Temporal and Spatial Variability and Trend Investigation of Total Ozone Column over Iraq employing remote sensing Data: 1979–2012

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ABSTRACT. The objective of this paper is to analyze the temporal and spatial variability of the total ozone column (TOC) distributions and trends over Iraq, during the last 30 years (1979–2012) using remote sensing-derived TOC data. Due to shortage of ground-based TOC measurements, TOC data derived from the Total Ozone Mapping Spectrometer (TOMS) for the period 1979–2004 and Ozone Monitoring Instrument (OMI) for the period 2005–2012 with spatial resolution (1º×1º) were used in present study. The spatial, long-term, monthly variations of TOC over Iraq were analysed. For the spatial variability, the latitudinal variability has a large range between (45 to 55) DU in winter and spring whereas during summer and autumn months ranged between (6 to 10) DU. Also represents an annual cycle with maximum in March and minimum in October. In contrast, the longitudinal variability is not significant. The long-term variability represented a notable decline for the period 1979–2012. The ozone negative trend was observed significantly during 1979–2004, for all months with trend ranged between (−0.3 to 2) DU/year whereas the ozone positive trend was appear clearly during 2005–2007, for all months (0.1 to 2.3) DU/year except February and September which presented negative trends. The results can provide comprehensive descriptions of the TOC variations in Iraq and benefit climate change research in this region.

1. INTRODUCTION

The composition of the atmosphere has undergone dramatic changes in the last decades due to human activities [1, 2]. The quasi-exponential growth in the world population and the industrialization have led to a strong growth in fossil fuel and biomass burning emissions of trace gases such as carbon dioxide (CO₂), carbon monoxide (CO), nitrogen oxides (NOx), methane (CH₄), and other hydrocarbons [3]. The emissions of nitrogen oxides and hydrocarbons have resulted in an increase of ozone (O₃) near the surface and a degradation of air quality on a global scale, while the increases of CO₂, CH₄ and other greenhouse gases have caused a rise in global mean temperature (global warming) [1]. Furthermore, the release in the atmosphere of manmade chlorofluorocarbons has resulted in depletion in stratospheric ozone and the formation of an ozone hole over Antarctica in spring [4–6]. Although ozone is a trace gas and constitutes less than 0.001% of the air by volume, it is one of the most important constituents of the atmosphere. The ozone layer in the stratosphere protects the biosphere by absorbing harmful solar ultraviolet (UV) radiation. Downward transport of ozone from the stratosphere contributes to the ozone abundance in the troposphere, but ozone is also produced in the troposphere by sunlight driven chemical reaction cycles, involving NOx, CO, CH₄ and other hydrocarbons, this can lead to excessive amounts of ozone near the surface which are toxic to ecosystem, animals and men. Ozone also acts as a greenhouse gas, with highest efficiency in the upper troposphere and lowermost stratosphere [7]. In this region, the emissions by subsonic aviation are an important source of nitrogen oxides, and locally enhance the photochemical production of ozone [8,9]. The aircraft induced ozone increase in the upper troposphere and lower stratosphere has a significant climate effect, with a positive radiative forcing of 0.02-0.05 W/m² [10]. The total increase of tropospheric ozone since pre-industrial times has led to a globally averaged positive radiative forcing of about 0.35 W/m² [11].
The total ozone column has been conducted by many research centres and researches. Among researches in world and our regions are those conducted this issue has used both ground station and satellites observations to examine the variability of total ozone column. The depletion of stratospheric ozone by anthropogenic emissions since the 1970s has been well documented using total ozone and ozone profile data [12, 13]. In recent years there has been an increasing anthropogenic process related to human activity, the substantial ozone decrease in spring season over Antarctica are well documented in numerous studies based on various ground and satellite measurements [14-17]. These studies have shown an overall declining trend of total ozone content globally during the period 1979 – 1993, these studies have led the researcher to monitor TOC trend such as Salihi [17] found a significant reducing of total ozone content in numerous cities in our region such as Jeddah, Bahrain, Baghdad, Tehran, Aleppo and Ankara for the period 1979 – 1992. Singh etal,[18] found a decreasing trend of TOC in the northern Indian region compared with other parts of India where the trends is almost stable for the period 1978 – 1993, also they found the effect of El-Nino on TOC for most cities in India, due to which the ozone trend is found to increase during the short period of 1996 – 2000 using ground station mesurements and Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) data. Demirhan etal [19] discuss the variation in total ozone over south-eastern Europe and the Eastern Mediterranean by examining the temporal and spatial variation of TOC, they found that the stratospheric ozone in mid-latitude is strongly influenced by lower stratospheric temperature. Attia and Sharobiem [20] have made a verification for TOMS data with those corresponded obtain by Dobson instrument in Cairo, they showed a good correlation between TOMS and Dobson instrument measurements. Sharobiem and Attia [21] found a negative trend through the period (1985 – 1995) and positive trend for the period (1995-2000) at Subtropical area. Awad and Al-Kalaf [22] found that the high land surrounding the Red sea and Arabian gulf areas and synoptic features permanent over the area have special effects on distribution of ozone and produce a zonal wave, which spreads to interior land on a weak gradient of ozone. AL-Salihi [23] analysed time series of daily TOC and the relation between TOC with solar activity for Baghdad city during the period (1997-2005) using spectral analysis and power density which show that the dominating oscillation periods are between 2.8 and 5.4 days and solar activity has a weak effect on total ozone production with correlation coefficient (0.22) for the entered period.

The aim of the present work is to investigate the temporal and spatial trends TOC during the last three decades for the period of 1979 to 2012 by employing two satellites data measured by Total Ozone Monitoring Spectrometer (TOMS) and Ozone Monitoring Instrument (OMI) sensors which included grid data which covered area of Iraq and surrounding area by 99 grid point.

2. SATELLITE DATA SOURCE AND ANALYSIS METHODOLOGY

2.1. Nimbus - 7 TOMS

Nimbus –7 satellites was launched on 24th October 1978, and the measurements began about a week later from 1st November 1978 to 5th May 1993. The Total Ozone Mapping Spectrometer (TOMS) experiment on board NASA’s Nimbus –7 satellites is a source of high-resolution daily global information about the total ozone content. Nimbus -7 satellite sensors measures the ultraviolet sunlight back scattered from the clouds or the ground at wavelength bands centred at 312.34, 317.35, 331.06, 339.66, 359.88 and 379.95 nanometres to measure the total ozone amount. The first four wavelengths are sensitive to ozone; the two longer wavelengths are used for estimating the scene reflectivity necessary for deriving ozone amounts. Total column ozone is inferred from the differential absorption of scattered sunlight in the ultraviolet using the ratio of two wavelengths, 312nm and 331nm for instance, where one wavelength is strongly absorbed by ozone while the other is negligibly absorbed. TOMS scans in the cross-track direction in 3-degree steps from 51 degrees on one side of nadir to 51 degrees on the other, for a total of 35 samples. At the end of the scan, the mirror quickly returns to the initial position without taking any measurements on the retrace. The next scan begins 8 seconds after the start of the previous scan. Consecutive cross – scans overlap, creating a contiguous mapping of ozone as the spacecraft moves from south to north.
Approximately 200000 measurements are made on a daily basis during the sunlit portions of the orbits. Nimbus-7 is in a south-north sun synchronous polar orbit such that it is always close to a local noon/midnight beneath the satellite. Thus, ozone over the entire world is measured every 24 hours [24].

2.2. Earth Probe TOMS

Earth-Probe TOMS was launched on 2nd July 1996. The satellite was flown in a 500 km polar orbit, rather than the 950 km orbit that was originally planned. The lower orbit increased the satellite’s resolution and also the probability of making measurements over cloudless scenes. The lower orbit also improved the ability of the TOMS instrument to make measurements of UV-absorbing aerosols in the troposphere, a capability that was recently developed using earlier TOMS data. The increased probability of making measurements over cloud-free areas will enhance the capability of converting the TOMS aerosol measurements into geophysical quantities such as optical depth. The increased resolution available with the lower orbit may even result in the ability of the TOMS instrument to detect urban aerosols such as pollution. Because of continuing changes in the optical properties of the front scan mirror (the reason for which could not be understood), a latitude dependent error was observed which could not be corrected by a simple calibration correction. The calibration appeared to be stable near the equator. But by 50 degrees latitude, a -2% to -4% error in TOMS was observed. Therefore, in view of the good performance of Ozone Monitoring Instrument (OMI) and the calibration problems with EP TOMS, Earth Probe TOMS data has been discontinued from January 1, 2006 and has been replaced by the OMI data [24].

2.3. Ozone Monitoring Instrument (OMI)

The OMI instrument can distinguish between aerosol types, such as smoke, dust, and sulfates, and can measure cloud pressure and coverage, which provide data to derive stratospheric ozone. It will continue the TOMS record for total ozone and other atmospheric parameters related to ozone chemistry and climate. OMI measurements will be highly synergistic with the other instruments on the Aura platform. The OMI instrument measures solar backscatter radiation in the visible and ultraviolet region. It will improve the accuracy and precision of the measurements of total ozone and will also allow for accurate radiometric and wavelength calibration over the long term. The instrument is a contribution of the Netherlands's Agency for Aerospace Programs in collaboration with the Finnish Meteorological Institute (FMI) to the Aura mission. OMI is a nadir-viewing near-UV/Visible spectrometer aboard NASA’s Earth Observing System’s (EOS) Aura satellite. Aura flies in formation about 15 minutes behind Aqua, both of which orbit the earth in a polar Sun-synchronous pattern. Aura was launched on July 15, 2004, and OMI has collected data since August 9, 2004. OMI measurements cover a spectral region of 264–504 nm with a spectral resolution between 0.42 nm and 0.63 nm and a nominal ground footprint of 13 × 24 km². Essentially complete global coverage is achieved in one day. The significantly improved spatial resolution of OMI measurements as well as the vastly increased number of wavelengths observed, as compared to TOMS, GOME and SCIAMACHY sets a new standard for trace gas and air quality monitoring from space.

The OMI is a contribution of NIASD (Netherlands Institute for Air and Space Development) of Delft, in collaboration with FMI (Finnish Meteorological Institute), Helsinki, Finland [25].

2.4. Study Area and Climate Situation

The study area is Iraq, a country in south-western Asia. It lies in the western part of Asia and occupies mostly the Mesopotamian Plain, located, between 29° and 38° N latitudes, and 39° and 49° E longitudes (a small area lies west of 39°). Iraq borders Turkey to the north, Syria to the northwest, Kuwait and Saudi Arabia to the south, Iran to the east, and Jordan to the southwest. An area (Fig. 1) comprises of 437,072 square kilometres (168,754 sq mi); it is the 58th-largest country in the world. Country divided into four major regions: highlands in north and northeast; alluvial
plain in central and southeast sections; and desert in west and southwest; rolling upland between upper Euphrates and Tigris rivers. These two major rivers run through the Centre of Iraq, flowing from northwest to southeast are fertile alluvial plains. The north of the country is mostly composed of mountains; the highest point being at 3,611 m (11,847 ft). Iraq has a narrow section of coastline measuring 58 km (36 mi) on the northern Arab Gulf.

As for the climate and the situation in Iraq can show that as the following: Average air temperatures in Iraq range from higher than 48 °C in July and August to near freezing in January. Most of the rainfall occurs from December through April and averages between 100 and 180 millimeters annually. The mountainous region of northern Iraq receives appreciably more precipitation than the central or southern region. Roughly 90% of the annual rainfall occurs between November and April, most of it in the winter months from December through March. The remaining six months, particularly the hottest ones of June, July, and August, are very dry. Except in the north and northeast, mean annual rainfall ranges between 100 and 170 millimeters. Data available from stations in the foothills and steppes south and southwest of the mountains suggest mean annual rainfall between 320 and 570 millimeters for that area. Rainfall in the mountains is more abundant and may reaches to about 1000 millimeters a year in some places, but the terrain precludes extensive cultivation. Cultivation on no irrigated land is limited essentially to the mountain valleys, foothills, and steppes, which have 300 millimeters more of rainfall annually. Mean minimum temperatures in the winter range from near freezing (just before dawn) in the northern and northeastern foothills and the western desert to 2 to 3 °C and 4 to 5 °C in the alluvial plains of southern Iraq. They rise to a mean maximum of about 16 °C in the western desert and the northeast, and 17 °C in the south. In the summer mean minimum temperatures range from about 27 to 34 °C and rise to maximums between roughly 42 and 47 °C. Temperatures sometimes fall below freezing and have fallen as low as −6 °C at Al-Rutbah in the western desert. They are more likely; however, to go over 49 °C in the summer months and several stations have records of over 53 °C.

The summer months are marked by two kinds of wind phenomena. The southern and south easterly sharji, a dry, dusty wind with occasional gusts, occurs from April to early June and again from late September through November. It may last for a day at the beginning and end of the season but for several days at other times. This wind is often accompanied by violent dust storms that may rise to heights of several thousand meters and close airports for brief periods. From mid-June to mid-September the prevailing wind, called the shamal, is from the north and northwest. It is a steady wind, absent only occasionally during this period. The very dry air brought by this shamal permits intensive sun heating of the land surface, but the breeze has some cooling effect. The combination of rain shortage and extreme heat makes much of Iraq a desert. Because of very high rates of evaporation, soil and plants rapidly lose the little moisture obtained from the rain, and vegetation could not survive without extensive irrigation. Some areas, however, although arid, do have natural vegetation in contrast to the desert.
3. RESULTS AND DISCUSSION

3.1 Spatial Distribution of Monthly Mean Total Ozone Column

Figures (2), (3), (4) and (5) show the spatial distribution of the monthly average of total ozone column (1979-2004) and (2005-2012) respectively for each month of the year. These figures depict monthly variability of total ozone column over Iraq based on all available data from 1979 to 2012. Because most ozone lies in the stratosphere, stratospheric ozone and total ozone column shows similar seasonal cycles and latitudinal variability. The largest ozone amounts occur in northern region especially during winter and spring months which coincide with a lowering of the tropopause. Generally, ozone is seen to increase with latitude, where Latitudinal gradients in total ozone column are very evident in winter and spring months especially northern regions are 3-4 times larger than in summer and autumn months. Despite the differences in latitudinal gradient in ozone below latitude 35° N, total ozone column values show the smallest amounts during all months through the year. With the beginning of May the values of total ozone column decrease gradually to reach minimum ozone values in October where its value in the middle and south of Iraq is lower than the previous months. The highest values of total ozone column during winter and spring months occur at the overall area of Iraq. The difference between the values of ozone at north and south of Iraq reaches to about (45 to 55) DU in winter and spring whereas during summer and autumn months ranged between (6 to 10) DU. The climatologically distribution of total ozone column throughout the months of the year reflects the effect of meteorological factors and pressure system affecting in weather and climate of these regions.

The existence of a link between meteorological features on the synoptic scale and total ozone column was established by Dobson and co-workers from the 1920s onward [27, 28]. They found that the total ozone column increases and decreases with the passage of cold and warm fronts respectively, and that high total ozone is found to the rear of developing surface cyclones and near the center of mature ones. Correspondingly, low total ozone accompanies surface anticyclones. These correlations occur because synoptic weather systems perturb the flow above as well as below the tropopause, and vertical-motion fields in the lower stratosphere associated with trough/ridge pattern were shown by Al-Khalaf [29] to be capable of producing most of the short-term variance in total ozone column. Finally the averages of total ozone column values during the years (1979-2004) and (2005-2012) have been compared and found that averages of total ozone column during the first time period was higher than the second time period for the months from December to June whereas the other months show a relative convergence in average values of total ozone column.
Figure (2) : The spatial distribution of the monthly average values of TOC (1979-2004) for the months January, February, March, April, May and June.
Figure (3) : The spatial distribution of the monthly average values of TOC (1979-2004) for the months July, August, September, October, November and December.
Figure (4) : The spatial distribution of the monthly average values of TOC (2005-2012) for the months January, February, March, April, May and June.
3.2 Spatiotemporal Trend Analysis

The TOMS ozone data have been arranged as a matrix contain columns (i) and rows (j) which represented the value of total ozone column in a certain point determined by longitude and latitude (i,j).
In order to identify the spatiotemporal trend of total ozone column during the periods (1979-2004) and (2005-2012), we have to convert TOMS ozone grid data from spatial domain to temporal domain. The following steps (as shown in figure 6) have been made:

1. Extract the total ozone column data from the main data file to obtain a file containing three columns (i,j,k) which represent the longitude, latitude and total ozone column values.
2. Arrange the third column (k) in a sigma plot 11.2 software work sheet.
3. Now we have a sheet containing columns of total ozone arrange by longitude, latitude for a certain month of the years (1979-2004).
4. Copy the work sheet contain and open a new work sheet then make transpose paste employing MATLAB R14a. Software (in this step we will convert spatial domain to temporal domain).
5. Copy the last work sheet contain and paste it in MAKESENS 1.0 free ware work sheet to make trend analysis and obtain a trend for each point over selected study area.

Spatial and temporal Total Ozone column (TOC) trends over Iraq during the last 30 years (1979-2012) have been analyzed. This analysis is carried out using satellite TOC data and it is divided into two periods in order to detect changes in the ozone trend pattern: from 1979 to 2004 using the NASA Total Ozone Mapping Spectrometer (TOMS) and from 2005 to 2012 employing Ozone Monitoring Instrument (OMI) data. The analysis of the long-term ozone trends is performed using grid monthly mean data. For the first period (1979-2004), the results show that the TOC trends was negative during most months of the year as shown in figures (7) (8). By contrast, the spatial trend analysis of the second period of study (2005-2012) presented positive TOC during all months of the year except February and September which presented a negative trends. The overall presented positive trends varied from 0.1 to 2.3 DU / year as illustrated in figures (9) and (10). The results of the two period trend analysis indicated that the ozone layer may be responding as expected to the controls on ozone-depleting substances imposed by the Montreal Protocol.
Figure (6): Spatial Trend Procedure Flow Chart
Figure (7) : The spatial distribution of the monthly average values trends of TOC (1979-2004) for the months January, February, March, April, May and June.
Figure (8) : The spatial distribution of the monthly average values trends of TOC (1979-2004) for the months July, August, September, October, November and December.
Figure (9) : The spatial distribution of the monthly average values trends of TOC (2005-2012) for the months January, February, March, April, May and June.
Figure (10) : The spatial distribution of the monthly average values trends of TOC (2005-2012) for the months July, August, September, October, November and December.
4. CONCLUSION

1. The monthly analysis of TOC for all considered regions shows a large variation of TOC throughout the year.
2. Maximum and minimum values TOC remain relatively above the permissible limits of TOC (i.e., 260 DU in mid-latitude regions).
3. The largest TOC amounts occur in the northern region especially during winter and spring months which coincide with a lowering of the tropopause.
4. The difference between the values of ozone at north and south of Iraq reaches to about (45 to 55) DU in winter and spring whereas during summer and autumn months ranged between (6 to 10) DU.
5. According to the spatial and temporal analysis the averages of TOC values during the years (1979-2004) and (2005-2012) have been compared and found that averages of TOC total ozone column during the first time period was higher than the second time period for the months from December to June whereas the other months show a relative convergence in average values of TOC.
6. The spatiotemporal TOC trends were negative during the most months of the year. The spatiotemporal trend analysis of the second period of study presented positive TOC during all months of the year except February and September which presented negative trends.
7. The overall presented positive trends varied from 0.1 to 2.3 DU/year.

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