Analysis of Meteorological Parameters at Shenzhen Astronomical Observatory During a Partial Solar Eclipse (Postprint)

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Abstract

On June 21, 2020, an annular solar eclipse occurred across China, with the annularity path passing through Tibet, Sichuan, Chongqing, Hunan, Jiangxi, Fujian, and Taiwan, while other regions observed a partial solar eclipse. The solar telescope at Shenzhen Observatory observed the entire process of the partial solar eclipse, while meteorological equipment at the station simultaneously monitored meteorological parameters including solar radiation, temperature, humidity, and atmospheric pressure. Analysis of the solar and meteorological observations during the eclipse revealed: (1) From first contact to maximum eclipse, solar radiation, temperature, and atmospheric pressure all decreased, then slowly increased thereafter; influenced by weather conditions, the times of minimum values lagged behind the time of maximum eclipse, with solar radiation lagging by 1.37 minutes, temperature by 6.37 minutes, and atmospheric pressure by 10.37 minutes; (2) From first contact to maximum eclipse, relative humidity first rose to a maximum value, persisted for 33 minutes, then decreased, with the time of maximum value lagging behind the time of maximum eclipse by 6.37 minutes; (3) Compared with meteorological element variations on the days before and after the eclipse, the rates of change in solar radiation, temperature, and relative humidity during the eclipse were approximately one order of magnitude higher than those without an eclipse, while the rate of change in atmospheric pressure showed little difference; (4) During the eclipse, there was strong correlation between the relative intensity of the solar disk and meteorological elements, with correlation coefficients reaching 0.95, 0.89, -0.82, and 0.75, respectively.

Analysis of Meteorological Elements at Shenzhen Astronomical Observatory During the Partial Solar Eclipse

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Abstract

On June 21, 2020, an annular solar eclipse occurred across China, with the path of annularity passing through Tibet, Sichuan, Chongqing, Hunan, Jiangxi, Fujian, and Taiwan. A partial solar eclipse was visible from all other regions of the country. The solar telescope at Shenzhen Astronomical Observatory captured the entire process of the partial eclipse, while meteorological instruments at the observatory simultaneously recorded solar radiation, temperature, humidity, and atmospheric pressure.

Analysis of the solar and meteorological observations during the eclipse reveals the following: (1) From first contact to maximum eclipse, solar radiation, temperature, and atmospheric pressure all decreased, then rose gradually thereafter. Due to weather conditions, the times of minimum values lagged behind the time of maximum eclipse, with solar radiation lagging by 1.37 minutes, temperature by 6.37 minutes, and pressure by 10.37 minutes. (2) Relative humidity increased to a maximum value from first contact to maximum eclipse, remained at this level for 33 minutes, and then decreased, with the maximum occurring 6.37 minutes after eclipse maximum. (3) Comparing the meteorological variations on the days before and after the eclipse, the rates of change in solar radiation, temperature, and relative humidity during the eclipse were approximately one order of magnitude greater than those on non-eclipse days, while the pressure change rate showed little difference. (4) During the eclipse, the relative intensity of the solar disk exhibited strong correlations with meteorological elements, with correlation coefficients reaching 0.95, 0.89, -0.82, and 0.75, respectively.

Keywords: solar eclipse; solar radiation; temperature; relative humidity; atmospheric pressure

1. Research Status of Meteorological Elements During Solar Eclipses

A solar eclipse occurs when the Moon passes between the Earth and the Sun, aligning the three celestial bodies in a straight line. Based on the Moon' s shadow projection on Earth, solar eclipses can be classified as total, annular, partial, or hybrid [1]. Throughout history, solar eclipses have not only provided spectacular visual experiences but also created unique scientific research opportunities. The most famous example is Sir Arthur Eddington' s observation of the 1919 total solar eclipse, which confirmed Einstein' s prediction of light deflection by gravity in his general theory of relativity [2]. During totality, the Sun' s outer atmosphere—the corona—becomes directly visible. Because the corona is extremely tenuous and faint, it is normally overwhelmed by the intense light from the solar photosphere, though faint coronal structures can sometimes be observed during annular eclipses with very high magnitude. Research on the dynamic characteristics of fine coronal structures, the coronal heating problem, and biological effects during eclipses constitutes important scientific investigation [3-4] and serves as a valuable complement to ground-based and space-based solar observations.

Although solar eclipses induce changes in meteorological elements, relevant research papers only began to increase significantly after the total solar eclipse of February 16, 1980 [5]. Quantitative measurements have revealed that solar radiation and air temperature decrease after eclipse onset [6]. Under clear skies and stable atmospheric conditions, the minimum solar radiation (solar irradiance or sky brightness) coincides precisely with the time of maximum eclipse, with solar irradiance variations showing excellent consistency with the eclipse progression. However, in cloudy or foggy conditions, the time of minimum solar radiation exhibits some delay [7]. Sky brightness is also affected by air mass and local environment, with urban and industrial areas showing brighter skies during modern total eclipses compared to historical events [8]. During totality, solar radiation drops to 0 $W \cdot m^{-2}$ at maximum eclipse, while temperature can decrease by several degrees Celsius [9]. After totality concludes, both solar radiation and temperature gradually recover [10]. Hua et al. [11] analyzed meteorological observations from Hangzhou during the July 22, 2009 total solar eclipse and found temperature variations of 0.6–3.0°C at altitudes above 20,000 meters, while ground temperature changed by a maximum of 2.3°C. Ma et al. [12] examined meteorological element changes in Wuhan during the same eclipse and observed a substantial decrease in total solar radiation; due to the thermal lag of temperature relative to radiation, the temperature followed a rise-decline-rise pattern with a variation range of 1.3°C. Mahmood et al. [13] observed during the 2017 total solar eclipse in the United States that solar radiation decreased from over 800 $W \cdot m^{-2}$ to 0 $W \cdot m^{-2}$, accompanied by a 4.5°C temperature drop. Solar eclipses also affect power consumption and generation; during the March 20, 2015 eclipse, electricity demand in the United Kingdom increased by approximately 3 GWh (4% higher than the same period on normal days), while wind and photovoltaic generation decreased by 1.5 GWh [14].

The annular solar eclipse of June 21, 2020 was the most spectacular annular eclipse of this century in China, reaching a maximum magnitude of 0.997 (source: National Astronomical Data Center Eclipse Calculator, https://nadc.china-vo.org/eclipse/). Although the path of annularity passed through Tibet, Sichuan, Chongqing, Hunan, Jiangxi, Fujian, and Taiwan, the annularity band was extremely narrow—only about 20 km wide—with only a partial eclipse visible from other regions. Located south of the annularity path, Shenzhen Astronomical Observatory observed a partial eclipse with a substantial maximum magnitude of 0.901. Figure 1 Figure 1: see original paper shows the overall eclipse path across China, while Figure 1(b) provides an enlarged view of the partial eclipse in Shenzhen, displaying the observatory' s geographic coordinates, eclipse magnitude, and the times of first contact, maximum eclipse, and last contact. The solar telescope captured the complete partial eclipse sequence, while standard meteorological instruments simultaneously conducted astronomical and meteorological observations—a typical example of integrated astronomy and meteorology research. Even during total solar eclipses, temperature typically drops by only a few degrees Celsius, with correspondingly smaller changes expected during partial eclipses. Whether these changes remain statistically significant during partial eclipses presents a worthwhile research question. Quantitative analysis of the relationship between solar disk variations and meteorological element changes, along with their correlations, can effectively predict meteorological behavior during future eclipses.

2. Solar and Meteorological Observations of the Partial Eclipse

Shenzhen Astronomical Observatory is located at Xichong, Nan' ao Peninsula, Dapeng New District, Guangdong Province, surrounded by the sea on three sides (east, south, and west) at an altitude of 224 meters, with seeing conditions sufficient for full-disk photospheric and chromospheric observations [15-16]. In April 2020, the observatory completed and commissioned an upgraded triple-channel solar telescope capable of full-disk chromospheric observations in Hα (656.28 nm) and Ca II K (393.37 nm) bands, as well as full-disk photospheric observations in white light. Triple-channel full-disk solar observations can capture solar activity information including sunspots, filaments (prominences), and flares [17], which is crucial for understanding the physical nature of solar activity and predicting hazardous space weather events. Additionally, full-disk chromospheric telescope observations of partial solar eclipses hold significant scientific research value, providing data and information for solar physics and geophysical effect studies [18].

This study utilizes Ca II K observation data from the triple-channel solar telescope. The Ca II K full-disk telescope has a primary mirror aperture of 203 mm and is equipped with a 2048$\times$2048 FLI CCD at the backend. During this eclipse observation, the telescope achieved a temporal resolution of 10 minutes, with observation times spanning 14:31:09 to 17:21:18 local time (06:31:09-09:21:18 UT), essentially covering the entire eclipse period. The triple-channel solar telescope also participated in live eclipse outreach broadcasts throughout the event. To analyze meteorological element variations during the eclipse, this study employs data from the observatory' s standard meteorological station, including solar radiation, temperature, humidity, and pressure observations with a temporal resolution of 1 minute over a duration of 3.5 hours (06:00–09:30 UT).

At Shenzhen Astronomical Observatory, the eclipse times were: first contact at

06:37:41 UT, maximum eclipse at 08:08:38 UT, and last contact at 09:24:30 UT. Figure 2 [Figure 2: see original paper] displays the complete eclipse sequence using blue images connected by red arrows, representing Ca II K full-disk observations. The images show that at 06:31:09 UT, the solar disk was completely unobstructed (no observation was captured at the exact moment of first contact due to the temporal resolution). From 06:41:09 UT to 09:21:18 UT, the solar disk underwent a progressive increase in occultation followed by the Moon' s shadow moving away and the disk returning to its full circular appearance. Limited by the temporal resolution, the maximum occultation was observed at 08:11:14 UT, near the time of maximum eclipse. Using solar radiation variation as an example (shown in the middle panel of Figure 2), the horizontal axis represents universal time and the vertical axis represents solar radiation. Three vertical red dashed lines indicate the times of first contact, maximum eclipse, and last contact, while the vertical green dashed line marks the observation time of maximum solar disk occultation. During the eclipse, solar radiation decreased rapidly from first contact, reached a minimum near maximum eclipse, and then gradually increased. Quantitative analysis of meteorological elements and solar disk area variations is detailed in Section 3.

3.1 Analysis of Meteorological Elements During the Eclipse

To compare the magnitude of variation in solar radiation, temperature, relative humidity, and atmospheric pressure during the eclipse versus non-eclipse conditions, we selected observations from the same time periods on the days before and after the eclipse, as shown in Figure 3 [Figure 3: see original paper]. Three vertical dashed lines in each panel indicate the times of first contact, maximum eclipse, and last contact. The red solid line represents the variation characteristics of each meteorological element during the June 21 eclipse, while the blue dotted line and green dashed line show the corresponding variations during the same time periods on June 20 and 22, respectively.

Figure 3(a) displays solar radiation variations from 06:00 to 09:30 UT on June 20, 21, and 22. Since the selected time period falls in the afternoon, solar radiation generally shows a decreasing trend with a magnitude of approximately 550 $\mathrm{W \cdot m^{-2}}$. Without an eclipse, solar radiation follows a smooth, gradual decline. During the eclipse, solar radiation dropped sharply after first contact, reaching a minimum value of 52.60 $\mathrm{W \cdot m^{-2}}$ (it would reach 0 $\mathrm{W \cdot m^{-2}}$ during a total eclipse). To quantify the difference in decline rates between eclipse and non-eclipse conditions, we performed linear fits to the observations from 06:37 to 08:08 UT (first contact to maximum eclipse) on each of the three days. The fitted slopes k were -2.8, -9.1, and -2.6, respectively, indicating that during the first contact to maximum eclipse phase, solar radiation decreased at an average rate of 9.1 $\mathrm{W \cdot m^{-2}}$ per minute, compared to only 2.8 and 2.6 $\mathrm{W \cdot m^{-2}}$ per minute during the same period on non-eclipse days. Thus, the rate of change in solar radiation during the eclipse was approximately four times greater than on normal days. The purple arrow indicates the time of minimum solar radiation, which lagged 1.37 minutes behind the time of maximum eclipse due to transient cloud interference and the limited temporal resolution of radiation observations. After maximum eclipse, solar radiation began to increase as the occulted area of the solar disk decreased. Several major dips in solar radiation intensity during the recovery phase correspond to brief cloud passages.

Figure 3(b) shows temperature variations. From first contact to maximum eclipse, temperature decreased by approximately 2°C, reaching a minimum of 27.70°C. Linear fitting reveals that the rate of temperature change during the eclipse was nearly one order of magnitude higher than on non-eclipse days. During the first contact to maximum eclipse phase, temperature decreased at an average rate of 0.02°C per minute, compared to only 0.003–0.004°C per minute on non-eclipse days. Because temperature responds to solar radiation with a time lag, the temperature minimum (indicated by the purple arrow) occurred 6.37 minutes after maximum eclipse. Temperature remained at this minimum for 7 minutes before beginning to recover gradually.

Figure 3(c) displays relative humidity variations. From first contact to maximum eclipse, relative humidity increased by approximately 10%, reaching a maximum of 93.0%. Linear fitting shows that during this phase, relative humidity increased at an average rate of 0.09% per minute, compared to only 0.02% per minute on non-eclipse days. The humidity maximum (purple arrow) lagged 6.37 minutes behind maximum eclipse, persisting for 33 minutes before gradually decreasing. During this partial eclipse, atmospheric pressure showed minimal change, as illustrated in Figure 3(d). From first contact to maximum eclipse, pressure decreased by approximately 1 hPa, with a rate of change similar to non-eclipse days—about 0.008 hPa per minute. The pressure minimum (purple arrow) lagged 10.37 minutes behind maximum eclipse, persisting for 25 minutes before recovery began.

3.2 Correlation Between Solar Disk Relative Intensity and Meteorological Elements

The Ca II K full-disk chromospheric telescope observed nearly the entire eclipse process. The most direct eclipse observation is the progressive occultation of the solar disk. The correlation between variations in solar disk relative intensity and meteorological elements can be used to analyze the dependence of meteorological parameters on solar radiation. The solar images reveal that the limb appears darker than the center—a phenomenon known as limb darkening. The brighter region near the disk center indicates higher temperature because deeper layers of the Sun become visible toward the center. Figure 4 Figure 4: see original paper shows the solar image at 06:31:09 UT before eclipse onset, clearly demonstrating the brighter central region. The blue curve in Figure 4(b) represents the intensity profile along the white dashed line passing through the solar center in Figure 4(a). Limb darkening occurs when observing the Sun in both visible and infrared continua. Under the Eddington approximation for all wavelength integration, the intensity at each point on the solar disk relative to the center follows:

$$I(\mu) = I(0) \tag{1}$$

where $\mu = \cos\theta$, θ is the heliocentric angle, $I(\mu)$ is the intensity at each point on the disk, and $I(0)$ is the central intensity [19]. The black curve in Figure 4(b) shows the calculated relative solar intensity variation with distance from the disk center. To compute the relative solar intensity during the eclipse (using the 08:11:14 UT image as an example), we first determine the position of each point on the full disk. Through digital image processing and least-squares circle fitting, we can calculate the center coordinates and radius of the solar disk. In the 2048\$×\$2048 CCD, the disk center is located at (1019, 1111) with a radius of 917 pixels, with the fitted circle shown as white points in Figure 4(d). This allows determination of the exact position of each point within the circle. Based on brightness differences between visible and occulted regions, we can distinguish between the visible solar crescent and other areas. In Figure 4(e), blue points mark visible disk pixels and yellow points mark occulted regions. Substituting the coordinates and radius into equation (1) yields the relative intensity. Summing the intensities within the crescent and within the full disk circle and taking their ratio reveals a relative intensity of approximately 0.10 at this time.

To analyze the correlation between temporal variations in solar disk relative intensity and meteorological elements from first contact to last contact, we calculated the time series of disk intensity relative to the full-disk intensity, shown as red star points in Figure 5 [Figure 5: see original paper]. The relative intensity ranges from 0 to 1 (reaching 0 at totality). Clearly, relative intensity decreases with the diminishing visible disk from first contact to maximum eclipse, then increases with the growing visible disk from maximum eclipse to last contact, reaching a minimum at maximum eclipse and returning to 1 before and after the eclipse. The figure demonstrates strong correlations between meteorological elements and solar disk relative intensity. During the first contact to last contact phase, the Pearson correlation coefficients between relative intensity and meteorological elements are: R = 0.95 for solar radiation, R = 0.89 for temperature, R = -0.82 for relative humidity, and R = 0.75 for atmospheric pressure. These correlation coefficients are all close to 1 or -1, indicating strong relationships. Solar radiation intensity, representing the amount of solar energy received per unit time per unit area, directly correlates with the visible solar disk, yielding the strongest correlation. Other meteorological elements exhibit time lags relative to solar radiation, resulting in slightly weaker correlations.

4. Conclusions

A primary objective of atmospheric science observations is to identify correlations among various elements or to demonstrate their independence, though establishing these relationships is often challenging [14]. Solar eclipses provide a unique observational opportunity to precisely measure meteorological elements at multiple locations within the eclipse path using high-sensitivity instruments, enabling interpretation through data modeling [20]. This study presents variations in meteorological elements during the eclipse and their correlations with solar disk relative intensity. The main conclusions are:

(1) During the eclipse, solar radiation, temperature, and atmospheric pressure underwent decline-recovery processes, with temperature and pressure persisting at their minimum values for 7 minutes and 25 minutes, respectively, while solar radiation recovered immediately after reaching its minimum.

(2) Relative humidity exhibited a rise-persistence-decline pattern, with the maximum persisting for 33 minutes.

(3) The times of extreme values for solar radiation, temperature, relative humidity, and atmospheric pressure lagged behind the time of maximum eclipse by 1.37 minutes, 6.37 minutes, 6.37 minutes, and 10.37 minutes, respectively. These lags likely resulted from observational temporal resolution and local weather conditions.

(4) Strong correlations existed between solar disk relative intensity and meteorological elements during the eclipse, with Pearson correlation coefficients reaching 0.95, 0.89, -0.82, and 0.75—values close to 1 or -1.

These findings characterize meteorological element behavior and its relationship with visible solar disk variations at a specific location during the eclipse. Integrating observations from multiple sites and developing observational models will provide guidance for predicting meteorological conditions during future eclipses.

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