

# Variation in Ozone at Night in Barrow, Alaska, during Different seasons, and its Relationship to Methane at Different Pressures

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## Abstract

The study is focus on the investigation of the night-time seasonal variability of ozone ( $O_3$ ) at Barrow, Alaska, and also it examines its association with methane ( $CH_4$ ) concentrations at different pressure levels along with solar flux variations on the basis of eighteen years (2003–2020) of observational data, including ground-based ozone measurements, satellite-derived methane data at 100, 200, 300, 400, and 500 hPa, and solar flux ( $F_{10.7}$ ) values. For finding the outcomes, monthly mean night-time data were computed and grouped into four seasons-winter, spring, summer, and autumn. The results indicate a consistent linear increase in methane concentrations across all seasons, with minimum growth observed at 100 hPa and maximum trends generally around 400 hPa. Methane trends exhibited strong statistical significance (above 95%) throughout the study period, suggesting limited seasonal influence on its increasing pattern. In contrast, ozone and solar flux predominantly showed decreasing trends during most seasons. Ozone exhibited notable seasonal variability, with comparatively stronger positive correlation with solar flux during the autumn season. The correlation analysis revealed that the solar flux and methane are generally negatively associated, while the relationship between the solar flux and ozone varies with seasons, with the highest positive correlation observed in October. Overall findings highlight the distinct seasonal behavior in ozone and methane dynamics at high latitudes and emphasize the importance of long-term night-time observations or understanding atmospheric chemistry, greenhouse gas interactions, and their implications for climate variability in the Arctic region.

**Keywords:** Ozone variability, Methane trends, Solar flux, Seasonal variation, Arctic atmosphere

## INTRODUCTION

Climate change is severely affecting human lives [1]. Changes in climate are classified as different seasons of the year [2]. A year is classified into four seasons: autumn, spring, summer, and winter [3]. The temperature of the atmosphere varies from season to season and this temperature is repeated by the atmosphere after each year, but the variation depends on many factors. The concentration of ozone in the atmosphere varies according to the season. Therefore, the concentration of ozone in the atmosphere also changes in different seasons. In India, a year is divided into four different seasons, which are autumn, spring, summer and winter. According to Jain [4], when the concentration of ozone was

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Received Date: March 03, 2026  
Accepted Date: March 17, 2026  
Published Date: April 14, 2026

**Citation:** Vimal Kumar Saraswat. Variation in Ozone at Night in Barrow, Alaska, during Different seasons, and its Relationship to Methane at Different Pressures. International Journal of Atmosphere. 2026; 3(1): 44–53p.

measured in New Delhi, its concentration was observed maximum in summer and autumn seasons and lowest in monsoon and winter seasons. It has been observed that variation in climate affect the Earth's atmosphere badly and therefore have serious effects on human lives [5]. The earth's lifespan is getting shorter day by day due to human pollution [6]. In recent years, global surface temperatures have generally seen an increase that has led to many studies [7–9].

After carbon dioxide, methane and ozone are also two most important gases involved in global

warming [10]. For the past few decades, developed and developing countries have been competing to outpace each other, which has given rise to the Industrial Revolution. The concentrations of both these gases have increased significantly during the course of Industrial Age. The studies on the seasonal variation of ozone were conducted by many scientists [11–13]. Along this revolution, earth rotates on its axis in a slightly tilted position of 23.5 degree. This inclination causes our seasons because due to this rotation some part of the earth at some time and some part at some other time is towards the sun, due to which sunlight reaches different parts of the earth at different times. That's why different countries have different seasons at different time.

One study found that daytime ozone concentrations in the mesosphere are higher after sunrise than before sunset. At night after sunset, ozone continued to increase at levels above 60 km, while decreasing below this level, and no diurnal variations were observed below 45 km [14]. Studying daily variation in ozone concentrations and other gases is important, not only to improve our understanding of the processes involved but also to improve the estimation of long-term trends based on measurements from different locations at different times of the day [15, 16].

The relationship of ozone and methane is also important for the analysis of those effects and to understand the measures to control them [17, 18]. It has been observed that methane produces more heat per unit mass than carbon dioxide, but its lifetime is much shorter [19].

On the contrary of carbon dioxide, methane is directly related with tropospheric ozone [20]. Reducing methane emissions would be an effective way to reduce global warming because methane is a potent greenhouse gas [21]. The tropospheric ozone can be managed by reducing methane emissions [22, 23]. Dalsoren in his research study concluded that the reduction of global mean tropospheric methane is likely to contribute to the reduction of recently observed levels in global mean methane concentration [24].

The seasonal variability of ozone is a topic of interest in present time [25, 26]. The climate is affected by methane both direct and indirect way [27, 28]. Methane is released during oil and natural gas production and 85% of it is emitted during the production, collection, and processing stages of oil and natural gas production [29, 30].

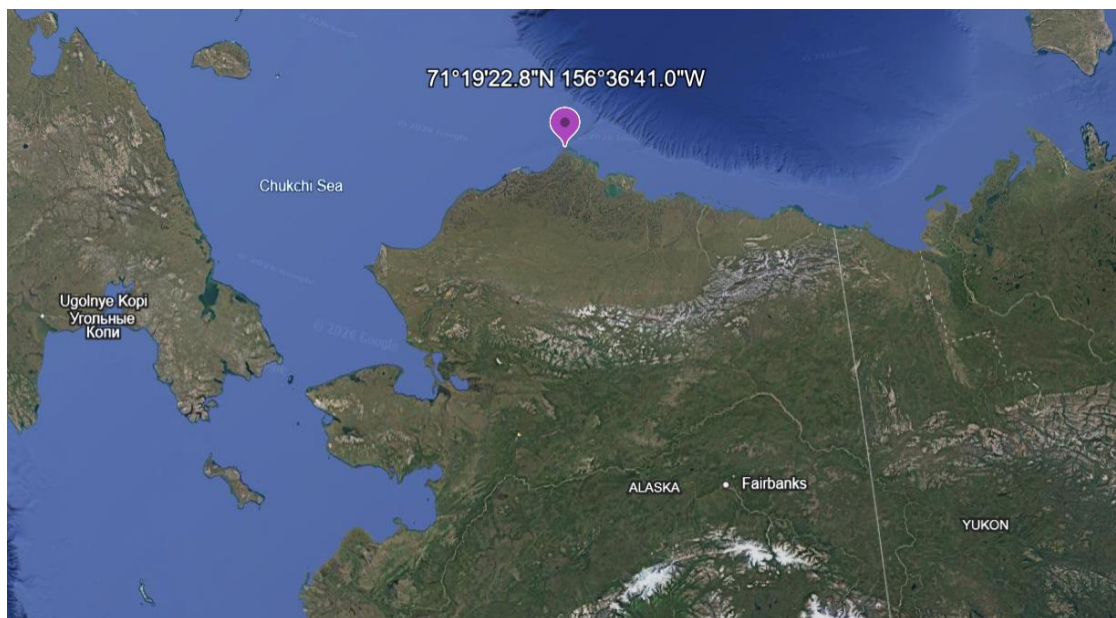
The present paper is focused on the analyzation of the night time variation of methane, ozone, and solar flux data. Several studies have been conducted to study about variations in ozone data in the presence of sunlight and in the absence of sunlight, i.e., in daytime hours and night hours [31].

In contrast, another study concluded that night-time ozone concentrations were mostly influenced by nitrogen oxides, with meteorological variables playing no significant role [32]. On some occasions like thunder-storms, the night-time increment in surface ozone concentrations have been observed [33].

### Data Set and Site Description

The primary objective of this study is to investigate the relationship among solar flux, ozone, and methane. To achieve this, a long-term and reliable dataset from a representative monitoring station was required. Therefore, the American station Barrow, Alaska, which is presently known as Utqiagvik, Alaska is selected. The surface ozone data for this station were obtained from the website of the NOAA Earth System Research Laboratory (ESRL).

The Global Monitoring Division of ESRL has been conducting surface ozone measurements at several global locations since 1973, including Barrow, Alaska, and Mauna Loa, Hawaii. The Barrow Atmospheric Baseline Observatory (BRW), established in 1973, is situated at 71.3230°N latitude and 156.6114°W longitude in the northernmost region of the United States as shown in Figure 1.



Source: Google Earth imagery, accessed March 2026

**Figure 1:** Geographic location of the barrow atmospheric baseline observatory (BRW) ( $71.3230^{\circ}\text{N}$ ,  $156.6114^{\circ}\text{W}$ ) in northern Alaska, USA.

This observatory is recognized as the longest continuously operating atmospheric observatory in the Arctic and provides highly reliable long-term atmospheric measurements for the region. Methane data used in this analysis were retrieved from the NASA Goddard Earth Sciences Data and Information Services Center through the Giovanni online platform. Giovanni is an interactive web-based tool that enables direct access to NASA satellite-derived Earth science datasets. For consistency, methane time-series, area-averaged data corresponding to the same Barrow station were selected. To compare ozone and methane concentrations at different atmospheric pressure levels, methane data were extracted at five pressure levels: 100, 200, 300, 400, and 500 hPa, covering a study period of eighteen years from 2003 to 2020.

Solar radio flux (F10.7) data were obtained from the Laboratory for Atmospheric and Space Physics (LASP) data archive portal.

## METHODOLOGY

For the period 2003–2020, surface ozone data were obtained from the previously mentioned database. The dataset included continuous hourly observations (24 measurements per day), which allowed a detailed comparison with other atmospheric parameters. For the same station and time span, methane concentrations at different pressure levels and corresponding solar flux values were also retrieved to ensure temporal consistency in the analysis.

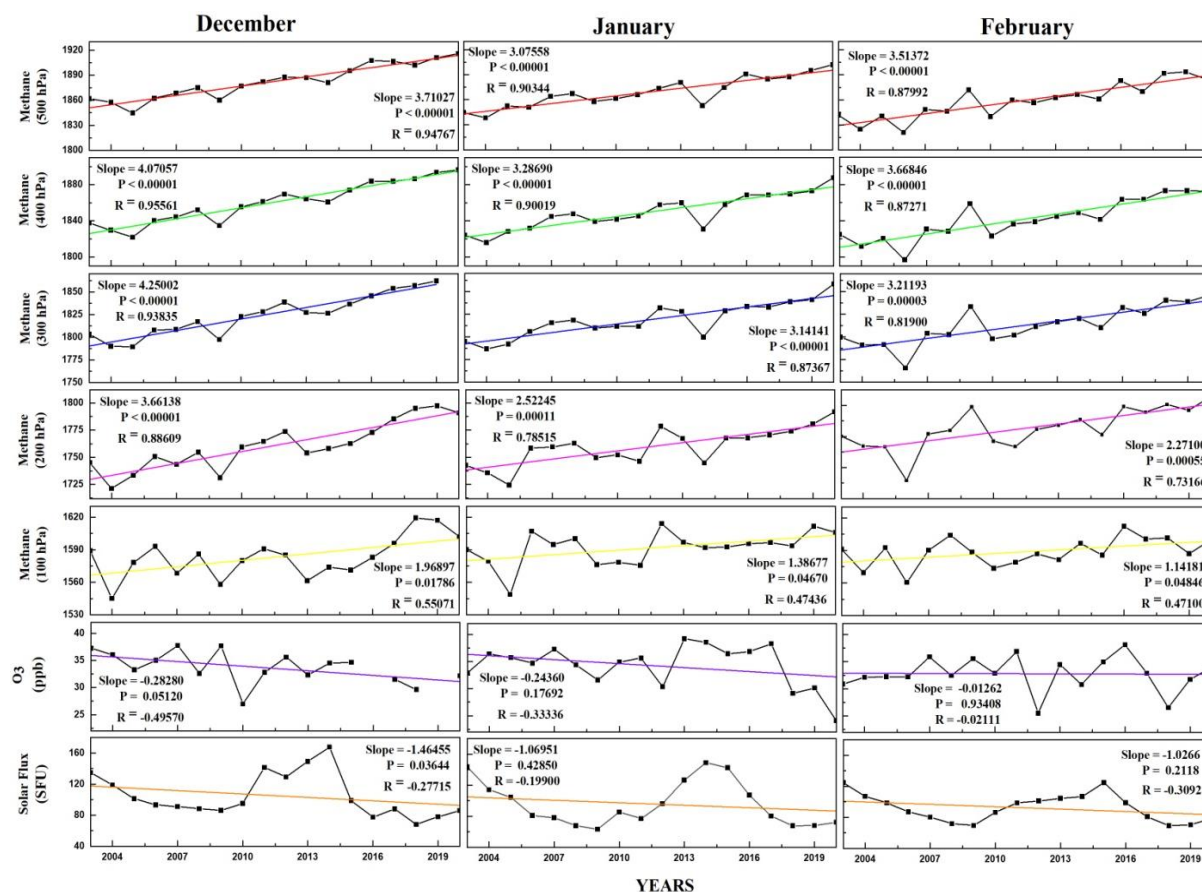
The raw datasets were initially available in gridded format. These data were reorganized and processed into a structured form suitable for analysis. The hourly values were first compiled month-wise for each year. Since the present research focuses specifically on nighttime seasonal variability, only the last 12 hourly observations of each day were extracted to represent nocturnal conditions. Subsequently, monthly mean values were computed for each year, resulting in twelve representative values per parameter annually.

This procedure was applied to all seven variables considered in the study: surface ozone ( $\text{O}_3$ ), methane ( $\text{CH}_4$ ) at 100, 200, 300, 400, and 500 hPa pressure levels, and solar flux (F10.7). The calculated monthly averages were then plotted against time (years) to clearly examine long-term trends and interannual variations in all variables.

The graphical outcomes were systematically analyzed, and the corresponding results were compiled into tabular form for clarity. Furthermore, to investigate seasonal behavior, the dataset was categorized into four standard seasons-winter, spring, summer, and autumn. The seasonal distributions and variations are illustrated in Figures 2, 3, 4, and 5.

### RESULTS AND DISCUSSION

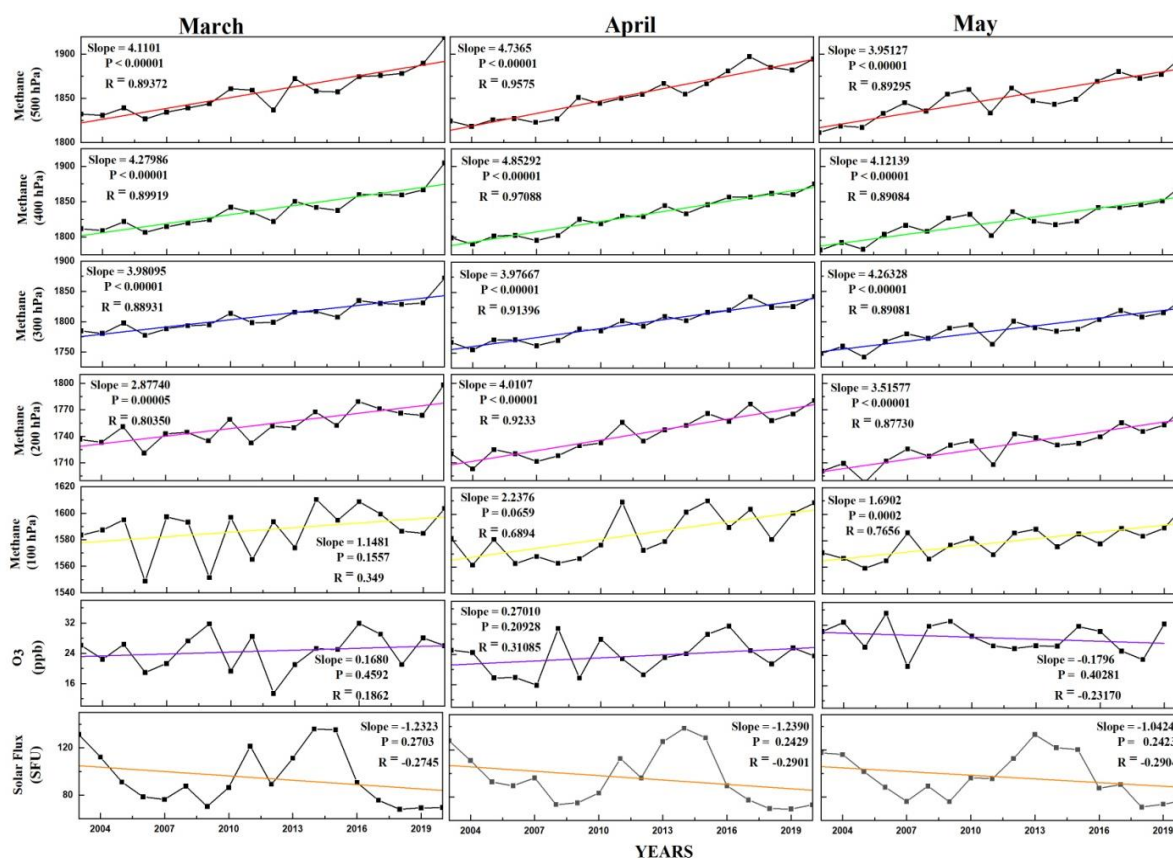
In Figure 2, the variation in the monthly mean value of ozone and methane during night time with the years covering a period of 18 years from 2003 to 2020 for the winter season is shown. From the slope of the corresponding methane data, it is observed that for every set of different pressures, the values are increasing linearly with good significance level above 95% in every three months of winter season i.e., from December to February month, also in December the highest increase in methane occurs at 300 hPa pressure, while the lowest increase occurs at 100 hPa pressure, with corresponding values of 4.250 and 1.968, respectively. Similarly, in the month of January, the highest increase is 3.286 for methane at 400 hPa pressure and the lowest increase is 1.386 for methane at 100 hPa pressure. In the same way for February month the maximum and minimum values are found to be 3.668 and 1.141 corresponding to 400 and 100 hPa pressure. Hence at 100 hPa, the minimum increment for each three months is observed for methane. The same figure also shows the variation in solar flux against the year during the winter season, and observations show that the ozone and the solar flux are decreasing in all three months of the winter season and hence their negative slopes are observed. In contrast to solar flux, which has a minimum slope of 1.4645 in December with a significance level over 90%, ozone exhibits a minimum slope of  $-0.282$  in December with a good significance level above 90% and a maximum slope of  $0.012$  in February with an average significance above 60%.



**Figure 2.** Night hours seasonal data variation of Ozone ( $O_3$ ), Solar flux and  $CH_4$  at 100 hPa, 200 hPa, 300 hPa, 400 hPa and 500 hPa pressures for three months December, January and February of winter season

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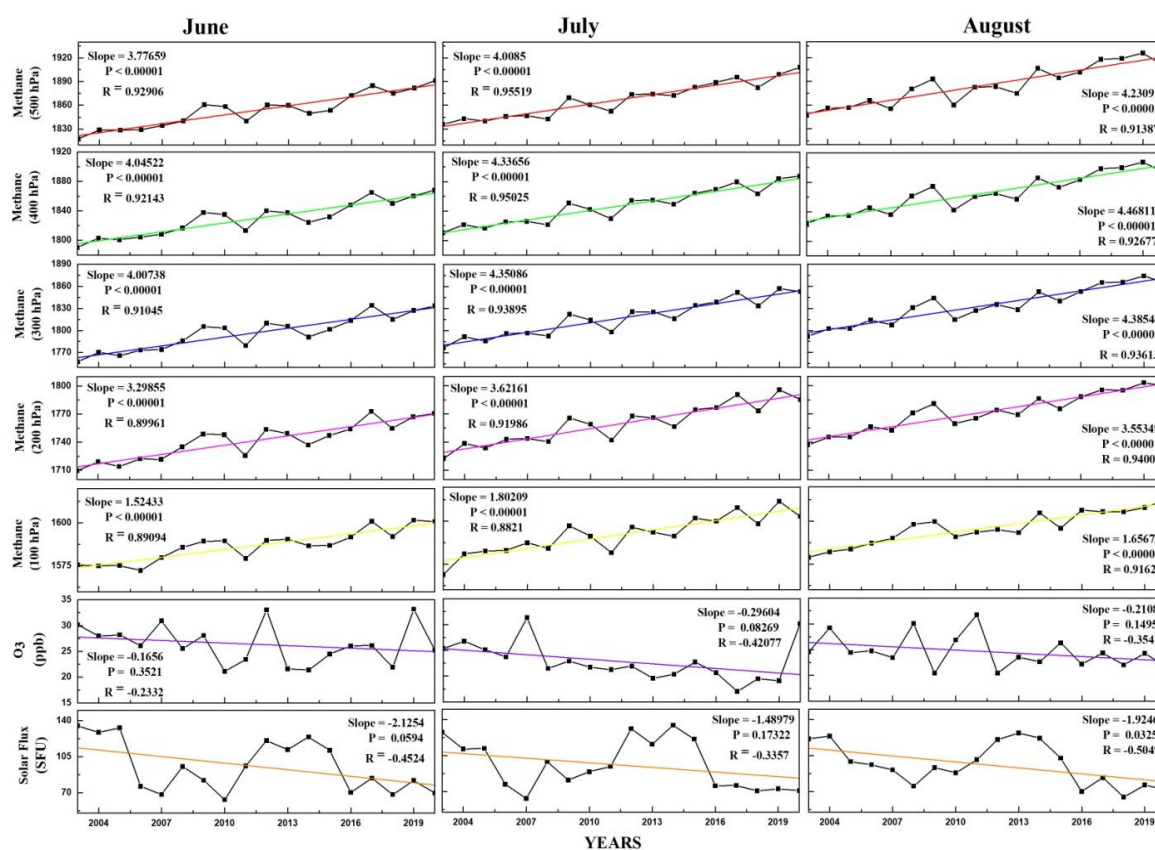
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**Figure 3.** Night hours seasonal data variation of Ozone (O<sub>3</sub>), Solar flux and CH<sub>4</sub> at 100 hPa, 200 hPa, 300 hPa, 400 hPa and 500 hPa pressures for three months March, April and May of *Spring* season.

The fluctuations in the aforementioned data during the spring season, which includes the months of March, April, and May, are depicted in Figure 3. During this season, methane exhibits a linear increase at all pressure levels with a significance level greater than 95% for each of the three months. In March, the maximum slope of 4.279 is observed for methane at 400 hPa pressure, while the minimum slope of 1.148 occurs at 100 hPa pressure. Similarly for April month the maximum and minimum rate of increment is 4.852 and 2.237 which is for methane at 400 hPa pressure and at 100 hPa pressure respectively. During the month of May the maximum slope is of 4.263 which is for methane at 300 hPa, and minimum slope is 1.690 at 100 hPa pressure. Subsequent analysis shows that the solar flux values are declining with a negative slope in all three of the spring season's months, and the ozone data slope is positive in March and April but negative in May. While solar flux has a minimum value of -1.239 in April with a significance level between 75 and 80%, also ozone has a minimum value of -0.179 in May and a maximum value of 0.2701 in April with a significance level above 75%.

The corresponding data for the summer season (June, July and August) is shown in Figure 4. According to the associated methane data, values throughout the summer season are increasing linearly with a good significance of more than 95% in each of the season's three months. In June month the maximum slope is 4.045, which is for methane at 400 hPa pressure and minimum slope is 1.524 for methane at 100 hPa pressure. Similarly in July month the maximum slope is 4.336 for methane at 400 hPa pressure and minimum slope is 1.802, which is for methane at 100 hPa pressure. August month shows the maximum slope of 4.468, and minimum slope of 1.656 for methane at 400 hPa and 100 hPa pressure respectively. On looking the ozone variation, it is found that the slope is negative in all three summer months, and its significance is more than 80% in the month of June. The variation of the solar flux is also negative for all three months with maximum slope -1.489 in July month with significance above 80% and minimum slope -2.125 in June month with good significance level above 90%.

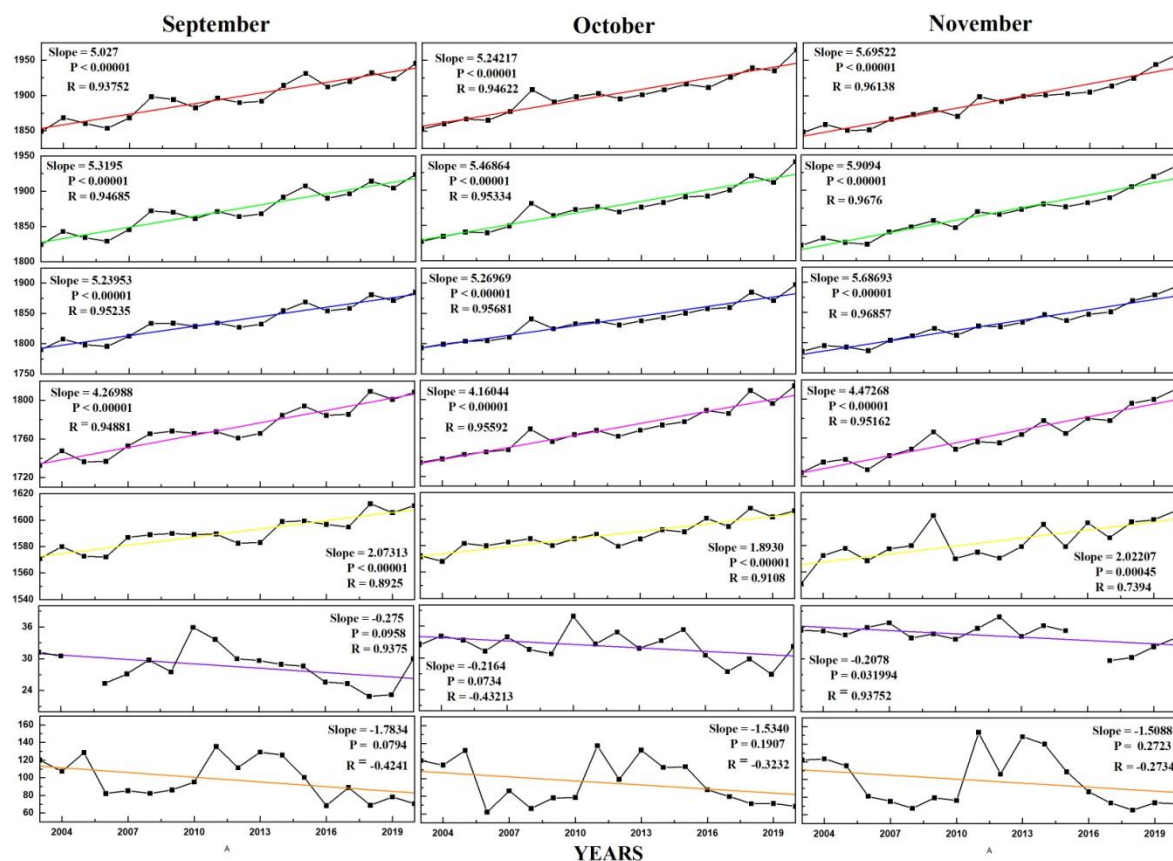


**Figure 4.** Night hours seasonal data variation of Ozone ( $O_3$ ), Solar flux and  $CH_4$  at 100 hPa, 200 hPa, 300 hPa, 400 hPa and 500 hPa pressures for three months June, July and August of *Summer* season.

Figure 5 represents the variation of ozone, methane and solar flux in the autumn season. Analysis of the methane time-series during the autumn season (September, October, and November) indicates a consistent upward linear trend at all examined pressure levels, with statistical significance exceeding the 95% confidence level. In September, the strongest positive trend in methane concentration is observed at 400 hPa, with a slope value of 5.319, whereas the weakest increase occurs at 100 hPa, with a slope of 2.073. A similar pattern is evident in October, where methane again shows its maximum rate of increase at 400 hPa (slope = 5.468) and the minimum at 100 hPa (slope = 1.893). In November, the highest and lowest slope values are 5.909 at 400 hPa and 2.022 at 100 hPa, respectively. These results demonstrate that methane concentrations exhibit stronger increasing trends at mid-tropospheric levels compared to lower pressure levels during the autumn months.

In contrast to methane, ozone displays a negative slope throughout all three months of the season, indicating a decreasing tendency. Similarly, solar flux values also show declining trends during September, October, and November. The most pronounced decrease in solar flux occurs in November, with a slope of  $-1.508$  and a significance level above 70%, while the largest negative slope is recorded in September ( $-1.783$ ) with a higher statistical significance exceeding 90%.

According to Table 1, there is a negative association between ozone and solar flux in February, March, and April months, and a positive correlation is found in other month of the year. The months of October and August have the highest and lowest positive correlation coefficients, respectively, at 0.530 and 0.111. In every season and at all pressure levels, there is a negative correlation between methane and solar flux, with a significance level exceeding 90% in the months of August, September, and October. At a good significance level of over 95% throughout the season, the correlation between solar flux and ozone is also found to be positive in the autumn, peaking at 0.530 in October and falling to 0.341 in November.



**Figure 5.** Night hours seasonal data variation of Ozone ( $O_3$ ), Solar flux and  $CH_4$  at 100 hPa, 200 hPa, 300 hPa, 400 hPa and 500 hPa pressures for three months September, October and November of Autumn season

**Table 1.** Correlation between the solar flux and ozone, and solar flux and methane at different pressures for different months.

Correlation Between						
	<i>solar flux and <math>O_3</math></i>	<i>solar flux and <math>CH_4</math> (100 hPa)</i>	<i>solar flux and <math>CH_4</math> (200 hPa)</i>	<i>solar flux and <math>CH_4</math> (300 hPa)</i>	<i>solar flux and <math>CH_4</math> (400 hPa)</i>	<i>solar flux and <math>CH_4</math> (500 hPa)</i>
<b>January</b>	0.304	-0.107	-0.272	-0.297	-0.289	-0.277
<b>February</b>	-0.034	-0.308	-0.384	-0.342	-0.309	-0.285
<b>March</b>	-0.072	0.191	-0.200	-0.304	-0.328	-0.339
<b>April</b>	-0.037	0.206	-0.155	-0.277	-0.319	-0.343
<b>May</b>	0.155	-0.307	-0.401	-0.453	-0.484	-0.502
<b>June</b>	0.282	-0.457	-0.501	-0.517	-0.530	-0.544
<b>July</b>	0.203	-0.402	-0.395	-0.375	-0.353	-0.327
<b>August</b>	0.111	-0.615	-0.566	-0.553	-0.541	-0.525
<b>September</b>	0.398	-0.537	-0.488	-0.465	-0.443	-0.419
<b>October</b>	0.530	-0.405	-0.425	-0.419	-0.416	-0.413
<b>November</b>	0.341	-0.368	-0.303	-0.266	-0.244	-0.226
<b>December</b>	0.373	-0.426	-0.293	-0.247	-0.255	-0.277

## CONCLUSION

After analyzing the graphical results, it is observed that for methane concentrations across all seasons, the lowest slope values occur at the minimum pressure level of 100 hPa. The slope gradually increases

with rising pressure levels up to 400 hPa; however, at 500 hPa, a declining trend is evident. This indicates that the slope increases with pressure height only up to a certain threshold, beyond which it begins to decrease. Additionally, the seasonal slopes exhibit a generally linear increasing pattern, suggesting that seasonal weather variations and temperature changes do not significantly influence the overall methane distribution pattern. Moreover, the statistical analysis demonstrates strong significance for methane data across all seasons, with confidence levels exceeding 95%. Over the 18-year study period, the analysis further reveals a strong positive correlation between ozone and solar flux during the autumn season, with a significance level above 95%. Similarly, methane also shows a notable correlation with solar flux in autumn, with statistical significance greater than 90%.

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