

Variability of Total Column Ozone with Solar Activity Features at Northern and Eastern Regions of India

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Abstract A statistical study of Total Column Ozone (TCO) with Different solar activity features (DSAF), viz. sunspot number, solar flare, solar active prominences for a Northern station Shimla (31°10'N, 77°17'E) and an Eastern station Imphal (24°82'N, 93°94'E) of India is presented using 11 years (2004-2016) of data. In this study we have compared the trends in TCO with DSAF annually as well as for seasonal months. Our study shows a negative correlation between TCO and DSAF. A negative correlation suggests that there is decrease in Ozone concentration during the given time period with solar activity.

Keywords: total column ozone, sunspot number, solar flare, solar active prominences

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1. Introduction

The Sun is a nearly perfect sphere of hot plasma, where internal convective motions generate an unusual magnetic field as a result of the dynamo process. This unusual, complicated and varying magnetic field leads to, several magnetic phenomena like Sunspot number (SN), Solar flares (SF), Solar Active Prominences (SAP) etc. These phenomena are collectively known as Different Solar Activity Features (DSAF). Ozone is a highly reactive ingredient of the Earth's atmosphere produced from oxygen activated by the sunlight. Ozone plays an important role in various stratospheric and troposphere activities, and also affects our space weather conditions. Majority of the ozone concentration (about 90%) is found in the stratosphere, a region that begins about 10-16 km above earth surface and extends up to about 50 km altitude. Maximum ozone concentration found in the lower stratosphere, is commonly known as the "ozone layer". The remaining ozone concentration (about 10%) is found in troposphere. Ozone layer absorbs 93-99% of the sun's high frequency ultraviolet radiation that otherwise has potential to damage life on Earth. The quantity of Ozone in the atmosphere is measured in terms of Dobson unit (DU). DU is a unit of measurement of the amount of a trace gas in a vertical column through the Earth's atmosphere. One Dobson unit is equal to the number of ozone molecules needed to create a pure layer of ozone 0.01 millimeters thick.

Many studies have been attempted to explain the relationship between Total Column Ozone (TCO) and Different Solar Activity Features (DSAF) [1-12]. A highly negative correlation is found between the relative sunspot

number and the worldwide average of TCO during 1933-1959 [1]. Reference [3] studied the phase relationship between sunspot number and TCO, which indicates that they vary in same phase and TCO decreases with decrease in sunspot number during 1970-1974. Reference [4] presented observational evidence for relation between atmospheric ozone amount and sunspot numbers and found a zero-lag correlation of 0.48. They concluded that as sunspot number increases, there is a relative increase in solar ultraviolet radiations. Trend of TCO over twelve Indian stations during period 1979-2010 has been studied by [13]. They stated that systematic variation of TCO is noted to have maximum value during May and minimum value during January and also concluded that TCO over Delhi shows highest depletion which may be due to transport of aerosol from nearby desert.

Reference [14] made a detailed study of ozone trend of different regions of the globe. They observed a decreasing trend at most of the places and an increasing trend of column ozone at Kagoshima, Mexico city, Quetta. Reference [15] reported that a statistically significant decrease in total ozone was being observed in all seasons in both the northern and southern hemispheres at middle and high latitudes. Reference [16] also found positive trend at Kodaikanal and New Delhi and negative trend at Srinagar. Long term trends of TCO at six stations (Kodaikanal, Pune, Ahmadabad, New Delhi, Srinagar and Varanasi) of India have been analyzed and an increasing trend of TCO is observed over the years at all places, except at Varanasi, where a decreasing trend has been found [17]. Reference [18] studied the TCO concentration at Rajkot over the period 1980-2004 and observed that there is an overall downward trend of TCO concentration. The rate of decline of ozone is found to be higher in recent

years over the northern parts of India, covering the Indo-Gangetic basin, compared with other parts of India [6]. A long term trend of TCO over New Delhi using multifunctional regression model shows that ozone concentration is decreasing [19].

A positive correlation has been found between SN and stratospheric ozone in some cities in Nigeria during period 1998-2005 [9]. [10] Studied the relationship between atmospheric ozone and solar activity for Tranquebar station during 1996-2004 and found a positive correlation between them. A statistical study between DSAF and TCO has been done for Nainital and Mussoorie hill stations of Uttarakhand, which reports a positive correlation between yearly averaged TCO and DSAF and also concludes that DSAF contribute to the production of ozone [20]. The aim of the present paper is to examine the variation of TCO with DSAF at Northern and Eastern stations of India.

2. Materials and Method

2.1. Study Site

The city of Shimla is nestled in Himalaya's southwestern ranges. The city is an 18 square kilometer mountainous region at sea level elevation of 7467 ft (2276 meters). At this altitude, the climate of the city has been classified as the subtropical highland. The climate of Shimla is predominantly cool during winters and moderately warm during summer. Temperatures typically range from -1°C to 31°C over the complete year in Shimla. Imphal is lying in the subtropical region where the monsoon trough exists. During summers, weather can be little hot as 30°C and humid too owing to its proximity near tropic of cancer. Torrential rains and humidity accompanies the monsoons that usually come in late June or early July for about two months.

2.2. Data Sources and Analysis

Data for DSAF like SN, SF and SAP has been taken from various sites namely <http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-indices/sunspot-numbers/>

<http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-flares/h-alpha/>
<http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/prominencesfilaments/>.

The ozone data during 2004-2016 has been downloaded from website: http://ozoneaq.gsfc.nasa.gov/ozone_overhead_all_v8.md. Due to lack of availability of ground based total column ozone data over Indian stations we have used Total Ozone Mapping Spectrometer (TOMS) on board satellite Nimbus 7, Meteor 3, Earth Probe and OMI (Ozone Monitoring Instrument) for our work. We have taken OMI data on daily basis from January 2004 to December 2016 and then averaged monthly and yearly for a normalized analysis. Table 1 (Appendix A) shows the detailed information about yearly mean of TCO-Shimla, TCO-Imphal data (In Dobson unit) and yearly mean of SN, SF and SAP during 2004-2016. During 2009-2016, no data were acquired for SAP, hence SAP data is missing, and similarly SF data is missing in 2016. Table 2 (Appendix B) shows the seasonal data of TCO-Shimla and TCO- Imphal during 2004-2016.

3. Results

3.1. Annual Trend

There is a consistent declining trend in ozone, SN, SF and SAP for all the seasons during 2004-2016. Figure 1(a) and Figure 1(b) show the annual variation of TCO with SN for Shimla and Imphal. In order to analyze the trend, a linear curve fitting method is used. A decreasing trend is observed with a good correlation coefficient $R = -0.74$ and -0.87 for Shimla and Imphal respectively. Figure 2(a) and Figure 2(b) represents annual variation of TCO with SF during the given period, it observed that a negative trend with a moderate correlation coefficient $R = -0.58$ and -0.63 for Shimla and Imphal respectively. The annual variation of TCO with SAP is analyzed in Figure 3(a) and Figure 3(b) for Shimla and Imphal respectively and it is observed that there is a weak decreasing trend with $R = -0.38$ for Shimla whereas a strong decreasing trend with $R = -0.79$ for Imphal.

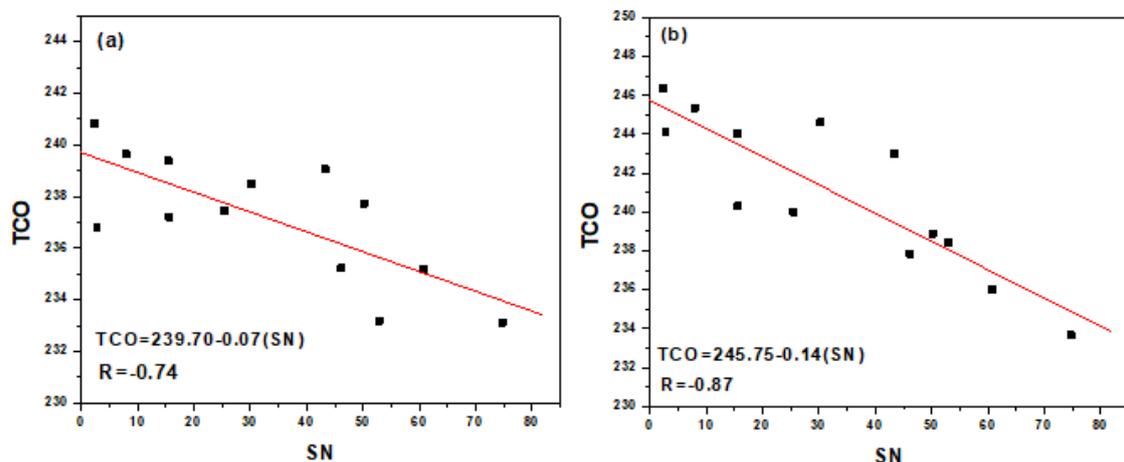


Figure 1. Annual variation of TCO with SN for the time period 2004-2016 at: (a) Shimla (b) Imphal

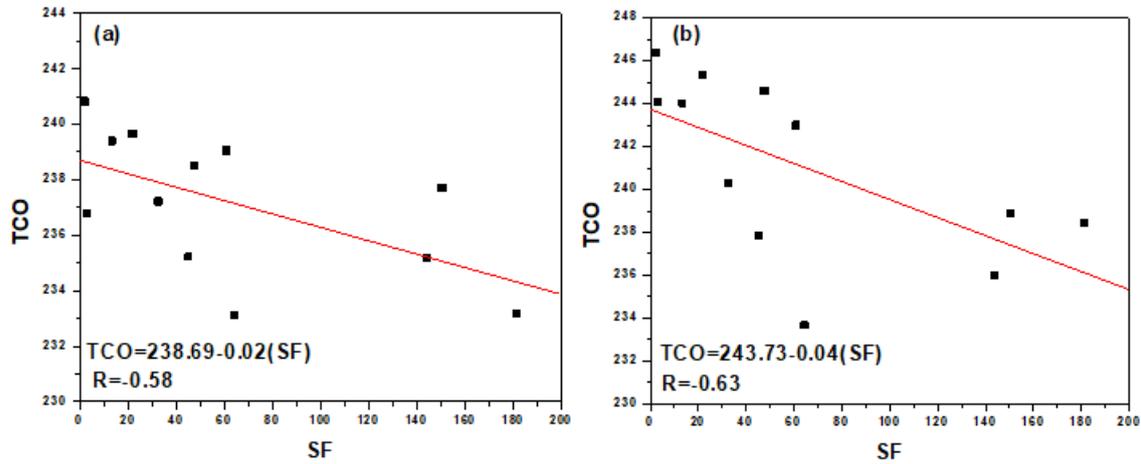


Figure 2. Annual variation of TCO and SF for the time period 2004-2016 at: (a) Shimla (b) Imphal

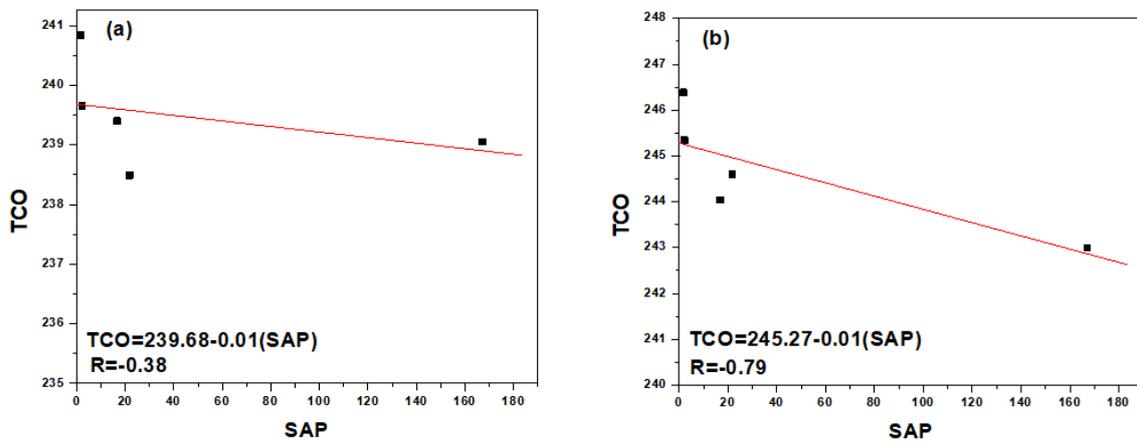


Figure 3. Annual variation of TCO and SAP for the time period 2004-2016 at: (a) Shimla (b) Imphal

3.2. Seasonal Trend

In another set of analysis we have considered four seasons where winter includes January and February (JF), summer from March to May (MAM) followed by rainy season from June to September (JJAS) and autumn from October to December (OND). Figure 4(a) to Figure 4(d) represent the seasonal plot of TCO with SN for Shimla and Figure 5(e) to Figure 5(h) represent the same for Imphal city. It is seen that there is a consistent declining trend with a correlation coefficient (R= -0.48, -0.46, -0.61, -0.41 for winter, summer, rainy and autumn respectively) for Shimla and a good negative correlation coefficient (R= -0.67, -0.67, -0.52, -0.56 for winter, summer, rainy, autumn respectively) for Imphal. It is observed that there is a minimum decreasing trend during autumn season, which clearly indicates that ozone concentration increases in autumn season. Similarly a moderate negative trend is found in the variation of TCO with SF shown in Figure 6(a) to Figure 6 (d) for Shimla and in Figure 7(e) to Figure 7 (h) for Imphal with a moderate correlation coefficient (R= -0.39, -0.49, -0.43, -0.34 for winter, summer, rainy and autumn respectively for Shimla and R= -0.57, -0.37, -0.39, -0.54 for winter, summer, rainy and autumn respectively for Imphal). A comparison of seasonal variation of TCO with SN and TCO with SF for both stations showed a less negative trend of TCO with SF which may indicates that

SF activity leads to increased ozone concentrations. A similar negative trends is also noticed in the seasonal variation of TCO with SAP in Figure 8(a) to Figure 8(d) for Shimla and in Figure 9(e) to Figure 9(h) for Imphal places during the given period whereas an abrupt positive trend in rainy and autumn season in Figure 9(g) and in Figure 9(h) for Imphal with a strong correlation coefficient of 0.97 and 0.18 respectively which is probably due to the fluctuations of solar insolation throughout the autumn season.

As observed the distribution of data is not quite normal and sample size is too small. The normal distribution is centered and symmetrical in shape, so we have used a non parametric test to determine the significance of data acquired. Non parametric tests can perform well with non normal continuous data. To assess the significance of our results we have applied a statistical χ^2 test on our data. On the basis of χ^2 test, we have rejected the null hypothesis (H_0 : TCO increases with solar activity features, H_1 : TCO decreases with solar activity features) at 95% confidence level. Using χ^2 test for the variation of TCO with SN and SF, the value of χ^2 is very small for Shimla and Imphal. Similarly we have calculated the value of χ^2 for the variation of TCO with SAP, which gives a small value (0.067) for both Shimla and Imphal. From statistical test we concluded that the TCO decreases with solar activity features in two stations of India during 2004-2016.

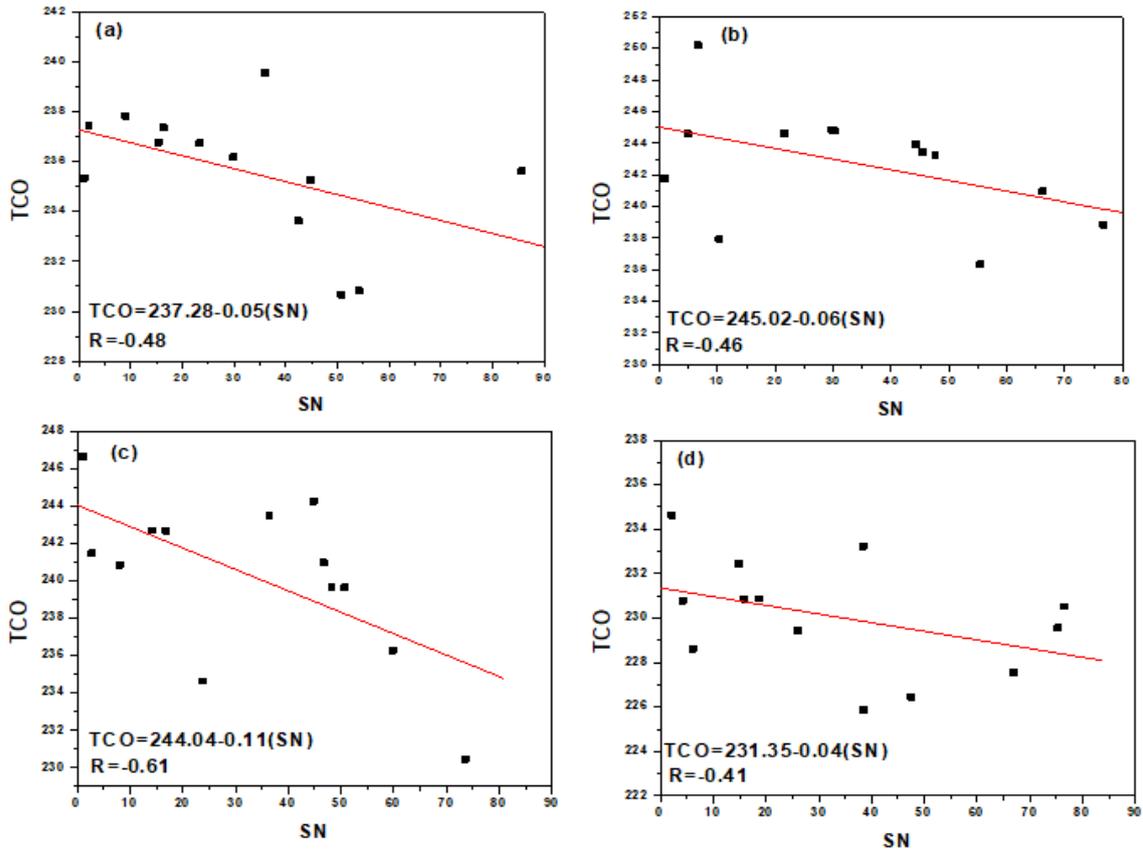


Figure 4. Seasonal variation of TCO and SN at Shimla [a -winter, b-Summer, c-Rainy, d-Autumn with their correlation coefficient (R) indicated in the figure]

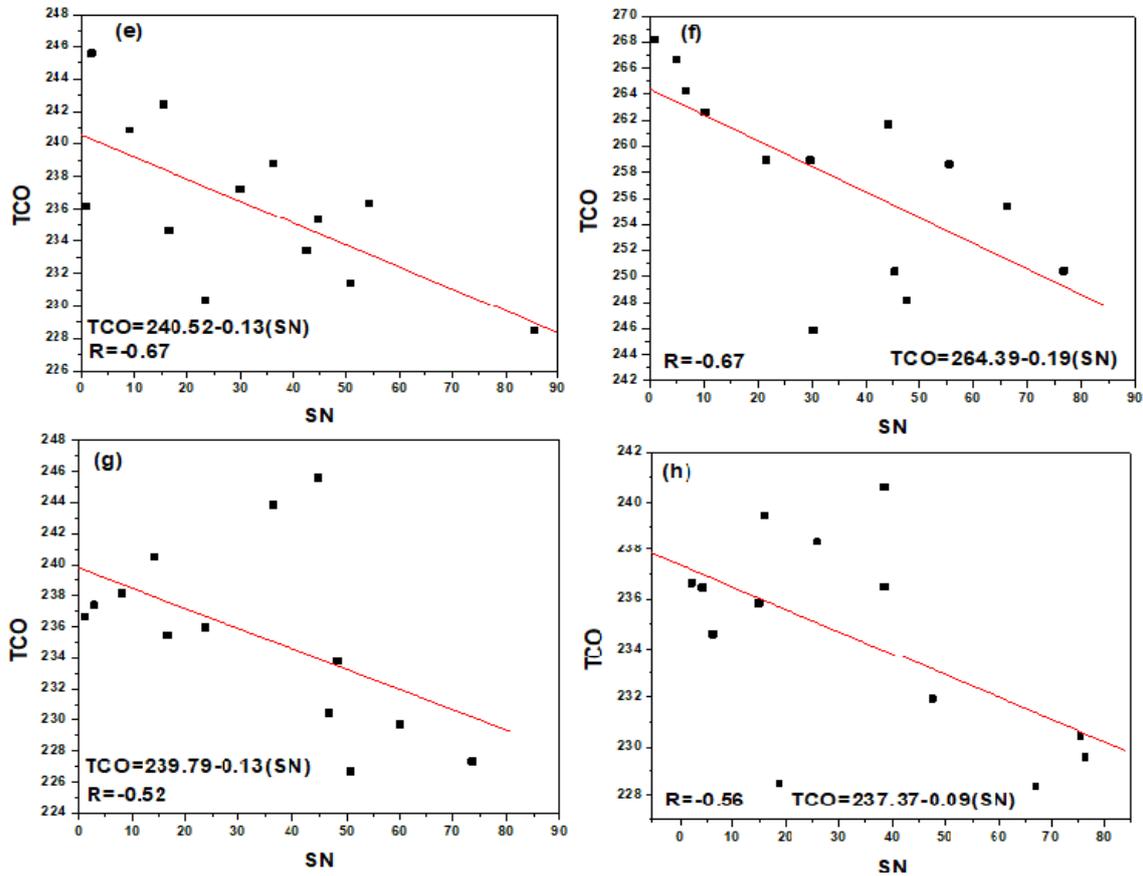


Figure 5. Seasonal variation of TCO and SN at Imphal [e - winter, f-Summer, g-Rainy, h-Autumn with their correlation coefficient (R) indicated in the figure]

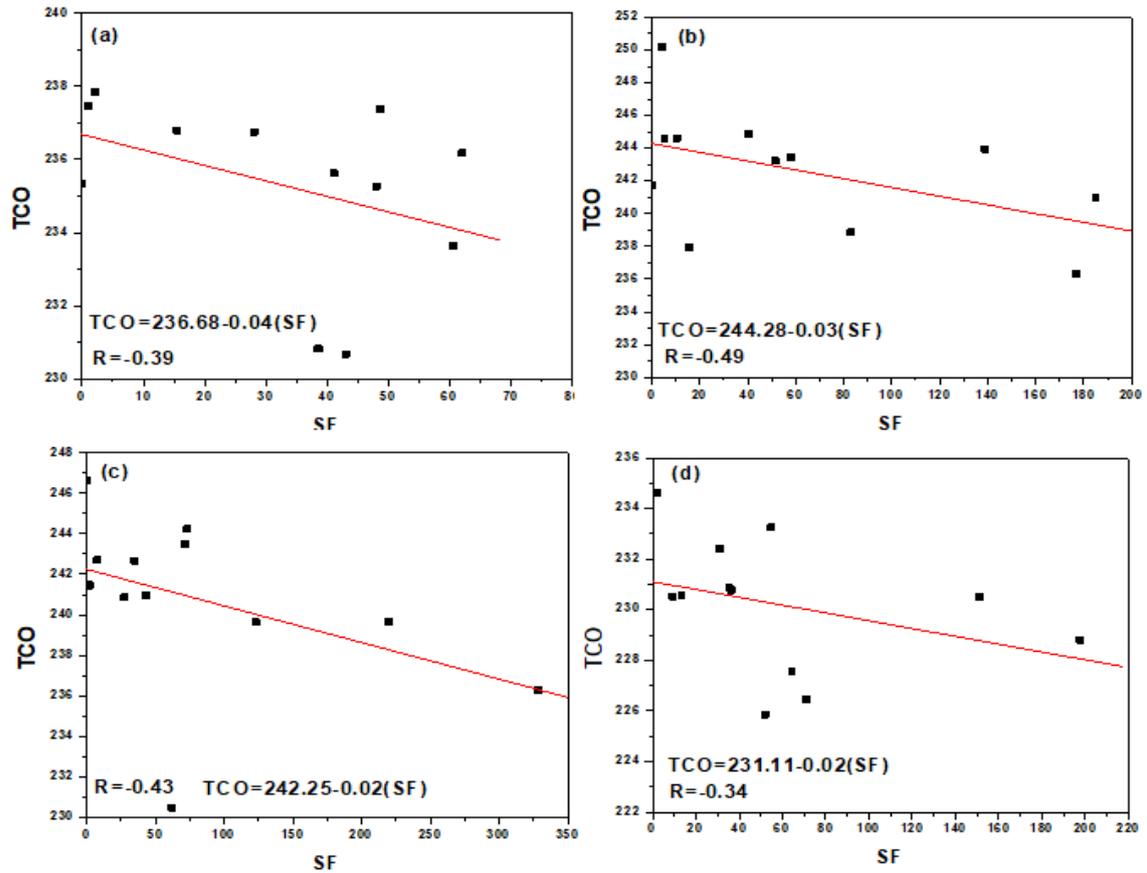


Figure 6. Seasonal variation of TCO and SF at Shimla [a - winter, b-Summer, c-Rainy, d-Autumn with their correlation coefficient (R) indicated in the figure]

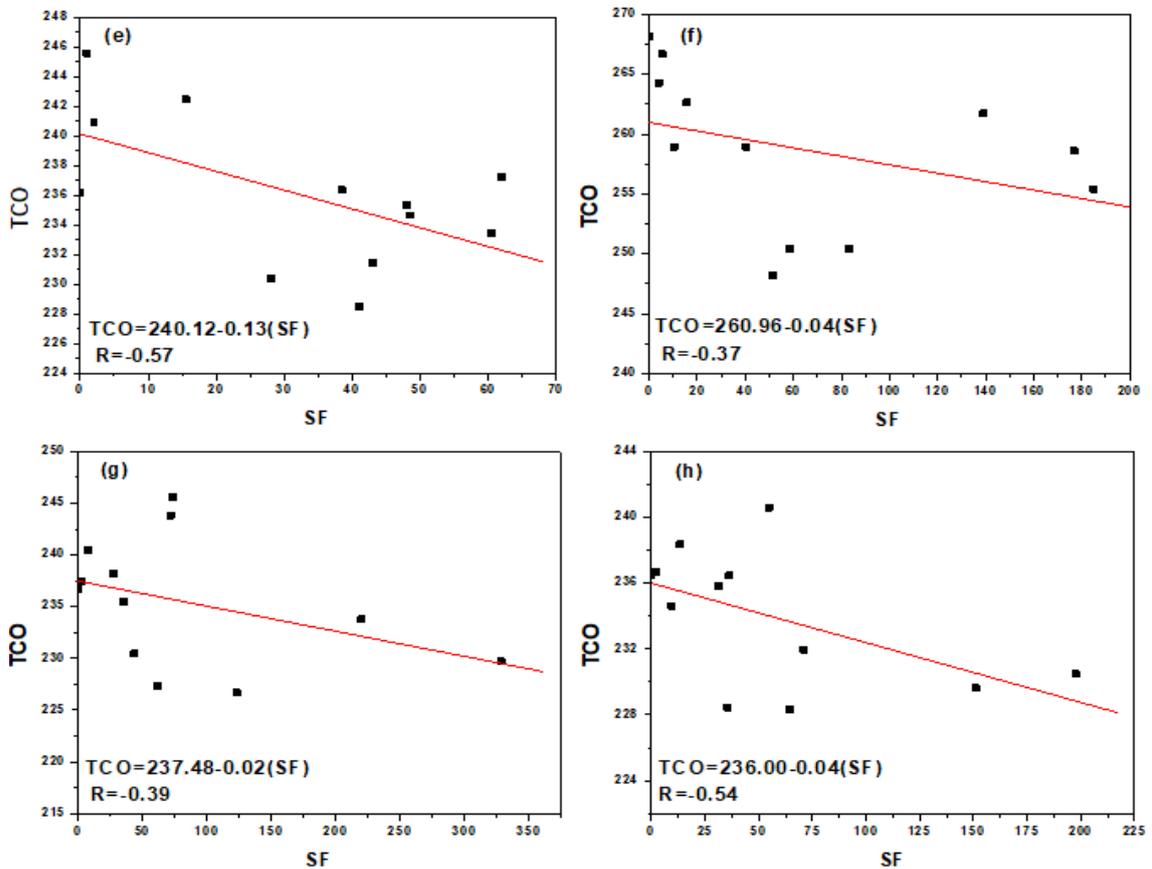


Figure 7. Seasonal variation of TCO and SF at Imphal [e - winter, f-Summer, g-Rainy, h-Autumn with their correlation coefficient (R) indicated in the figure]

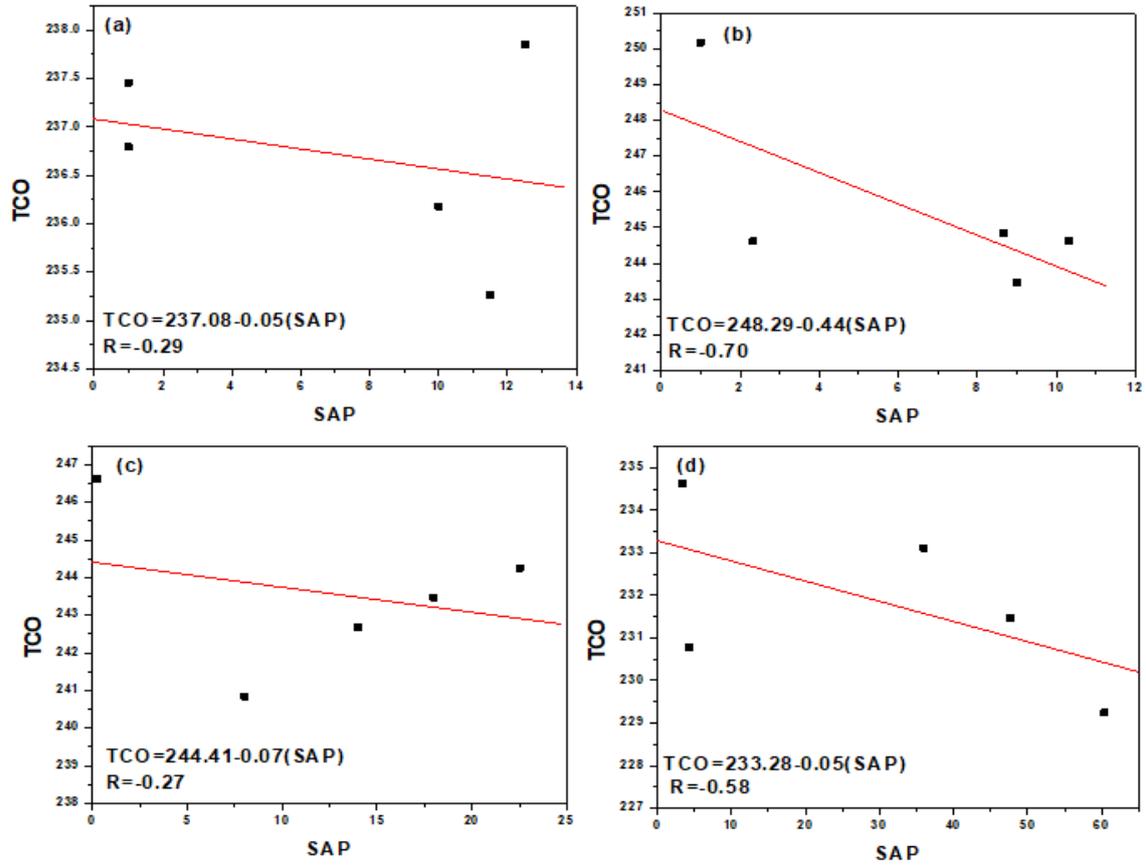


Figure 8. Seasonal variation of TCO and SAP at Shimla [a - winter, b-Summer, c-Rainy, d-Autumn with their correlation coefficient (R) indicated in the figure]

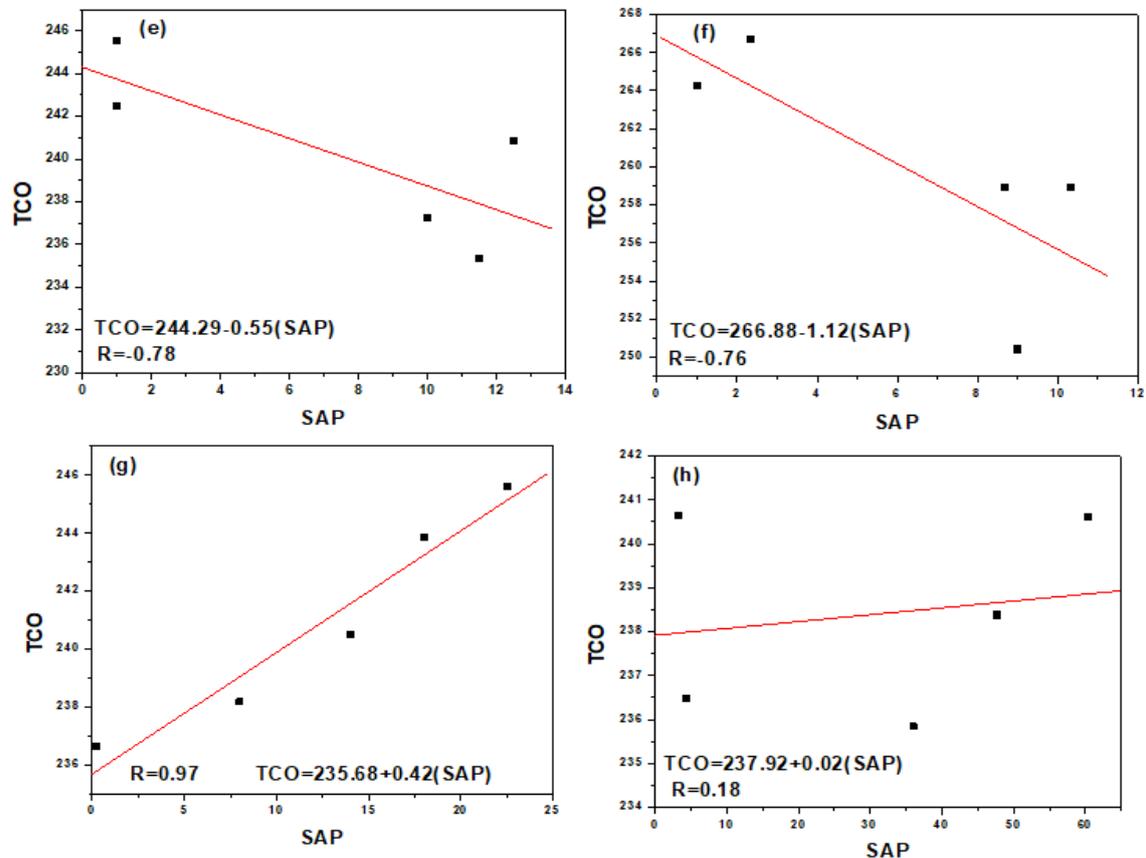


Figure 9. Seasonal variation of TCO and SAP at Imphal [e - winter, f-Summer, g-Rainy, h-Autumn with their correlation coefficient (R) indicated in the figure]

4. Discussion

To study the statistical analysis of TCO with DSAF (SN, SF, and SAP), the overall average value of TCO and different solar activity is calculated from their monthly mean values for a Northern station Shimla and an Eastern station Imphal of India during 2004-2016. A negative trend is found for both the stations which indicates that Ozone concentration decreases with solar activity during the given time period. Reference [1] showed that sunspot variation can cause about 2-4 % variations in ozone concentrations, but it is significant to cause long term change in the climate which in turn causes the impact on biosphere. The solar forcing can modify the circulation in the lower atmosphere [21]. To find out the effect of solar activities on TCO, we have calculated the annual mean, seasonal mean and monthly mean values of TCO and DSAF for Shimla and Imphal stations. In the annual variation of TCO with SN, an overall negative trend is observed with a strong correlation coefficient of -0.74 for Shimla and -0.87 for Imphal.

Maximum TCO value was observed in the months of April to June for both the stations and after that TCO decreases from July to December. The lowest value of TCO is observed in the month of December for both the stations, thereafter it increases till the month of June (Table 2). The mean TCO and DSAF for different seasons for Shimla and Imphal stations is shown in Table 2,

Table 3 and Table 4. TCO values are maximum in summer season and minimum during autumn season which clearly indicates that maximum ozone concentration is found during summer months whereas during autumn months ozone concentration decreases. It is also due to fluctuations of solar insolation throughout the season [22].

It is evident from our study that correlation coefficient of annual TCO with SAP over Shimla is -0.38, which is very poor, it is due to low activity of SAP during the period 2009-2016. For the annual variation of TCO with DSAF it is observed that the correlation coefficients between TCO and SN are found to be stronger than SF and SAP for both the stations. This difference is due to the missing data of SF and SAP which affect the variation and size of correlation coefficients.

The variation in the ozone level is also affected by the meteorological conditions, such as wind speed, wind direction, solar radiation and outdoor temperature [23]. The ozone level generally increases with the increase in solar radiation and outdoor temperature. An abrupt positive correlation is found between TCO and SAP at Imphal during rainy and autumn season, which indicates that TCO increases with SAP (Figure 9 g, h). The cause of maximum ozone is due to higher solar activity in summer season which facilitates ozone formation (Figure 10) [22]. For the monthly variation of DSAF, it is observed that SF has its maximum value during JJAS season while SAP is maximum at OND season (Figure 11).

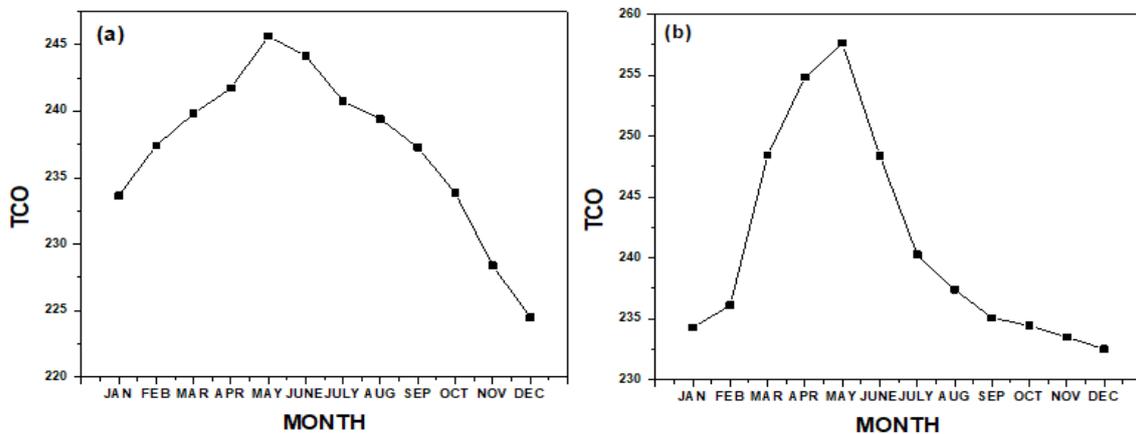


Figure 10. Monthly variation of TCO for time period 2004-2016 at: (a) Shimla (b) Imphal

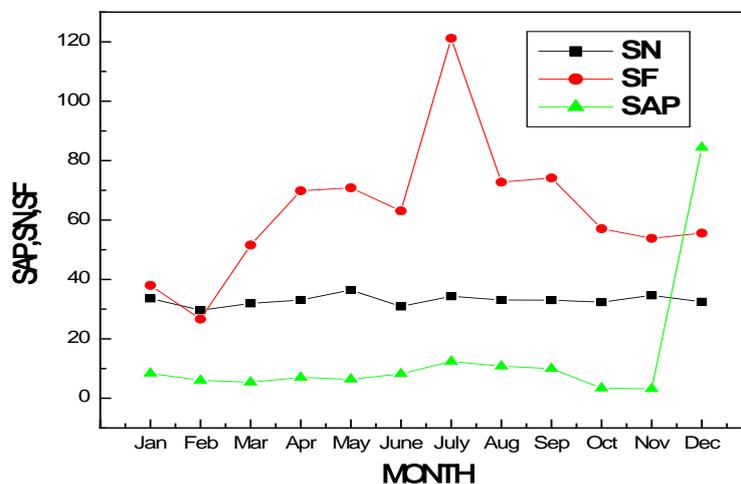


Figure 11. Monthly variation of SAP, SN, SF for time period 2004-2016

5. Conclusion

We have analyzed the statistical relationship between TCO and different solar activity features (SN, SAP, SF) along with their annual, seasonal and monthly variations during 2004-2016 of solar cycle 23 & 24. Our study indicates that the TCO shows strong negative correlation with solar activity features for both the stations. The negative pattern demonstrates that the measure of ozone is decreasing over these stations during the given timeframe. In the month to month variation of TCO at Shimla and Imphal from 2004-2016, a general negative pattern is found for both the stations. It is also seen that TCO attains its maximum value over both the stations in the month of May and from that point it diminishes from June to December. The minimum value of TCO is found during December for both the stations than a slight increment in January, after which it keeps on expanding till the long stretch of May. The main cause of the TCO variation might be due to solar activity as well as wind transport. Regarding seasonal variation of TCO over both the stations, higher value of TCO is observed during summer and rainy season which indicates that there is indeed production of ozone during these seasons while small value of TCO are seen during autumn and winter season portraying depletion of ozone layer in these seasons.

In order to understand the long term trend we have studied the annual variation of TCO with DSAF wherein it is clearly visible that DSAF take minimum values corresponding to the maximum value of TCO. From [Figure 10](#), it is clear that the TCO level for Shimla and Imphal is maximum during MAM while from [Figure 11](#), SF maximum values during JJAS season and SAP is maximum at OND season. DSAF during OND season rises to maximum value while TCO decreases to minimum value.

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Appendix A

Table 1. Data of TCO-Shimla, TCO-Imphal, SN (M), SF (M), SAP (M) during 2004-2016

S.No.	Year	TCO-Shimla (DU)	TCO-Imphal (DU)	SN	SF	SAP
1	2004	239.05	243.00	43.3	60.67	167
2	2005	238.49	244.60	30.2	47.58	21.75
3	2006	239.40	244.03	15.4	13.25	16.67
4	2007	239.65	245.34	7.9	21.75	2.17
5	2008	240.83	247.38	2.4	2	1.67
6	2009	236.79	244.09	2.8	3.08	NIL
7	2010	237.21	240.30	15.6	32.5	NIL
8	2011	237.72	238.87	50.1	150.42	NIL
9	2012	233.17	238.43	52.8	181.42	NIL
10	2013	235.20	235.99	60.7	143.83	NIL
11	2014	233.12	233.66	74.7	64.33	NIL
12	2015	235.22	237.86	46.1	45	NIL
13	2016	237.45	240.01	25.5	NIL	NIL

Appendix B

Table 2. Data of seasonal variation of TCO-Shimla and TCO-Imphal during 2004-2016

Year	TCO-Shimla (DU)				TCO-Imphal (DU)			
	JF	MAM	JJAS	OND	JF	MAM	JJAS	OND
2004	235.27	243.45	244.25	233.24	235.35	250.41	245.62	240.62
2005	236.18	244.85	243.47	229.46	237.25	258.94	243.85	238.38
2006	237.85	244.63	242.69	232.43	240.87	258.94	240.49	235.84
2007	236.79	250.19	240.85	230.78	242.46	264.28	238.18	236.47
2008	237.46	244.62	246.62	234.63	245.56	266.69	236.64	240.65
2009	235.34	241.78	241.46	228.61	236.16	268.2	237.42	234.61
2010	237.38	237.94	242.68	230.87	234.64	262.64	235.47	228.46
2011	236.76	243.94	239.65	230.52	230.37	261.71	233.78	229.63
2012	233.63	236.34	236.28	226.46	233.42	258.63	229.73	231.94
2013	230.68	240.95	239.63	229.56	231.45	255.41	226.67	230.46
2014	235.62	238.85	230.46	227.56	228.51	250.43	227.34	228.36
2015	230.82	243.25	240.96	225.86	236.35	248.17	230.45	236.49
2016	239.56	244.78	234.64	230.85	238.78	245.85	235.96	239.45

Appendix C

Table 3. Data of seasonal variation of SN and SF during 2004-2016

Year	SN				SF			
	JF	MAM	JJAS	OND	JF	MAM	JJAS	OND
2004	44.7	45.37	44.78	38.43	48	58.33	73.25	54.67
2005	29.9	29.7	36.4	25.97	62	40.33	71.5	13.33
2006	9.05	21.57	14.15	14.87	2	10.33	7.75	31
2007	15.35	6.6	8.05	4.17	15.5	4	27.25	36.33
2008	1.95	4.83	1.03	2.17	1	5.33	0	2
2009	1	0.77	2.83	6.07	0	0	2.25	9.33
2010	16.35	10.27	16.83	18.6	48.5	15.67	35	35.33
2011	23.4	44.2	48.23	76.43	28	139	219.75	151
2012	42.5	55.43	59.83	47.47	60.5	176.67	328.25	71
2013	50.8	66.2	50.65	75.4	43	185	123	197.67
2014	85.65	76.7	73.53	66.97	41	83	62	64.33
2015	54.15	47.6	46.75	38.43	38.5	51.33	43.5	0
2016	36.05	30.27	23.78	15.93	NIL	NIL	NIL	NIL

Appendix D

Table 4. Data of seasonal variation of SAP during 2004-2016

Year	SAP			
	JF	MAM	JJAS	OND
2004	11.5	9	22.5	60.33
2005	10	8.67	18	47.67
2006	12.5	10.33	9	36
2007	1	1	2	4.33
2008	1	2.33	0.25	3.33
2009	NIL	NIL	NIL	NIL
2010	NIL	NIL	NIL	NIL
2011	NIL	NIL	NIL	NIL
2012	NIL	NIL	NIL	NIL
2013	NIL	NIL	NIL	NIL
2014	NIL	NIL	NIL	NIL
2015	NIL	NIL	NIL	NIL
2016	NIL	NIL	NIL	NIL



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