidity. All the data set used in the present study is freely available at the website of the Central pollution control board (CPCB): https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing/data. CPCB has deployed different types of instruments fitted with sensors certified by world meteorological organization to collect data (CAAQMS Guidelines, 2019). For the measurement of surface ozone (O_3), an ambient ozone analyzer was used which works on the principle of UV Photometric / Chemiluminescence and gives data digitally having a range of 0–500 ppb. Its lowest detectable limit is 1.0 ppb and the noise level is ± 0.5 ppb. While for the measurement of all the meteorological parameters namely temperature, wind speed, wind direction, relative humidity and Solar irradiance a crank-up telescopic 10 m tower was erected for mounting of different meteorological sensors interfaced directly with the Data Acquisition System after passing through a lightning protection isolation box. An ultrasonic type of sensor is deployed for measurement of wind speed which has a range of 0–60 m/s and which can sustain wind speed up to 75 m/s. Its threshold value is 0.5 m/s with an accuracy of ± 0.5 m/s and response time is 10 s or better (CAAQMS Guidelines, 2019). Wind direction is also measured using the ultrasonic type of sensor which has an accuracy of ± 3°, resolution of 1° and range of 0–359°. For measurement of temperature resistance type sensor is deployed which has a range of −10 °C to 60 °C, resolution of 0.1 °C with an accuracy of 0.2 °C. Relative humidity is measured using a capacitive sensor which has a range of 0–100% with an accuracy of ± 3% or better. A silicon photodiode sensor was employed to obtain Solar irradiance measurements having a range of 0–1500 W/m^2 with an accuracy of ± 5% (CAAQMS Guidelines, 2019).

Eight different sites hailing from different states have been considered where overwhelming obscuration of the solar eclipse was seen. The location of the different observation sites in Amritsar (31.6° N, 74.8° E) and Jalandhar (31.3° N, 75.5° E) located in northwestern Indian state

Punjab; Chandigarh (30.7° N, 76.7° E), capital of Punjab and Haryana and also a Union territory of India; Delhi (28.7° N, 77.1° E), the capital territory of India; Jaipur (26.9° N, 75.7° E), the capital city of Rajasthan; Sirsa (29.5° N, 75.0° E) and Kurukshetra (29.9° N, 76.8° E) located in Haryana state and Varanasi (25.3° N, 82.9° E), located in the Uttar Pradesh state of India. The maximum magnitude of solar eclipse found at Amritsar, Chandigarh, Delhi, Jalandhar, Jaipur, Sirsa, Kurukshetra and Varanasi is 91.5%, 95.4%, 93.7%, 91.0%, 88.1%, 98.6%, 98.6% and 77.2% respectively. Solar eclipse details at different locations used in the present study in India with their maximum eclipse magnitudes are tabulated in Table 1.

In order to take a vivid and clear picture of the solar eclipse phenomenon at different stages, a solar telescope installed at the Department of Physics, Banaras Hindu University, Varanasi, was used. This telescope has a primary lens diameter of 90 mm and a focal length of 1000 mm. The telescope uses a CCD camera of 6.1 MP having a resolution of 3032 × 2016 with pixel size 7.8 μm × 7.8 μm (Tripathi et al., 2020). It has a wide range of exposure time which vary from 1 ms to 1 h. The solar telescope is equipped with an intensity filter to observe solar disk and records the images and intensity (Tripathi et al. 2020). Images of the partial solar eclipse of different magnitudes photographed at Varanasi at different stages using the telescope are shown in Fig. 2. The eclipse images are taken at (a) 11:53:12 am with magnitude 71.1 % and obscuration 11.58 (b) 10:33:22 am with magnitude 2.7 % and obscuration 1.98 (c) 11:06:01 am with magnitude 18.4 % and obscuration 5.18 (d) 11:20:30 am with magnitude 43.4 % and obscuration 8.46 (e) 11:33:02 am with magnitude 55.1 % and obscuration 9.81.

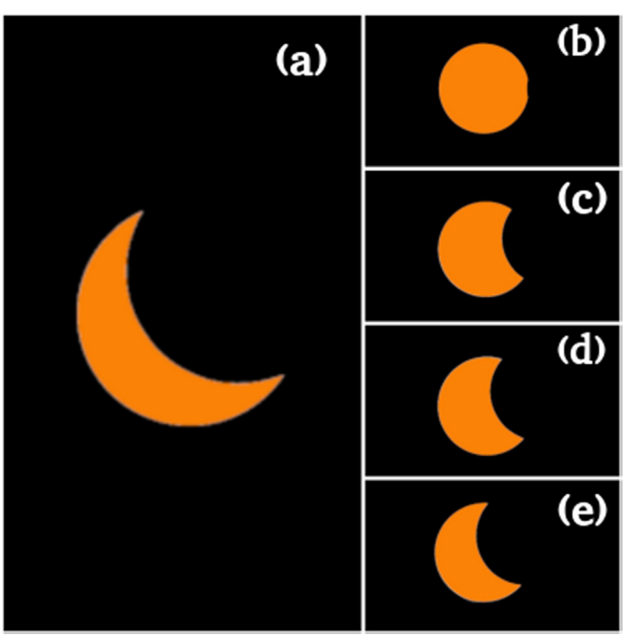

Fig. 2. Images of partial solar eclipse of different magnitudes photographed at Varanasi using the telescope at different stages (a) 11:53:12 am with magnitude 71.1 % (b) 10:33:22 am with magnitude 2.7 % (c) 11:06:01 am with magnitude 18.4 % and (d) 11:20:30 am with magnitude 43.4 % and (e) 11:33:02 am with magnitude 55.1 %.

3. Results and discussions

3.1. Solar irradiance

Fig. 3 represents the 15 min mean of Solar irradiance measurements at annular solar eclipse day along with average of seven days before, during and after the solar eclipse of 21st June 2020 at different stations (Amritsar, Chandigarh, Delhi, Jaipur, Jalandhar, Kurukshetra and Varanasi). Solar irradiance measurement for the Sirsa location was not available. A substantial reduction in solar radiance is evident during maximum obscuration at all places. A similar reduction in Solar irradiance was also reported by various workers at different locations of the world during solar eclipse events (e.g. Sharp et al., 1971; Founda et al. 2007 and references therein). Calculated percentage change in Solar irradiance at the time of maximum obscuration compared to average of seven days before and solar eclipse day is tabulated in Table 2. Maximum reduction of 902.9 W/m^3 as compared to average of seven days measurements in Solar irradiance was experienced in Jalandhar where eclipse magnitude was also reported high i.e. 91.0 %. After that Chandigarh and Kurukshetra witnessed a decrease of approx 664.6 W/m^2 and 761.5 W/m^2 as compared to the average of seven days. Similarly Amritsar, Delhi, Jaipur and Varanasi recorded a percent decrease of 116.8 W/m^2, 406.8 W/m^2, 573.4 W/m^2, and 594.4 W/m^2 respectively in Solar irradiance as compared to the average of seven days. At the beginning of the event, Solar irradiance value starts decreasing and reaches its minimum value during the solar eclipse maximum obscuration and then it starts to increase to reach its normal behavior. Since the solar eclipse occurred during monsoon season, on the day of the eclipse some cities showed partial cloud coverage due to which the Solar irradiance has some fluctuation showing effect of clouds. The results were found to be in agreement with previously reported studies (Tzanis et al., 2008; 2005). Similar behavior has been reported by Founda et al. (2007) over Thessaloniki and Kastelorizo showing 89 % and 100 % reduced Solar irradiance respectively. It is also reported that there is greater cooling during solar eclipses when it occurs at noontime (Aplin et al., 2016). The solar eclipse of 21st June 2020 also took place at noontime at all the places in India causing significant changes in solar irradiance. Girach et al. (2012) reported a maximum decrease in direct solar irradiance occurred with maximum obscuration over Thumba, India during the annular eclipse of 15 January 2010. Recently, Madhavan and Ratnam (2021) also reported maximum decrease in global horizontal irradiance (GHI) and direct normal irradiance (DNI) (about 62 %) and in diffuse horizontal irradiance (DHI) (about 75 %) during annular solar eclipse on 26 December 2019.

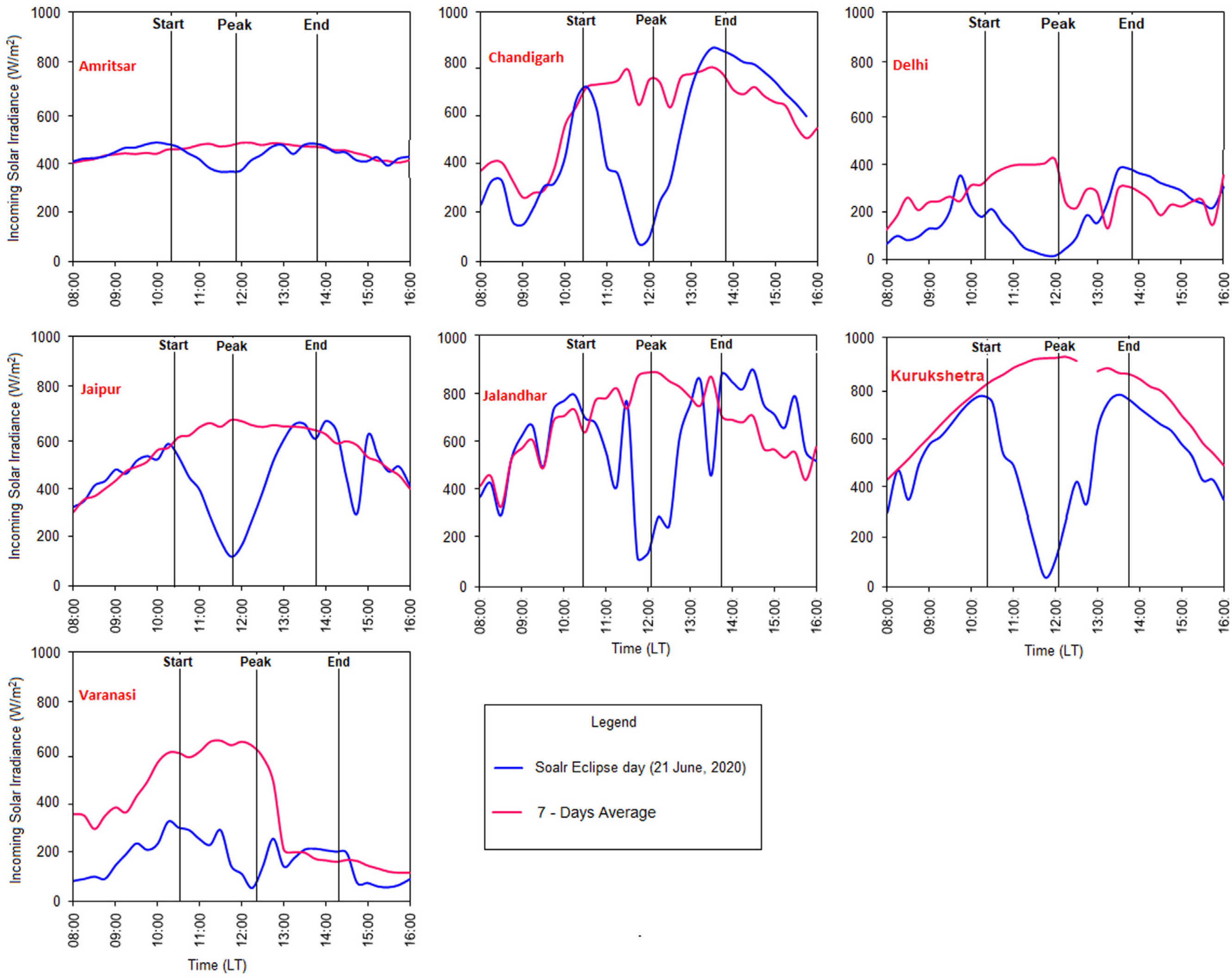

Fig. 3. The solar radiation measurements over different sites on solar eclipse day (21st June 2020) before, during and after the solar eclipse along with the average of seven days measurements of solar radiation.

Table 2
Change in different parameters at the time of maximum obscuration compared to average of seven days and Solar Eclipse day.

Parameters/Places	Amritsar	Chandigarh	Delhi	Jalandhar	Jaipur	Kurukshetra	Sirsa	Varanasi
Solar Radiation (W/m^2)	−116.8	−664.6	−406.8	−902.9	−573.4	−761.5	———	−594.4
Surface Ozone ($\mu g/m^3$)	———	−18.0	−21.8	−11.7	−56.6	−24.8	−15.5	−55.1
Temperature (°C)	−3.5	−3.9	−6.2	−3.3	−4.2	−5.1	−5.7	−9.4
Relative Humidity (%)	23.4	25.1	41.1	———	2.3	15.1	16.3	34.1

3.2. Surface ozone

Fig. 4 shows the variation of surface ozone concentrations at different sites before, during and after the solar eclipse occurred on 21st June 2020 (event), together with average of seven days observations. The surface ozone data of Amritsar was not available at CPCB cite. The decline in surface ozone concentrations started just after the beginning of the solar eclipse at all the sites and reached its minimum concentration during the maximum obscuration time (Kumar et al., 2011). As a consequence, decreased solar light intensity affects the formation of ozone. Ozone behaviour becomes normal after a delay which is known as photochemical processing delay. The obtained behavior of ozone may be attributed to change in photochemical processes within the planetary boundary layer as a result of solar irradiance attenuation during the eclipse event (Tzanis et al., 2008). Ozone production and destruction mechanisms are controlled by photochemistry involving several other trace gas species in a reactive chain manner

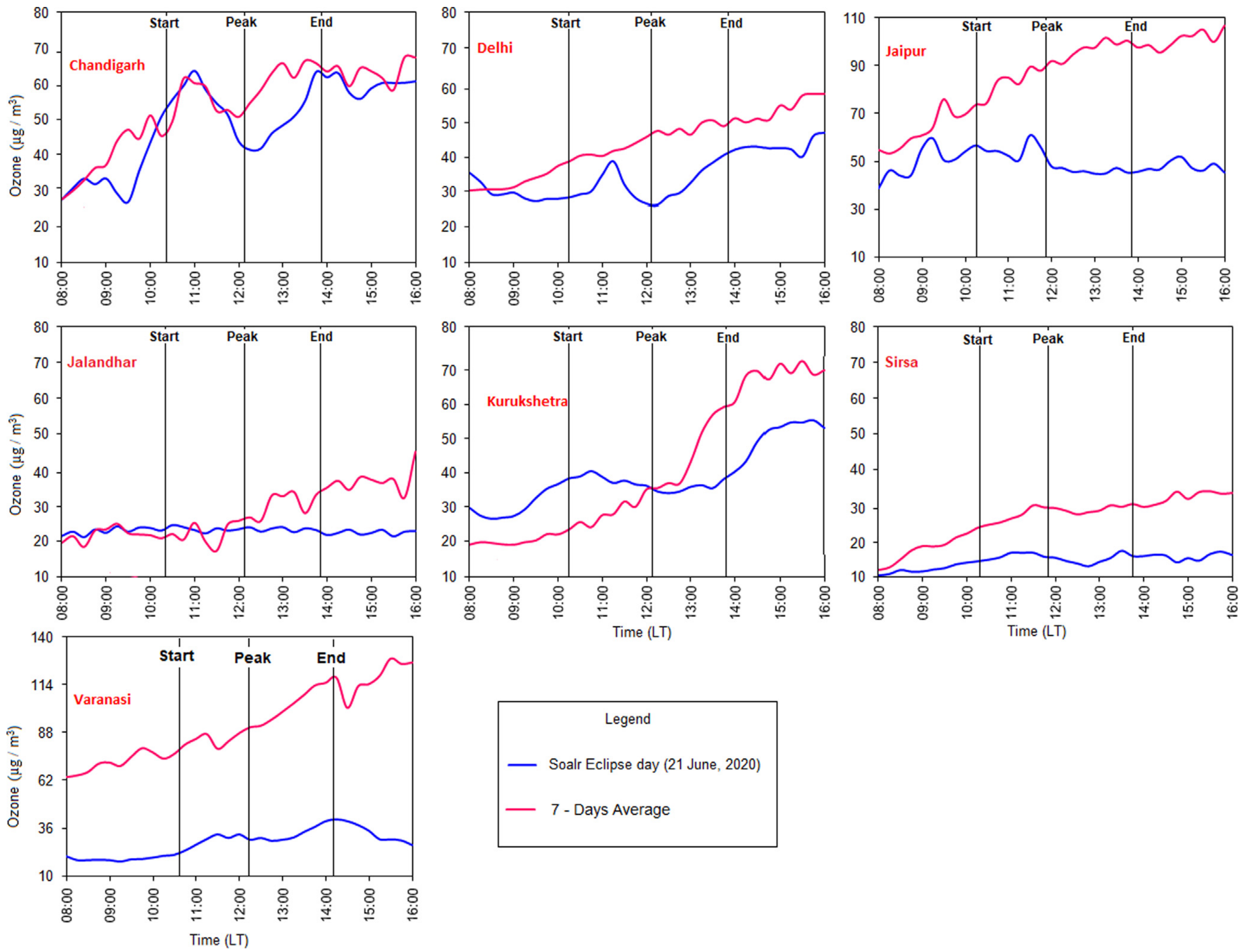

Fig. 4. The variation of surface ozone concentrations at different sites before, during and after the solar eclipse day (21st June 2020) along with the average of seven days.

in the lower atmosphere (Monks, 2005). Jain et al. (2020) have analyzed direct and indirect photochemical impacts on Ozone during the solar eclipse over a tropical rural location and 48 % reduction in ozone concentration was reported. Calculated percentage change in surface ozone at the time of maximum obscuration compared to average of seven days before and solar eclipse day is tabulated in Table 2. The greater value of difference of 56.6 µg/m^3 (65 %) in surface ozone concentrations was observed at Jaipur. The other observational sites viz. Chandigarh, Delhi, Jalandhar, Sirsa, Kurukshetra, and Varanasi also witnessed a significant decrease of about 18.0 µg/m^3, 21.8 µg/m^3, 11.7 µg/m^3, 15.5 µg/m^3, 24.8 µg/m^3 and 55.1 µg/m^3 respectively in ozone concentrations during solar eclipse maximum. All the seven stations showed a decrease of about (30 % to 65 %) in surface ozone concentration. Zerefos et al. (2001) reported a decrease of around 10–15 ppbv in surface ozone concentration during the solar eclipse of 11 August 1999 in Thessaloniki, Greece. A decrease of 32.7 % in surface ozone concentrations during the solar eclipse of 29th March 2006 at Athens and Greece was reported by Tzanis et al. (2008). He further demonstrated that the influence of the eclipse effect was manifested with a certain delay and lasted almost two hours. Naja and Lal (1997) reported a decrease in surface Ozone concentration in the range of 18–21 % at the maximum phase of solar eclipse of October 24, 1995 over Ahmadabad, India. They further reported that Ozone levels were found to be lower even after the eclipse due to loss and delay in ozone production. Whereas, Srivastava et al. (1982) reported no substantial change in Ozone concentration measurements near the ground at Raichur, India during the solar eclipse of 16 February 1980. Girach et al. (2012) reported a decrease in surface Ozone by 12 ppb (35 %) over Thumba, India during the annular eclipse of 15 January 2010 with the time lag of 40 min from the maximum phase of eclipse. They explained that the presence of the time lag was due to the slow process of ozone destruction. Jain et al. (2020) explained that the decrease in ozone is directly related to the fall in production rate of its precursors and a shift of the photochemical stationary state derived from the coupling reactions.

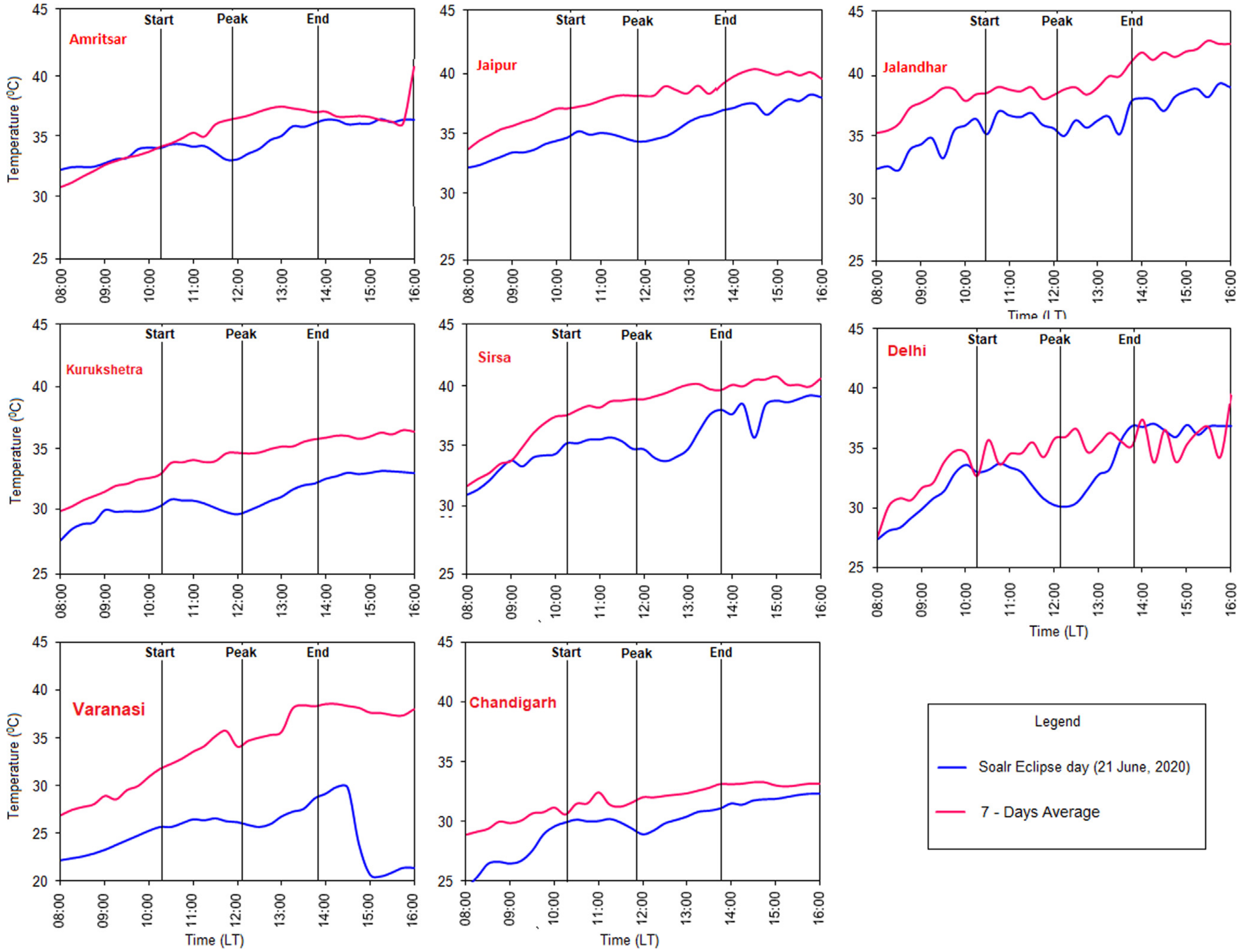

Fig. 5. The variation in temperature (°C) at our different observation sites before during and after the solar eclipse day (21st June 2020) along with the average of seven days.

3.3. Meteorological parameters

The meteorological parameters observed at different stations during the solar eclipse of 21st June 2020 showed that all of them got affected by the solar eclipse as a result of the decrease in solar irradiance. However, they do not depend only on eclipse magnitude but are also controlled by local factors like timing of the eclipse, surrounding environment, synoptic situation, etc. (Gerasopoulos et al., 2008). Aplin and Harrison (2003) reported an "eclipse wind" during many eclipses, whereas Anderson (1999) reported wind chill effect. Fernandez et al. (1993) also reported a decrease in mean wind speed during the eclipse. Hanna (2018) reported the meteorological effects of the 20 March 2015 solar eclipse over the United Kingdom showing decrease in surface temperature and wind speed.

Figs. 5–7 depict 15 min mean variation of temperature, relative humidity and wind speed respectively at different stations during the solar eclipse together with the average of seven days. In general, the temperature started decreasing as the eclipse progressed at all the stations and continued to fall till 10–15 min later the eclipse maximum and then starts tending to achieve its normal trend. Calculated change in temperature at the time of maximum obscuration compared to average of seven days before and solar eclipse day is tabulated in Table 2. In Amritsar, the temperature fall was observed of 3.5 °C as compared to the average of seven days for the same period during the eclipse maximum. In Jaipur too, the temperature started increasing as the day progressed but due to the eclipse, the temperature was observed to be decreased despite the mid-noon due to occultation of the Sun by the Moon which resulted in decreased Solar irradiance reaching the earth. Jaipur witnessed a 4.2 °C decline in temperature during the same period of average of seven days. In Jalandhar, the decline in temperature was observed at 3.3 °C as compared to the average of seven days. Similarly, Kurukshetra and Sirsa also experienced a fall of temperature by 5.1 °C and 5.7 °C respectively as compared to the average of seven days. Similarly, Delhi faces a decline of 6.2 °C and Chandigarh

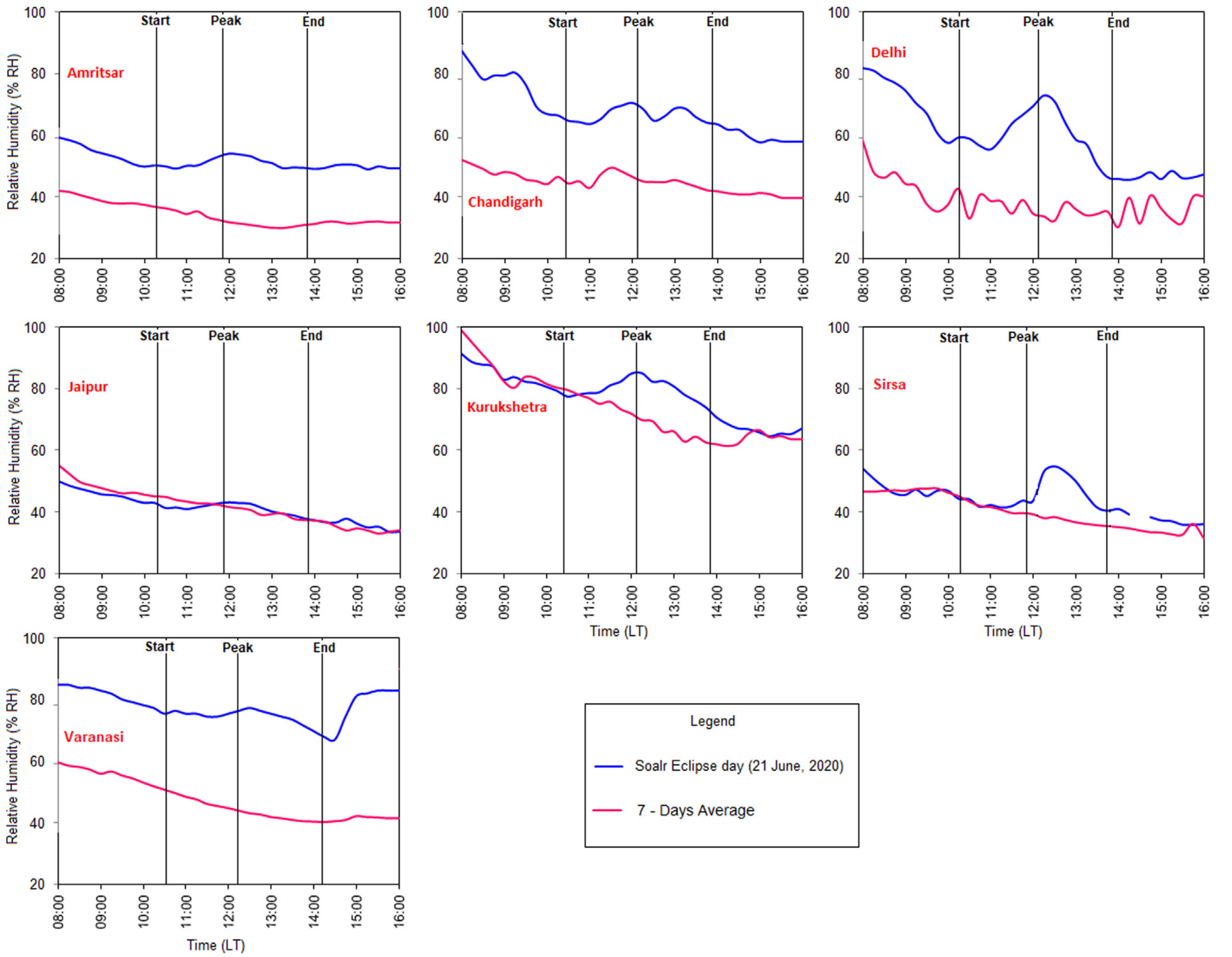

Fig. 6. The variation of relative humidity (%) at our different observation sites before during and after the solar eclipse day (21st June 2020) along with the average of seven days.

faces decline of 3.9 °C in its ambient temperature during the maximum obscuration time as compared to the average of seven days before eclipse. Burt (2018) in their study over the US during the solar eclipse of 21 August 2017 observed a decrease of 8.2 °C with a lag of 15 min from peak totality. It was reported by Anderson (1999) that the cooling of the atmosphere became visible when half of the Sun is covered. He further reported that the minimum value of temperature was observed with a time lag of 5 and 20 min with peak eclipse time. A temperature decrease of 5 °C was recorded during the total solar eclipse of 21 June 2001 over northern Zimbabwe that occurred near local noon (Milford, 2001). Eaton et al. (1997) also reported a decline of 7 °C in surface temperature during the eclipse of 10 May 1994. Tzanis et al. (2008) reported a decrease of temperature near the ground from 20.1 °C to 19.4 °C during the eclipse event of 29 March 2006 at Patision station and after that, it began to increase abruptly. Krishnan et al. (2004) also reported a decrease of 0.5 °C in temperature during a total solar eclipse effect of August 11, 1999 over Ahmadabad, India. Girach et al. (2012) reported a decrease in temperature by 1.2 °C over Thumba, India during the annular eclipse of 15 January 2010 with the time lag of 13 min from the maximum phase of eclipse. Subrahmanyam et al. (2011) reported a temperature reduction of ~ 2–8 °C in the troposphere and lower stratosphere with ~ 4 °C cooling around the tropopause and ~ 6–8 °C in the lower stratosphere during the maximum phase of eclipse using balloon based measurements during the annular solar eclipse of 15 July 2010 over Thumba, India. Dutta et al. (1999) also reported a temperature reduction of 9–10 °C below the tropopause during the solar eclipse of 24 October 1995 over Hyderabad using balloon based measurements. Appu et al. (1982) reported a warming of 10 °C around 30 km, and a cooling of 14 °C around 58 km making rocket measurements from the Thumba, India during a partial solar eclipse of 16 February 1980. From balloon measurements they further also reported a warming of 5 °C around 13 km at Thumba, and a systemic cooling in 3–20 km height region at Hyderabad. Dolas et al. (2002) reported a decrease of temperature by 1–2 °C during the total solar eclipse of 11 August 1999 over Akola, India. They further reported a lag of

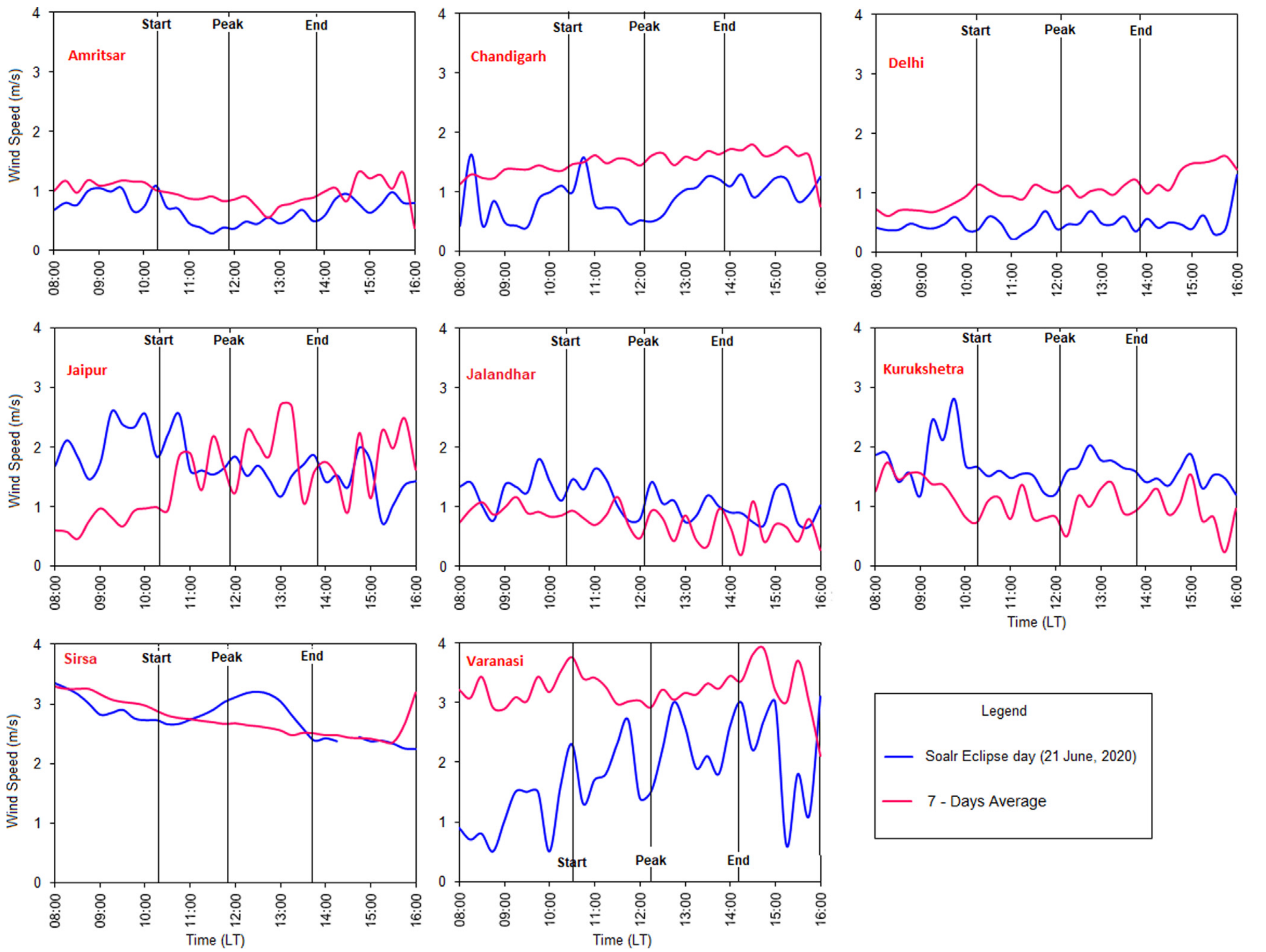

Fig. 7. The variation of wind speed (in m/s) at our different observation sites before during and after the solar eclipse day (21st June 2020) along with the average of seven days.

10 min in local minimum of temperature with respect to totality phase. Kameda et al. (2009) reported a 6–30 min time lag between totality and temperature minimum as observed in our case. The time lag between maximum obscuration of eclipse and temperature minimum may be caused by the thermal inertia of the atmospheric surface layer (Aplin and Harrison, 2003).

Temperature and humidity are inversely proportional, as the ambient air water holding capacity changes with the changes in the temperature. Calculated changes in relative humidity at all the stations at the time of maximum obscuration compared to solar eclipse day and average of seven days are tabulated in Table 2. The relative humidity data of Jalandhar station is not available at CPCB cite. Fig. 6 and Table 2 shows that the highest increase in relative humidity was observed at Kurukshetra i.e. 56 % but this may not be solely attributed to eclipse magnitude but surrounding environment and local conditions. Other observational sites viz. Amritsar, Chandigarh, Delhi, Jaipur, Sirsa and Varanasi also showed an increase in relative humidity by 23.4 %, 41.1 %, 2.3 % 3.5, 16.3 % and 34.1 % respectively with a time lag of 15–30 min from peak totality. Namboodiri et al. (2011) also reported a maximum increase of 19 % in relative humidity during the annular solar eclipse of 15 January 2010 over Thumba, India with a time lag of 28 min with maximum obscuration of the eclipse. During the eclipse event of 29 March 2006 at Patision, Tzanis et al. (2008) also reported an increase in relative humidity.

It is observed that the wind speed also decreases during the eclipse period at all the stations as depicted in Fig. 7. It may be recognized by the cooling and stabilization of the boundary layer of the atmosphere (Amiridis et al., 2007). Fernandez et al. (1996) measured a decline in wind speed from 2.5 m s^{-1} to a minimum of less than 1 m s^{-1} during maximum obscuration. Kolev et al. (2005) also reported a decrease in wind speed during the solar eclipse of 11 August 1999 in Bulgaria. During the solar eclipse period, the atmosphere stabilizes due to the gradual cooling of the boundary layer which reduces the wind speed (Anderson, 1999). Girach et al. (2012) reported a decrease in wind speed by 1.2 m s^{-1} over Thumba, India during the annular eclipse of 15 January 2010 with the time lag of 40 min from the maximum phase of eclipse. During a longer annular eclipse of 15 January 2010 that occurred at Thumba in south India, Subrahmanyam et al. (2013) reported significant variations in both zonal and meridional winds after ~ 4 h of the maximum eclipse phase at local noon hours. Dutta et al. (1999) reported that no appreciable change was observed in both zonal and meridional winds below the tropopause during the solar eclipse of 24 October 1995 over Hyderabad using balloon based measurements. All the measurements of the meteorological parameters observed in the present study were found in close agreement with previously reported studies (Anderson, 1999; Founda et al., 2007; Tzanis et al., 2005; 2008). All the above-mentioned parameters regain their original behavior after the end of the solar eclipse period.

All the above results using different measurements simultaneously at various stations should be taken into account for the planning of more integrated and focused experiments in the future for upcoming solar eclipse events. Various types of models such as radiative transfer, meteorological, air quality, etc. may be planned for similar situations in the future for better study of the effects of the solar eclipse on the environment.

4. Conclusion

The occurrence of the annular solar eclipse of 21st June 2020, one of the longest solar eclipses of the recent period has given us an opportunity to investigate its effect on various parameters simultaneously at eight different cities of India where overwhelming obscuration of the solar eclipse was seen. The different stations were located nearly perpendicular to the eclipse axis having an eclipse magnitude from 98.6 % to 77.2 % to provide a better impact on the investigation. The measurements of Solar irradiance, surface ozone and meteorological parameters (temperature, relative humidity, and wind speed) for all the stations were affected mainly due to rapid solar attenuation as expected. A maximum reduction of 902.9 W/m^2 in Solar irradiance was observed in Jalandhar during the maximum phase of the eclipse as compared to the average of seven days measurements. The surface ozone concentrations were found to be minimum during eclipse totality and soon after that it starts increasing and tends to achieve its normal behavior after the end of the eclipse. A decrease of 30 % to 65 % in surface ozone concentration was recorded for all the seven stations. Maximum change of 65 % (56.6 $\mu g/m^3$) in surface ozone concentrations was observed at Jaipur. The obtained behavior of ozone may be attributed to change in photochemical processes within the planetary boundary layer as a result of solar irradiance attenuation during the eclipse event. In general, the temperature started decreasing as the eclipse progressed at all the stations and continued to fall till 10–15 min later the eclipse maximum and then starts tending to achieve its normal trend. In addition, due to a decrease in temperature relative humidity started increasing at all the stations that may also be attributed to atmospheric cooling caused by less solar irradiance reaching the earth. The wind speed was also found to suppress during the maximum solar eclipse which may be attributed to cooling and stabilization of the atmospheric boundary layer. However, the changes in meteorological parameters are mainly governed by local weather conditions. All the parameters showed a tendency to regain their normal trend after the end of the solar eclipse.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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