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Trend Analysis of Total Column Ozone over New Delhi, India

S.L. JAIN, PAVAN S. KULKARNI, SACHIN D. GHUDE[1], SURAJ D. POLADE[1], B.C. ARYA, P.K. DUBEY AND SHAHNAWAZ[2]

National Physical Laboratory (NPLI), CSIR, New Delhi -110012
[1]Indian Institute of Tropical Meteorology, Pune - 411008
[2]Department of Physics and Astrophysics, University of Delhi, Delhi - 110007

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Abstract

Total Column Ozone measurements from Total Ozone Mapping Spectrometer (TOMS) onboard satellite Nimbus 7, Meteor 3 and Earth Probe have been used to determine trends in column ozone over New Delhi. Long term trend obtained with ozone time series data and least square fitting without removing Seasonal cycle, QBO, Solar effect and ENSO, shows that ozone concentration is decreasing by 2.11 (± 1.04) % per decade over New Delhi. Therefore, to calculate the exact trend, multifunctional regression model have been used to remove the effect of seasonal cycle, solar cycle, QBO and ENSO. The obtained long term trend with multifunctional regression model shows that column ozone over Delhi is actually decreasing by 1.83 (± 1.02) % per decade. The trend obtained from ozone time series data with least square fit overestimates multifunctional regression model by about 15%. The objective of this paper is to present the result of a long term trend analysis of the TOMS total ozone data over New Delhi.

1. Introduction

Total Ozone Column (TOC) is photo-chemically controlled by chemically active species in the oxygen, hydrogen, nitrogen, chlorine and bromine families. Most of the ozone is created over the tropics and transported into the polar region by the general circulation of the stratosphere. The total ozone column is decreasing at mid latitudes of northern and southern hemisphere [1]. The formation of ozone hole over Antarctica during Antarctic spring is mainly because of catalytic depletion of ozone [2-3]. Numerous studies based on various ground and satellite measurements [4-10] have shown an overall declining trend of total ozone (TOZ) content globally during 1979-93 and over Indian region during 1979-2003 [11]. The evidence is overwhelming that under cloud-free skies UV-B radiation is controlled largely by ozone [12]. Ozone depletion specifically enhances the shorter wavelengths of the UV spectrum (280-320 nm) and allows more biologically damaging, UV-B radiation to reach the earth's surface [13,14]. It is reported that a 1% decrease in stratospheric ozone could cause about 2% increase in UV-B radiation [15-17].

Singh et al. (2002) found a greater decreasing trend of TOC in the northern Indian region compared with other parts of India and reported the effect of El Nin˜o on TOC. This paper analyze TOMS data using two different technique, least square fit and multifunctional regression model, for the determination of long term trend in TOC, during 1979-2004, measured over New Delhi. It gives detailed insight of strong seasonal cycle effect along with solar cycle, ENSO and QBO effects embedded in it [19]. The results show a substantial difference in the trend values in TOC.

Table 1
Characteristics of the total ozone content dataset

Satellites	Nimbus-7, Meteor 3 and Earth Probe
Instrument	Total Ozone Mapping Spectrometer (TOMS)
Parameter	Total ozone concentration
Temporal coverage	Jan 1979 to Apr 1993, May 1993 to Jun 1994, and Aug 1996 to Dec 2004 respectively
Temporal resolution	Monthly data

2. Dataset

The TOC data over New Delhi (28°65' N, 77°28' E, 220 m.a.s.l) was taken from three different TOMS instruments developed by National Aeronautics and Space Administration (NASA)/Goddard Space Flight Center (GSFC) (ftp://toms.gsfc.nasa.gov/pub/). The TOMS instrument was designed to enable long-term daily mapping of the global distribution of the Earth's atmospheric ozone apart from aerosols and sulphur dioxide. The TOMS reprocessed (version 8) daily total ozone observations are made with spectral range of 311-380 nm and spectral resolution of 1nm. TOMS makes 35 measurements every 8 s, each covering a width of 50-200 km on the ground, strung along a line perpendicular to the motion of the satellite. Table 1 gives details about the TOMS ozone data used in this analysis.

Backscatter technique is used by TOMS to compute the TOC values from ratio of solar backscattered irradiance from earth at specific wavelength. This way, all instrument-related changes are cancelled, except for degradation of the diffuser plate, which is used to reflect diffuse solar light into the instrument optics. A non-diffused-based technique (spectral discrimination) based algorithm is used to calibrate the TOMS data and retrieve TOC data which used in the present study.

3. Data Analysis Methodology

To analyze the TCO time series obtained from TOMS, least square fit method and a multifunctional regression model has been used in this work and comparison of the two methods has been discussed in detail.

3.1 *Least Squares Fit Method*

The method of least squares assumes that the best-fit curve of a given type is the curve that has the minimal sum of the deviations squared (least square error) from a given set of data [19].

3.2 *Multifunctional Regression Model*

Multifunctional Regression model consists of seasonal cycle, linear trend, solar cycle, Quasi-Biennial Oscillation (QBO) and El Nin˜o Southern Oscillations (ENSO). Solar cycle, QBO and ENSO can be explained as follows:

A regular variation in the number of sunspots visible on the solar disk, attends a minimum and a maximum number, over a period of around 11 years, in a regular cyclic fashion, is called the solar cycle. The period is not constant, but varies between about 9.5 and 12.5 years. Another indicator of the level of solar activity is the flux of radio emission from the Sun at a wavelength of 10.7 cm (2.8 GHz frequency) called F10.7 solar flux. F10.7 follows the sunspot number quite closely. The direction of the winds in the tropical stratosphere are observed to reverse from easterly to westerly and back to easterly again approximately every 26 to 28 months. This reversal of winds in the tropics is known as the quasi-biennial oscillation or QBO. Similarly, large variations in the ocean temperature of the equatorial Pacific Ocean have become popularly known as the El Niño phenomenon. It is part of a larger, coupled ocean-atmosphere phenomenon known as the El Niño-Southern Oscillation (ENSO). Typically, the waters of the Eastern Pacific near South America are quite cool as a result of upwelling. During a "warm ENSO" or El Niño year, the warmer waters of the Western Pacific migrate eastward, causing a substantial rise in temperatures in the waters of the equatorial eastern Pacific off the coast of Peru and Ecuador. The "Southern Oscillation" part refers to the seesaw of pressure between the Pacific and the Indian Ocean where the normal situation of higher pressures over the tropical eastern Pacific and lower pressures over the tropical central Pacific undergo a reversal.

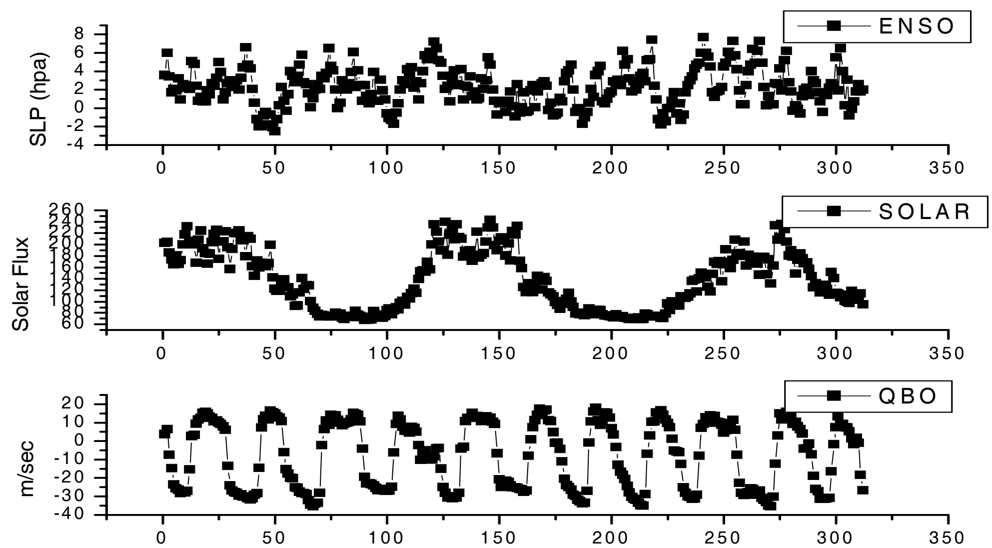

Fig. 1. Distribution of ENSO, Solar and QBO Proxy for 1979 to 2004 period

The general expression for the regression model equation used for the analysis can be written as follows:

$$O_3(t) = \alpha(t) + A(t).\,\text{Trend}(t) + B(t).\,\text{ENSO}(t) + C(t).\,\text{Solar}(t) + D(t).\,\text{QBO}(t) + \text{Res}(t) \quad (1)$$

where,

t - month index (1-324 for 1979-2004),
O_3 (t) - TCO time series ozone,
α(t) - seasonal cycle coefficient,
A (t) - seasonal trend coefficient,
B (t) - seasonal ENSO coefficient,
C (t) - seasonal solar cycle coefficient,
D (t) - seasonal QBO coefficient, and

Res (t) - residual error time series for the regression model which includes all other parameters not considered including noise and also the sporadic events like Kalimantan big fire of 1997.

Trend models often use a particular harmonic expansion to represent the seasonality of the interaction between O_3 (t) and a particular surrogate (proxy). In the present statistical model, the ENSO proxy time series are based on the actual measured values of Southern Oscillation Index (http://www.cpc.noaa.gov/data/indices/). For ENSO proxy, Tahiti (18S, 150W) minus Darwin (13S, 131E) monthly-mean sea-level pressure (hPa) has been used. The data were provided by the National Centers for Environmental Prediction (NCEP) Climate Prediction Center. Solar Proxies have been used for Ottawa monthly-mean F10.7 solar flux (standard flux units) from January 1947 through the most recent month (ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_RADIO/FLUX). Similarly, QBO proxy has been used from monthly-mean QBO zonal winds at 30 hPa. Units are meters per second. Fig. 1 shows the distribution of these three Proxies for 1979 to 2004 period. Proxy time series have been further de-trended and de-seasonalized in the model to avoid any tampering of the derived seasonal fits and to remove any fictional trends caused by sudden changes in the proxies on the long term variations of ozone.

4. Result and Discussion

As it appears from Fig. 2, long term trend obtained with ozone time series data and least square fitting without removing Seasonal cycle, QBO, Solar effect and ENSO, shows that ozone concentration is decreasing by 2.11 (±1.04) %/ per decade over New Delhi. Month to month and seasonal variation can be seen clearly in Fig. 2. These variations are due to the various effects such as monthly and seasonal changes in solar insolation along with solar cycle, QBO, ENSO, residual error and the sporadic events. Table 2 shows the trend in % per decade for every month with error using least square fitting without removing Seasonal cycle, QBO, Solar effect and ENSO. Similarly, Fig. 3

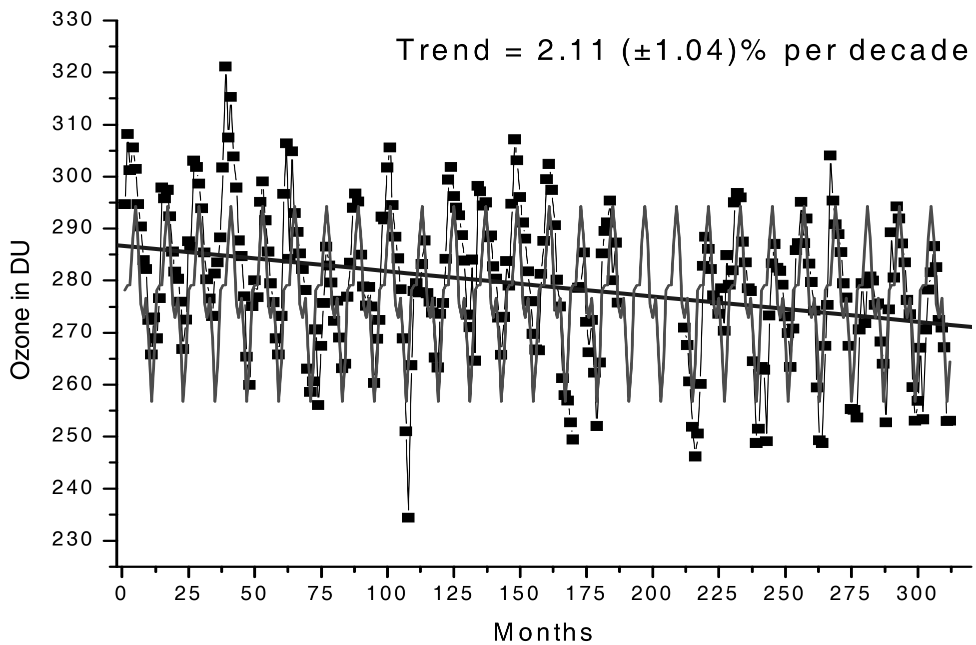

Fig 2. Column ozone time series over Delhi for the period 1979-2004 (Line with square boxes : ozone time series [monthly mean], Contineous line: seasonal fit by model on ozone time series and Straight bold line : linear fit on ozone time series)

Table 2
Trend in % per decade for every month without removing seasonal cycles, ENSO, Solar cycle and QBO

Month	Trend (± error)
Jan	-3.05 (± 2.79)
Feb	-3.23 (± 3.82)
Mar	-2.58 (± 3.67)
Apr	-2.38 (± 2.63)
May	-2.36 (± 2.07)
Jun	-1.16 (± 1.28)
Jul	-0.99 (± 1.50)
Aug	-1.01 (± 1.41)
Sep	-0.97 (± 0.94)
Oct	-1.26 (± 1.43)
Nov	-1.98 (± 1.96)
Dec	-2.70 (± 3.06)

Table 3
Trend in % per decade for every month with 2-sigma standard error using multifunctional regression model

Month	Trend (± error)
Jan	-2.83 (± 1.47)
Feb	-2.72 (± 1.66)
Mar	-2.58 (± 1.5)
Apr	-2.43 (± 0.97)
May	-1.98 (± 0.91)
Jun	-1.27 (± 0.49)
Jul	-0.82 (± 0.71)
Aug	-0.85 (± 0.62)
Sep	-0.99 (± 0.45)
Oct	-1.17 (± 0.75)
Nov	-1.77 (± 1.06)
Dec	-2.54 (± 1.62)

shows Solar Fit and QBO Fit on the column ozone time series over Delhi. Solar fit and QBO fit indicates contribution of solar flux and QBO proxies, shown in Fig. 1, on the column ozone concentration. Therefore, to remove the effect of seasonal cycle, solar cycle, QBO and ENSO, multifunctional regression model had been used to compute the trend.

The obtained long term trend with multifunctional regression model shows a negative trend of 1.83 (± 1.02) %/ per decade. The trend obtained from ozone time series data with least square fitting, without removing Seasonal cycle, QBO, Solar effect and ENSO, overestimates multifunctional regression model by about 15%. Table 3 shows the trend in % per decade

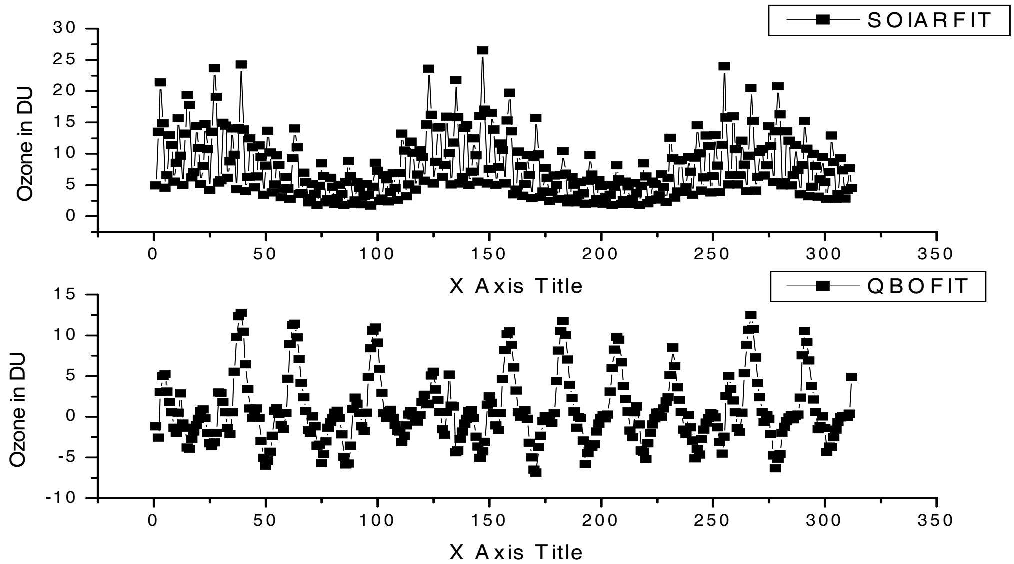

Fig. 3. Solar Fit and QBO Fit on the column ozone time series over Delhi for the period 1979-2004

Table 4
Monthly/yearly QBO coefficient and solar coefficient with 2 sigma standard error for total column ozone over Delhi

	Trend	QBO (±error) DU Per 10m/s	SOLAR (±error) DU per 100 F10.7
Jan	-2.83	-3.24 (± 1.9)	2.42 (± 5.88)
Feb	-2.72	-3.98 (± 2.11)	6.6 (± 6.77)
Mar	-2.58	-4.03 (± 1.84)	11.51 (± 6.52)
Apr	-2.43	-3.37 (± 1.17)	8.55 (± 4.61)
May	-1.98	-2.2 (± 1.11)	2.77 (± 4.6)
Jun	-1.27	-1.19 (± 0.59)	3.65 (± 2.37)
Jul	-0.82	-0.67 (± 0.84)	7.8 (±)
Aug	-0.85	-0.19 (± 0.72)	6.57 (± 2.67)
Sep	-0.99	0.5 (± 0.54)	2.79 (± 1.89)
Oct	-1.17	0.73 (± 0.92)	3.92 (± 3.08)
Nov	-1.77	-0.18 (± 1.27)	6.75 (± 4.03)
Dec	-2.54	-1.82 (± 1.97)	4.74 (± 6.08)
Year	-1.83	-1.64 (± 1.25)	5.67 (± 4.32)

for every month with 2 sigma standard error using multifunctional regression model. Comparison of trend values and 2-sigma standard error obtained with least square fit and multifunctional regression model, given in Tables 2 and 3 respectively, shows that multifunctional regression model has lesser negative trend in % per decade for every month with better confidence level.

Further to quantify the effect of QBO and solar insolation on ozone concentration, QBO coefficient for per 10m/s increase in wind at 30 hPa and solar coefficient for per 100 unit increase in solar flux F10.7. (where F10.7 is a standard flux unit) is calculated. Table 4 shows Monthly/yearly QBO coefficient and solar coefficient for total column ozone.

QBO coefficient indicates that, Ozone concentration decreases by 1.64 (± 1.25) DU (Average) for per 10m/s increase in wind at 30 hPa and solar coefficient indicates that, ozone concentration increases by 5.67 (± 4.32) DU over Delhi (average) for per 100 unit increase in solar flux F10.7.

5. Conclusion

Long term trend of TOC computed with least square fitting, without removing Seasonal cycle, QBO, Solar effect and ENSO, shows ozone concentration decrease of 2.11 (± 1.04) % per decade, where as multifunctional regression model result shows ozone concentration decrease of 1.83 (± 1.02) % per decade. This shows that the trend obtained from ozone time series data with least square fit overestimates multifunctional regression model by about 15% over New Delhi. So to estimate the exact trend it is very important to remove the effects of Seasonal cycle, QBO, Solar effect and ENSO from the ozone time series data. Apart from this, the effect of various parameters like Seasonal cycle, QBO, Solar effect and ENSO on long term trend of TOC can be studied individually with the help of multifunctional regression model which is not possible with least square fit method.

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