

Influence of Meteorological Parameters on Seasonal Ozone Variation over a Low Latitude Region of Rajasthan

Vimal Kumar Saraswat^{1,*} Pranjal Joshi²

Abstract

The seasonal variation of total column ozone (TCO) in Ajmer, Rajasthan, India, from 2005 to 2023 using meteorological parameters such earth skin temperature (TS) and relative humidity at 2m depth (RH_{2m}) is investigated in this study. This is satellite and instrument-based data taken from GIOVANNI. For the investigation, the data is averaged annually and then grouped into four seasons: winter, pre-monsoon, monsoon, and post-monsoon. There is notable seasonal variation in the total column ozone concentration. TCO levels ranged from 250.9 to 271.7DU in the winter, from 271.4 to 296.8DU in the pre-monsoon, from 271.8 to 285.7DU in the monsoon, and from 259.3 to 276.2DU in the post-monsoon season between 2005 and 2023. It exhibits clear peaks before the monsoon season and troughs during the winter. Pre-monsoon months (March, April, and May) see an average TCO peak value of 283.3DU, while winter months (December, January, and February) see an average TCO minimum value of 261.7DU. TCO levels decline after the monsoon. However, the pre-monsoon period has the lowest RH_{2m} , with 25.87%. However, TCO and RH_{2m} have a weakly positive correlation throughout the year. This correlation between TCO and RH_{2m} is 0.265 prior to the monsoon season. This is because the local microclimate (Pushkar Lake, Ajmer) may marginally increase RH_{2m} , but not enough to significantly affect TCO. Furthermore, as TS decreases, TCO also decreases. Just like in winter season, the lowest TCO (261.7DU) is caused by the lowest average TS (16.58 °C). however, all seasons show a moderately negative correlation between TCO and TS. This is because the direct impact of TCO on TS close to Pushkar Lake, Ajmer, is obscured by local microclimate effects, seasonal fluctuation, and time lags.

Keywords: Total column ozone (TCO), earth skin temperature (TS), relative humidity at 2m depth (RH_{2m}), seasonal variation, climate change

INTRODUCTION

The ozone layer is one of the most important components of Earth's atmosphere because it absorbs a major fraction of harmful ultraviolet radiation coming from the Sun [1]. Ozone is an essential constituent of the atmosphere that protects humans, animals, and vegetation from harmful UV radiation and also helps in maintaining the thermal structure of the atmosphere [2, 3]. Variations in total column ozone are strongly affected by atmospheric dynamics, meteorological parameters, and human activities. Understanding the relationship between ozone concentration and meteorological factors is essential for studying climate change and atmospheric behaviour [2].

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Stratospheric ozone is mainly formed through photochemical reactions between solar ultraviolet radiation and molecular oxygen in the upper atmosphere. It is well known that stratospheric ozone significantly influences various

environmental parameters, and a strong relationship exists between ozone concentration in the stratosphere and weather conditions in the troposphere [4, 5]. The maximum concentration of ozone is generally observed at an altitude of nearly 25 km above mean sea level. Total Column Ozone (TCO) represents the total amount of ozone present in both the troposphere and stratosphere over a particular region. Although ozone exists in low concentration, it plays an important role in atmospheric chemistry, weather conditions, and climate variability. Several regional and global studies have shown that ozone variability is closely related to meteorological conditions such as temperature, humidity, cloud cover, solar radiation, vertical air circulation, and water vapour content. These parameters along with wind speed and cloud cover significantly influence ozone formation, transport, and distribution processes [2, 6]. Seasonal and temporal changes in atmospheric pollutants are strongly influenced by meteorological conditions, and understanding these variations is important for evaluating environmental changes and their possible impacts on regional climate systems and human health [7]. Studies have also reported that meteorological conditions at different spatial and temporal scales strongly affect ozone concentration and variability [8].

Among different meteorological parameters, Earth skin temperature and relative humidity are particularly important because they influence atmospheric convection, moisture transport, and chemical reactions associated with ozone formation and destruction [2, 9]. In recent years, global surface temperatures are generally increasing which gave rise to many studies [10–12]. When Earth's surface temperature rises, the surface emits more infrared radiation, which contributes to greenhouse warming due to gases such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) [13–15]. Increased surface temperature also enhances evaporation and atmospheric convection, thereby affecting ozone distribution [13, 16].

Relative humidity is another significant meteorological parameter because it determines the moisture content of the atmosphere and influences cloud formation, precipitation, and atmospheric chemistry. Studying the combined behaviour of TCO, TS, and RH_{2m} helps in understanding regional climate behaviour and environmental changes [17]. Studies over the Indian region have shown that increased humidity, cloud cover, and convective activity during the monsoon season generally reduce ozone concentration over tropical and subtropical regions [2]. Understanding the relationship between ozone and meteorological parameters is important for studying atmospheric chemistry, climate variability, and environmental changes. Such studies are also useful for improving ozone prediction and understanding the influence of regional meteorological conditions on atmospheric processes [2, 8, 18].

Continuous urban growth, industrial activities, transportation, and increased energy consumption have contributed to rising atmospheric pollution levels in several regions of Rajasthan. In addition to particulate pollutants, gaseous pollutants such as ozone and nitrogen dioxide are also increasing, creating serious environmental and health-related concerns [6]. Rising concentrations of atmospheric pollutants over urban areas can significantly affect atmospheric chemistry, regional climate behaviour, and air quality conditions. Therefore, the study of ozone variability and its interaction with meteorological parameters has become increasingly important [7].

This study focuses on the low latitude region of Ajmer, Rajasthan, where industrial activities and climatic variability make the region environmentally important. The objective of the study is to investigate seasonal variations of total column ozone and determine its relationship with Earth skin temperature and relative humidity over the period 2005–2023.

STUDY AREA

The present study is conducted over Ajmer district, Rajasthan, India, located at coordinates 26.4499° N and 74.6399° E (Figure 1). Ajmer lies in the central part of Rajasthan and represents a low latitude semi-arid region with distinct seasonal climatic conditions. The district experiences extremely hot summers, moderate rainfall during the monsoon, chilly winters, and generally low humidity conditions.



Figure 1. Highlighted portion is geographic location of the research station Ajmer, Rajasthan, India (26.4499°N, 74.6399°E)

Ajmer was selected for this study because it has a large number of industries that significantly influence the regional environment. Industrial sectors in the region include textile, leather, rubber, plastic, coal products, beverage, and tobacco industries. According to the MSME Development Institute, Ajmer contains around 19,221 industrial units, among which approximately 17,663 are registered industries. The industrial growth contributes to atmospheric pollution and environmental stress in the region.

The region also faces severe water scarcity problems, with groundwater quality affected by high salinity, fluoride, and nitrate concentrations that often exceed WHO standards [19]. Nearly 90% of the annual rainfall occurs during the monsoon season, leading to strong seasonal variations in meteorological conditions. These characteristics make Ajmer an important region for studying ozone variability and meteorological interactions [20].

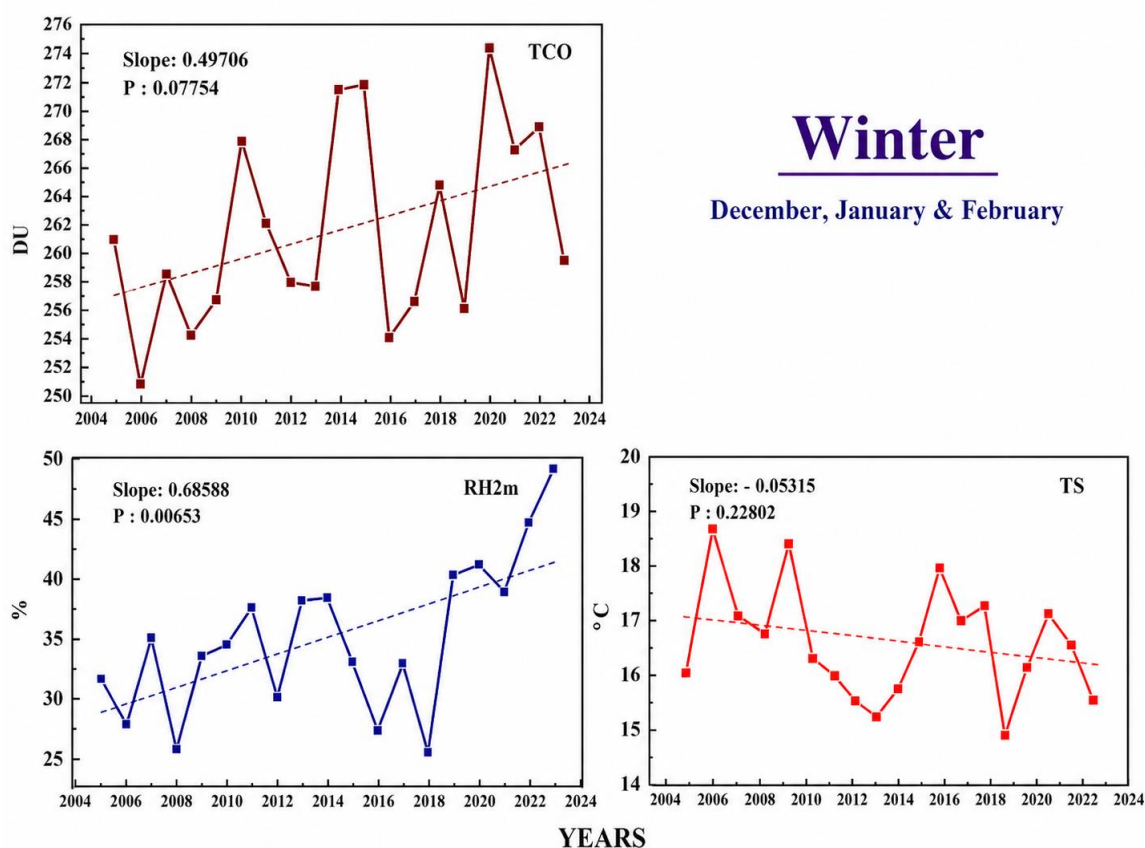
DATA SET AND METHODOLOGY

The datasets use for gathering for the investigation of the Ajmer station begins in 2005 and continues until 2023. This is satellite and instrument-based data taken from GIOVANNI. It allows to visualize the selected geophysical parameters [21]. Earth skin temperature data were obtained from the MERRA-2 atmospheric reanalysis model with an average spatial resolution of $0.5^{\circ} \times 0.625^{\circ}$ latitude–longitude. Total column ozone data were obtained from the Total Ozone Mapping Spectrometer (TOMS) and the relative humidity data at 2m depth (RH_{2m}) were collected from the AIRS (Atmospheric Infrared Sounder) instrument. The collected raw datasets were processed using a quantitative statistical approach. The raw data set consists of daily observations (30 observations per month), which are initially available in gridded format. The data is then modified and structured so that it can be used for additional research. The daily data is first converted to monthly average data, which is then transformed to an annual average. The data is then organised by seasons, which include winter, pre-monsoon, monsoon, and post-monsoon. The mean value is calculated as needed.

This process is used for all the parameters: Total Ozone Column, Earth Skin Temperature, and Relative Humidity at 2 m deep for the same station and time period. The aforementioned data is plotted against time and then attempt to fit them. Statistical tools are used to analysis the data. Linear regression and time series analysis techniques were employed to determine seasonal trends and correlations among TCO, TS, and RH_{2m}

Table 1. Seasonal classification used in the study.

S.N.	Season	Months
1	Winter	December – February
2	Pre – monsoon	March – May
3	Monsoon	June – August
4	Post – monsoon	September – November

**Figure 2.** Variation of TCO with RH_{2m} and TS during winter season from 2005 to 2023.

RESULTS AND DISCUSSION

The analysis of seasonal variations of TCO with Earth skin temperature and relative humidity produced several important observations.

Figure. 2 represents a variation in the annual mean of TCO with RH_{2m} and TS throughout the winter months of 2005 to 2023. The TCO data slope shows that, with a 92% confidence level, the yearly averaged values are rising linearly over the three months of the winter season i.e., from December to February month (Table 1). TCO was found to have a maximum value of 274.29DU in 2015 and a minimum value of 250.92DU in 2006. During the winter, the average TCO value is 261.75DU.

In a similar manner, the slope of RH_{2m} is likewise shown to be positive in winter season with a confidence level greater than 99%. RH_{2m} is found to reach its maximum in 2023 and its low in 2018, with values of 49.9% and 25.9%, respectively, whereas 35.31% is its mean value during the whole winter season. However, it is found that TS has a negative slope. It has a maximum value of 14.94°C in 2006 and a lowest value of 18.76°C in 2019, while its mean value is 16.58°C. The correlation between TCO and RH_{2m} is moderately positive i.e., 0.4 while TCO and TS are negatively correlated with value -0.3 (Figure 3).

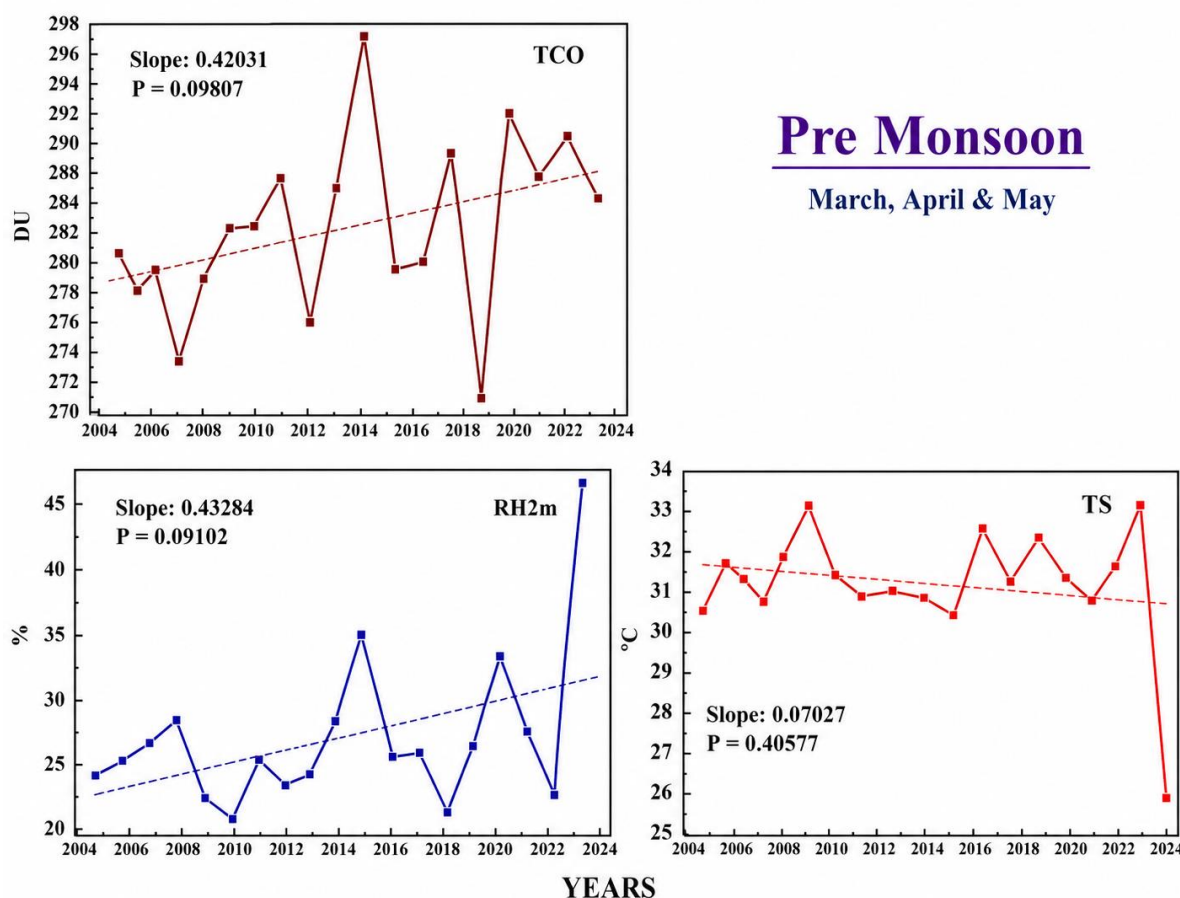


Figure 3. Variation of TCO with RH_{2m} and TS during pre - monsoon season from 2005 to 2023.

The variations in the annually averaged data of TCO, RH_{2m} and TS during pre-monsoon season from 2005 to 2023 is plotted in Figure 3. TCO exhibits a linear increase throughout this season, with a confidence level more than 90%. The highest and lowest values of TCO during the pre-monsoon were recorded in 2015 and 2019, respectively. These are 296.89DU and 271.42DU, respectively. Its mean from 2003 to 2023 during the pre-monsoon season is 283.39DU. When it comes to RH_{2m}, a similar pattern is seen. During this time, the slope has increased with a 91% confidence level. RH_{2m} ranges from 19.68% to 46.25%; its lowest and highest values were noted in 2010 and 2023, respectively, whereas its mean value during the season is 25.87%. On contrary the value of TS decreases from 2005 to 2023 during pre-monsoon period. Its maximum value was measured in 2022, while minimum was in 2023 which are 33°C and 25°C respectively. During this season its average value is 30.86°C. TCO and TS have a weakly negative correlation of -0.1, but TCO and RH_{2m} have a weakly positive correlation of 0.3.

Figure 4 represents the variations in annually averaged data of TCO from 2005 to 2023 during the monsoon season (June, July, and August). With a 97% confidence level, the TCO slope increases linearly over time. TCO had a high value of 285.78DU in 2015 and a low value of 271.82DU in 2007. However, its average value for the entire season is 278.10DU. Additionally, RH_{2m} has a positive slope throughout the monsoon season from 2003 to 2023 with a confidence level greater than 98%. In the months of June to August, its average value is 61.24%. Conversely, the graph's slope between TS and corresponding years is declining. However, the confidence level is over 95%. TS ranges from 29.51°C to 33.60°C during the monsoon, whereas 32.35°C is its mean value. TCO and TS have a slight negative

correlation, but TCO and RH_{2m} have a weak positive relationship with values of -0.20 and 0.10, respectively.

Figure 5 illustrates how TCO varied in relation to TS and RH_{2m} throughout the post-monsoon season between 2005 and 2023. With a confidence level greater than 98%, the positive slope of TCO indicates a linear increment in the yearly averaged values. TCO peaks in 2023 and reaches its lowest point in 2005. The corresponding numbers are 276.23DU and 259.31DU. The average TCO value from 2005 to 2023 is 265.54 during the post-monsoon months. RH_{2m} has a similar pattern and its value increases as the number of years grows; its slope has a positive value with a 99% confidence level. The range of RH_{2m} is 37.62% to 65.54%. Between 2005 and 2023, its yearly mean value was 51.28%. In contrast, TS has a negative slope, meaning that between 2005 and 2023, its value continues to decline. In the post-monsoon season of 2012 and 2023, TS displayed minimum and maximum values of 22.30°C and 27.30°C, respectively, whereas its annual mean value throughout these years has been 25.11°C.

The graphs depicting winter, pre-monsoon, monsoon, and post-monsoon seasons, along with correlation values from 2005 to 2023, indicate that TCO rises as TS values decline, and TCO also increases with rising RH_{2m} values (Table 2).

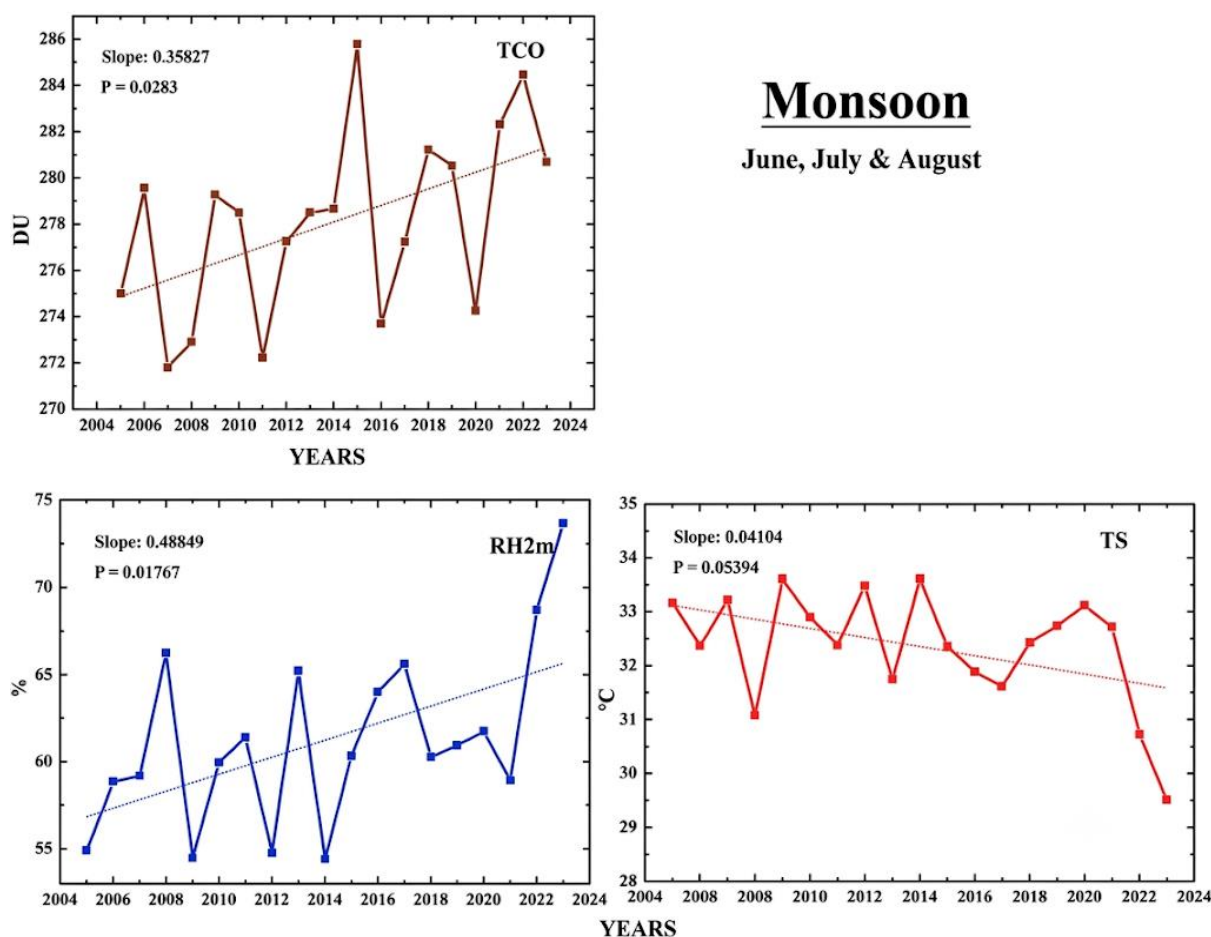


Figure 4. Variation of TCO with RH_{2m} and TS during monsoon season from 2005 to 2023.

Table 2. Correlations between TCO and TS, TCO and RH_{2m}

Correlation Coefficients		
Seasons	TCO vs TS	TCO vs RH _{2m}
Winter	-0.30	0.40
Pre-monsoon	-0.07	0.26

Monsoon	-0.20	0.10
Post-monsoon	0.30	0.07

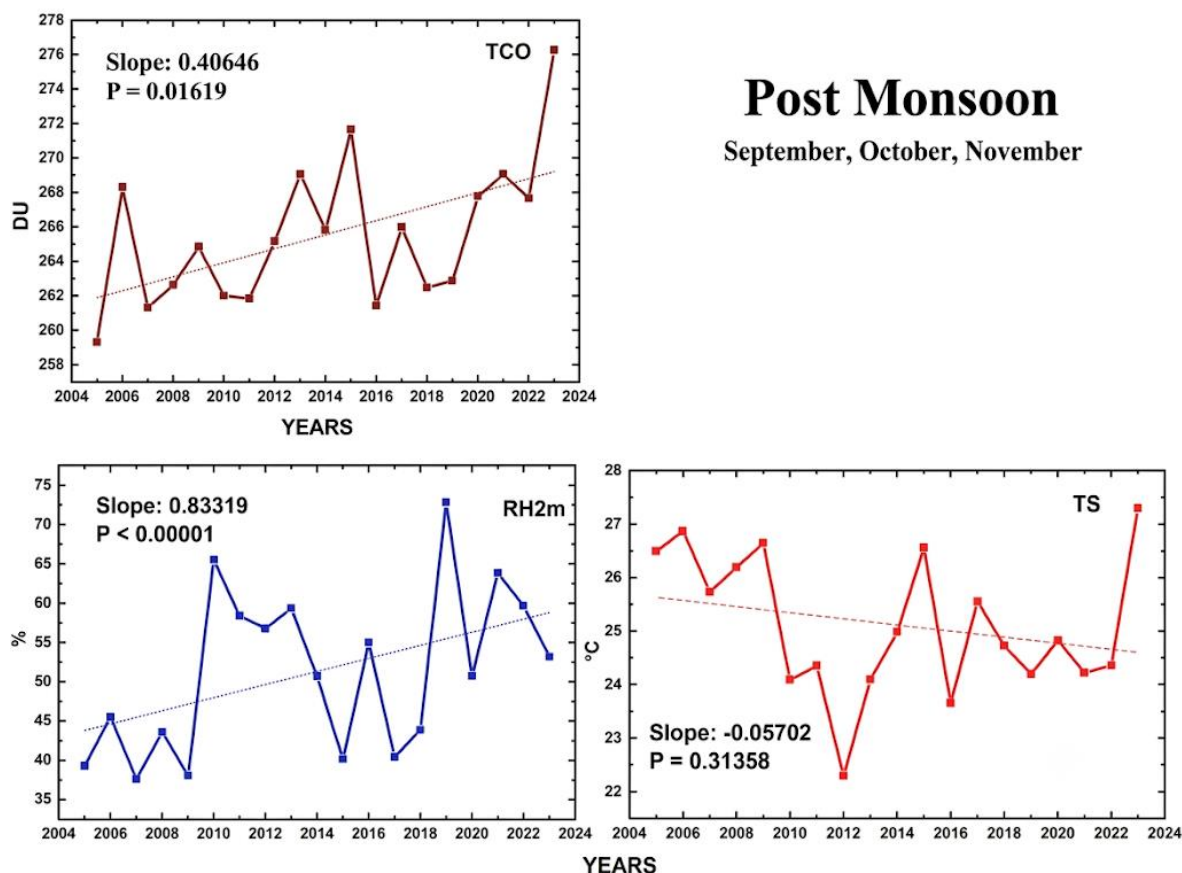


Figure 5. Variation of TCO with RH_{2m} and TS during post - monsoon season from 2005 to 2023.

Relationship between TCO and TS

The study observed a moderate negative correlation between TCO and TS during the winter season with a correlation coefficient of approximately 0.30. During the monsoon season, a negative correlation of around 0.20 was also observed. In the pre-monsoon season, the correlation was weakly negative. However, the post-monsoon season exhibited a weak positive correlation between TCO and TS.

The decrease in ozone concentration with increasing surface temperature can be explained through atmospheric convection and ozone destruction processes. When surface temperature increases, warm air near the ground rises upward due to convection. This rising air contains less ozone compared to the ozone – rich air present in the stratosphere. This ozone-poor air mixes with ozone-rich stratospheric air, reducing total column ozone.

Furthermore, higher temperatures increase atmospheric water vapor content, enhancing ozone-destroying chemical reactions, which further reduces the ozone content. Changes in surface temperature also modify atmospheric circulation patterns, redistributing ozone vertically and horizontally, which contributes to variations in total column ozone [22].

Relation between TCO and RH_{2m}

Relative humidity showed a moderate positive correlation with TCO during winter, while correlations in pre-monsoon, monsoon, and post-monsoon seasons were weak or insignificant [22]. The results indicate that RH_{2m} has mainly an indirect influence on TCO through its interaction with temperature.

Relative humidity generally exhibits a negative relationship with earth skin temperature (TS). Therefore, when RH_{2m} increases, earth skin temperature (TS) tends to decrease, indirectly contributing to higher ozone values.

Seasonal Variation of TCO

The pre-monsoon season exhibited the highest mean TCO value of approximately 283.40DU, whereas the winter season showed the lowest mean TCO value of around 261.76DU.

The higher TCO values during pre-monsoon may be attributed to clearer skies and stronger ultraviolet radiation, which enhance photochemical ozone production. In contrast, winter conditions often include cloud cover and weaker ultraviolet intensity, leading to lower ozone formation.

CONCLUSION

The present study investigated the seasonal variation of total column ozone and its relationship with Earth skin temperature and relative humidity over Ajmer, Rajasthan, during the period 2005–2023. TCO exhibit significant seasonal variability over the study region. The findings suggest that surface temperature (TS) is a stronger controlling parameter for seasonal ozone variation than relative humidity at 2m depth (RH_{2m}). An increase in Earth's skin temperature (TS) leads to enhanced convection, atmospheric expansion and faster ozone loss process, resulting in a decrease in total column. RH_{2m} itself has a weak direct correlation with TCO, the study supports the idea that understanding meteorological influences on TCO requires considering intermediate factors like temperature. The study highlights the importance of meteorological influences in understanding regional climate change and atmospheric chemistry over industrial low latitude regions.

Overall, the results provide useful insight into regional atmospheric behaviour and may contribute to future climate and environmental studies related to ozone dynamics and air quality assessment.

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