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Global and Hemispherical Interannual Variation of Total Column Ozone from TOMS and OMI Data

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Abstract

Daily Total Column Ozone (TCO) measurements compiled from Total Ozone Mapping Spectrometer (TOMS) and Ozone Monitoring Instruments (OMI) were used to analyze the global and hemispherical TCO interannual variations. Two periods of TCO measurements were analyzed separately covering full years. For the 1978-1994 period, the TCO showed a global decade decrease rate of 13.45 DU (about −4.3%). For the Northern Hemisphere(NH) the decade decrease rate was of 12.96 DU (−4.0%), while in the Southern Hemisphere (SH) was of 13.57 DU (−4.5%). These decreases in ozone trends, using the totality of TOMS and OMI satellite measurements, are greater than those reported in literature. The 1998-2014 period global TCO decade decrease rate was of 1.56 DU, corresponding 0.94 DU and 0.138 DU for the NH and SH, respectively. The global TCO variations must show a double annual periodicity, the first one with maxima in March due to the Northern Hemisphere (NH) and the second one during September due to the Southern Hemisphere (SH). However, the maxima due to SH TCO interannual variations have gradually vanished. A disturbance in the SH TCO interannual variations has appeared since 1980; graphically the periodicity brakes down and transforms to a double peak from 1985 and on. This effect can be attributed to the hemispheric impact of the ozone hole at the South Pole. Between October 1, 2004 and December 14, 2005 TOMS and OMI have recorded this disturbance unequivocally. We conclude that the disturbance in SH TCO has an irreversible character.

Keywords

Global and Hemispherical Ozone Trends, Total Column Ozone, Interannual Variation, TOMS Data, OMI Data

1. Introduction

Atmospheric Ozone is formed by photo-dissociation induced by UV-C solar radiation in oxygen molecules. Assuming a constant amount of UV-C radiation in the solar spectrum, ozone formation began since the early atmospheric evolution. Since ozone accumulation was very slow, it took hundreds of thousand years to accumulate an equivalent quantity of about 300 Dobson Units (DU) or 0.3 atmosphere-cm. This value is known as the TCO typical value [1]. The poor accumulation results from the relatively easy ozone molecule destruction with UV-B and UV-A solar radiation. Consequently, the concurrence between formation and destruction reactions is much closed.

Since the 30's of the twentieth century, the atmospheric accumulation of chlorofluorocarbons (CFCs) molecules began; these molecules are generally known by the trade name Freons. These are very stable gaseous chlorine molecules, developed for refrigeration, air conditioning and fire extinguishers. Molina and Rowland have highlighted the role of chlorine as a catalyst in ozone destruction reactions, and alerted the world to the destruction of stratospheric ozone by the action of CFCs [2]. Farman *et al.* in 1984 found the ozone layer hole over Antarctica, confirming the predictions of Molina [3]. The identification of a significant TCO levels decrease at mid-latitudes released by the World Meteorological Organization [4] [5] [6] [7] transformed the study of the interannual variations of TCO in an interest topic.

Ozone trends have been analyzed in different ways, by different methods and for different time periods. Geographically, there are multiple local and regional or area studies. Nair analyzed the TCO behavior in Haute-Provence Observatory (France) in two periods, 1984-1996 and 1997-2010 [8]. An analysis between 1979 and 2012 was performed, by Chehade for twenty six 5˚-wide latitude bands from 65˚S to 65˚N; the analysis explained most of the ozone variability to within 70 to 90% [9]. The diversity of studies and approaches makes it difficult to systematize and compare data relating to the behavior of TCO.

There are few studies of global and hemispheric ozone trends. Rowland set the guideline on overall trends and hemispheric TCO [1]. By integrating TOMS data over a 9 year period (November 1978-November 1987), analysis of the 53˚S - 53˚N band led to find a decrease of 2.5% of TCO globally, 1.8% in the NH (0˚N - 53˚N) and 2.9% in the SH (0˚S - 53˚S). Douglas by chemistry climate model simulations (CMM simulation) found that the average global ozone values in 2006-2009 remained at the same level for the past decade, about 3.5% and 2.5% below the 1964-1980 averages for 90˚S - 90˚N and 60˚S - 60˚N, respectively [10].

In this work, we aimed to study the shape and amplitude of interannual mean values of Global and Hemispherical TCO. Non interpolations have been made in the polar night region neither in the case of failure in measurements. That means, non-simulation has been used, and TCO direct values were used from TOMS and OMI data. It is assumed, that to know their behavior is necessary to assess the total ozone amount in the whole atmosphere.

2. Materials and Methods

TOMS and OMI have been producing the largest amount of daily data for TCO. TOMS aboard Nimbus-7 provided global measurements of TCO from November 1, 1978 to May 6, 1993. TOMS aboard Meteor-3 covered from August 22, 1991 until the Meteor-3 failure on November 25, 1994. Earth Probe TOMS was launched on July 2, 1996 and it had continued coverage until December 14, 2005. Long ago, before the Earth Probe failure, on July 15th, 2004, the Aura spacecraft was launched with OMI instruments aboard. Thus, between October 1, 2004 and December 14, 2005, TOMS and OMI relieved the TCO simultaneously.

Each daily TOMS file admits 51840 data corresponding to parcels from 1˚ latitude by 1.25˚ longitude.OMI data file admits 64800 data, corresponding to parcels from 1˚ latitude by 1˚ longitude. However, the parcels, registered by TOMS and OMI never get to the total 100%. Since the TCO measurement principle depends upon the solar UV radiation reflection on certain spectrum bands, those corresponding to the polar night or low light areas cannot be measured.

The polar nights affect the daily global coverage; it does not manage to cover a significant region, which reaches a maximum 29˚ of latitude near the poles on solstices: June 21st-22nd, for the SH and December 21st-22nd, for the Northern Hemisphere.

Moreover, due to the low luminance of the Polar Regions during spring (March 20th-21st) and autumn (September 22nd-23rd) equinoxes, daily global coverage does not manage to cover 6˚ of latitude in the vicinity of the poles.

Due to poor lighting, at the equinoxes you can measure up to about 48,600 daily values of TCO, while on the solstices can measure a maximum of about 43,200 values. Most measurable ozone in the atmosphere is obtained at the time of the equinoxes.

Additionally, occasionally is left unmeasured a variable number of slots in the form of segments, ranging from about 25˚S to 25˚N. These ones appear as Satellite blank images and zeros in the digital files. In the present work no interpolations have been made, and direct values of TCO from TOMS an OMI data were used.

Ozone, corresponding to the parcels uncovered in the vicinity of the poles, due to the polar night or low lighting, it is important in terms of global transportation, but it is not so from the point of view of production and destruction ozone. Therefore, rather than assessing the ozone in the dark polar regions by interpolation, it simply was not taken into account.

3. TCO Interannual Variations (1978-2014)

Two periods of TCO measurements were analyzed separately in such a way that full years were covered. The first one coincides with the major ozone layer deterioration over the Antarctica, comprising from November 1978 to November 1994. The second one coincides with the stabilization period (WMO); it comprises from February 1998 to February 2014. Meteor-3 failure in 1995 produced a lack of data of 18 months. By 1996, the Earth Probe began orbiting, but as shown in Figure 1(a) a second stabilization did not occur until early 1998.

TCO analysis was performed from daily files of measurements covering more than 75% of earth observation parcels; the total number of observable parcels was 51,840 and 64,800 for TOMS and OMI, respectively.

Figure 1 shows global TCO seasonal variations. Graphically, TCO behavior should appear with a double annual periodicity; *i.e.* a maximum between March and April (NH) and another maximum between September and October (SH). The pronounced peaks correspond to the NH and the smaller peaks, interspersed among the large ones, correspond to the SH. However, small peaks gradually fade down away to become a small perturbation from 1990 and on.

Theoretically, seasonal variations are due to concurrence between ozone production and depletion processes. Ozone production must be higher in the periods of the year when the UV-C radiation intensity is higher. The greater the intensity of radiation, the greater oxygen molecules photo-dissociation density. Resulting from the photo-dissociation, oxygen free radicals will react with other oxygen molecules to form ozone.

In Figure 2 the NHTCO seasonal variations are shown. Maxima occur between March and April.

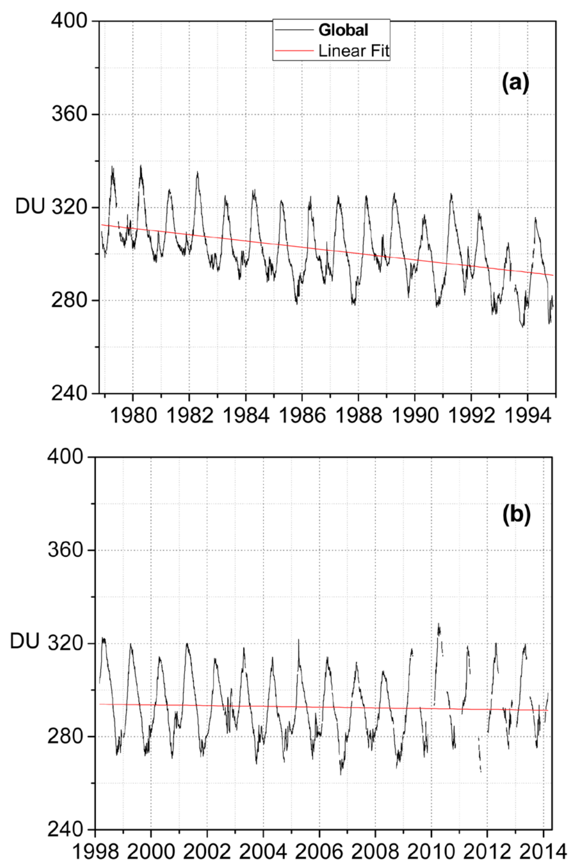

Figure 1. Average daily TCO global values from TOMS: (a) 1978-1994, (b) TOMS (1998-2004) and OMI (2004-2014).

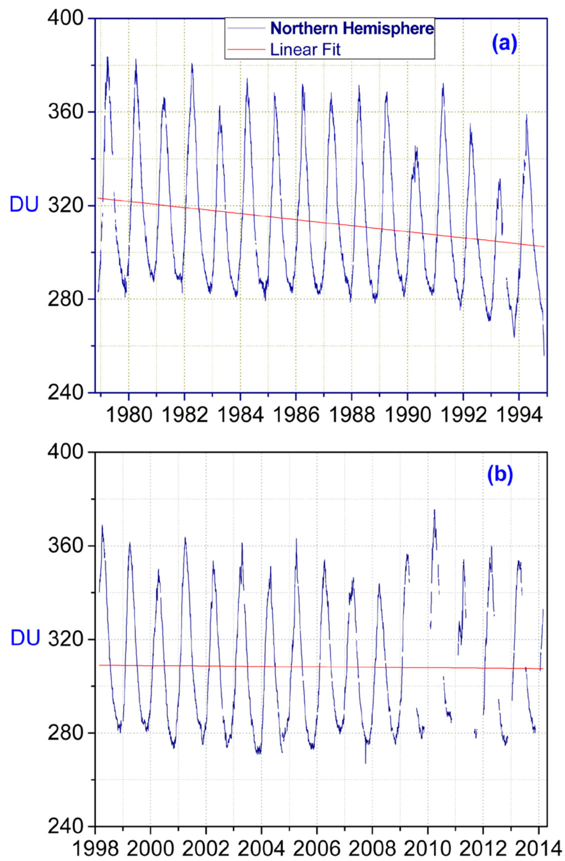

Figure 2. Average daily TCO values from TOMS for the NH (a) 1978-1994, (b) TOMS (1998-2004) and OMI (2004-2014).

SH Interannual variations have no the regularity of the NH ones (**Figure 3**). Since the beginning of TOMS measurements, a disturbance has appeared on the peaks. By 1979, it only appears as a shift on the maximum; from 1980 to 1984 it appears as a maximum depression; while from 1985 and on, the disturbance becomes double peaks, located about September and October (**Figure 3(a)**).

In a previous paper, our working group highlighted the appearance of a disturbance in the TCO seasonal variations at 59.5˚S by analyzing TCO trends for narrow bands of 1˚ latitude [11]. In the present work, it is observed that this disturbance actually hit all the SH.

In the SH ozone peak production should occur in late September; however at this time the ozone layer hole in the polar region is enhanced. Consequently, it can be concluded that the ozone loss is so high that it contracts the SH TCO average and therefore the peak does not have a precise location.

Figure 1(a), **Figure 2(a)** and **Figure 3(a)** highlight the serious TCO deterioration in both hemispheric and global levels along the period 1978-1994, while **Figure 1(b)**, **Figure 2(b)**, and **Figure 3(b)** show a relative stability. The behavior of seasonal variations shows substantial differences between the two hemispheres (**Figure 2** and **Figure 3**).

During 1978 to 1994, the NH TCO seasonal variations ranged between 280

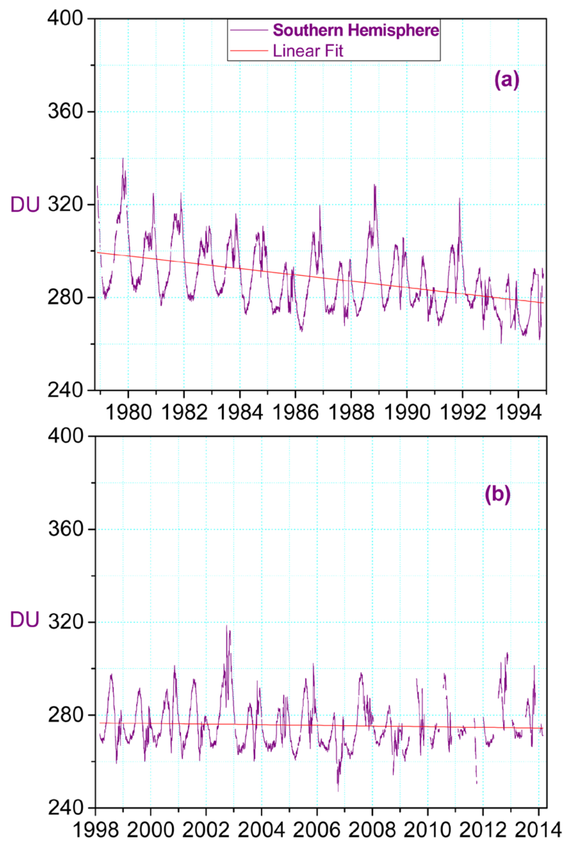

Figure 3. Southern Hemisphere TCO average daily values (a) from TOMS (1978-1994) and (b) TOMS (1998-2004) and OMI (2004-2014).

and 370 DU with an amplitude of 90 DU (Figure 2(a)), while the Southern Hemisphere ones ranged between 250 and 300 DU with an amplitude of 50 DU (Figure 3(a)). The NH TCO daily average values were 24 DU higher than the Southern Hemisphere ones.

In the period 1998-2014, the NH TCO average daily values were 32 DU higher than the SH ones. NH TCO Seasonal variations ranged between 270 and 350 DU with an amplitude of 80 DU (Figure 2(b)); whereas in SH ranged between 260 and 290 with an amplitude 30 DU (Figure 3(b)).

3.1. Period TCO Mean Values

This section aims to verify how far the typical TCO value, of about 0.3 atmosphere-cm or 300 DU, is still a representative global average value.

In Table 1 are presented the TCO average values for both periods, along with its associated standard deviation, and the annual decline and its associated standard error.

3.1.1. Period 1978-1994

At the beginning of the period, *i.e.* between November 1978 and November 1979, the average annual values with a standard deviation were 312.9 ± 10.3 DU global, 320.2 ± 32.8 DU NH and 303.6 ± 17.4 SH. That is, the three mean values

Table 1. Global and hemispherical TCO mean values per period.

	1978-1994				1998-2014			
	Initial TCO 1978-1979		Annual variation		Mean TCO		Annual variation	
	(DU)	σ	(DU/y)	S.E.	(DU)	σ	(DU/y)	S.E.
Global	312.88	10.28	−1.3455	0.0357	292.80	13.64	−0.1558	0.0443
Northern Hemisphere	320.18	32.79	−1.2958	0.0837	308.38	26.99	−0.094	0.0878
Southern Hemisphere	303.35	17.41	−1.3575	0.0367	275.73	10.11	−0.0138	0.032

exceeded the typical TCO value (300 DU).

At the end of the period, the average values were 292.8 ± 13.6 DU global, 308.4 ± 27.0 DU NH and 275.7 ± 10.1 DU SH. Only the NH average value exceeded the typical TCO value.

These data confirm that the difference between the two hemispheres is remarkable, since the TCO deterioration began long before the start of TOMS measurements and is higher for the SH; and the NH deterioration it is more important than it has been considered.

As for trends, the global TCO decreased a 4.3% per decade in the period 1978-1994, equivalent to 1.35 DU per year or DU 13.5 per decade (**Figure 1(a)**). The NH decrease was 4.05% per decade, equivalent to 1.3 DU per year or 13 DU per decade (**Figure 2(a)**). While the SH decrease was 4.5% per decade, equivalent to1.36 DU per year or 13.6 DU per decade (**Figure 3(a)**).

3.1.2. Period 1998-2014

During this period, the global average value was 292.8 ± 13.6 DU, *i.e.* 7.2 DU or 2.4% less than the typical TCO value. The NH average value was 308.4 ± 26.9 DU while the SH was 275.7 ± 10 DU. In both hemispheres a decreased in TCO average is found.

While from the start of satellite measurements the North and South Hemisphere average TCO difference was only 16.6 DU, during the period 1998-2014 this difference was of 32 DU.

Regarding global trends in the period 1998-2014, it was recorded a slight TCO decrease of −0.156 DU, which implies a variation of −1.56 DU per decade. The NH decrease was −0.094 DU per year (−0.94 DU per decade), while the SH was −0.0138 DU per year (−0.138 DU per decade). The order of magnitude of these changes is not significant with respect to the standard deviation. In this case, it can be concluded that there has been a global stabilization of TCO in the past 16 years.

Some influence in recent ozone increases was attributed to the rise in the solar cycle number 23 [12] [13].

4. Conclusions

Using all daily TCO measurements from TOMS and OMI, TCO trends were analyzed. The study was divided into two periods, from November 1978 to November 1994 and February 1998 to February 2014.

In the period 1978-1994, a global decrease of 13.45 DU per decade (−4.3% per decade) was recorded. In the Northern Hemisphere, the decrease was 12.96 DU (4.05%), while in the SH it was of 13.57 DU (4.5%).

Rowland *et al.* reported decreases of 2.5% per decade for the period 1978-1988, taking into account only the latitude 65˚S - 65˚N bands; 1.8% and 2.9% decrease for the NH and the SH, respectively [1]. According to Douglass *et al.* the average total ozone values in 2006-2009 have remained at the same level for the last decade; about 3.5% and 2.5% below the 1964-1980 averages for 90˚S - 90˚N and 60˚S - 60˚N, respectively [10].

The difference, with respect to Rowland *et al.* report, is probably due to the fact of not taking into account the behavior near the poles. Our calculus shows the importance of taking into account the totality of TCO values.

WMO report that the total column ozone averaged over 60˚S - 60˚N and between 2008 and 2012 is lower by about 2% than it was during 1964-1980 [7]; this is slightly less than the value of about 2.5% for 2004-2008 reported in the last assessment [6]. Douglass report decreases in the order of 3.5% and 2.5%, corresponding to 90˚S - 90˚N and 60˚S - 60˚N bands, between 1960-1980 and the 2006-2009 [10]. Probably the fact that the decreases are by decade was omitted in their text. If this was the case, the decrease corresponding to 90˚S - 90˚N band has a close match with our calculations.

In any case, we can remark that we are using the totality of TOMS and OMI measurements to calculate in one hand, the mean daily global and hemispherical TCO values, and in the other, the trends by decade.

In the period 1998-2014 a slight decrease in global TCU of 1.56 DU per decade was recorded. In the NH the decrease was of 0.94 DU, whereas in SH it was of 0.138 DU per decade. The order of magnitude of these changes is not significant. In this case, it is confirmed that there has been a global stabilization in the TCO for the past 16 years, without meaning that there has been a recovery of TCO.

The global TCO variations must show a double annual periodicity, the first one with maxima in March due to the Northern Hemisphere (NH) and the second one during September due to the Southern Hemisphere (SH).These correspond to a global biannual oscillation. However, the TCO SH maxima have gradually vanished. A disturbance in the SH TCO interannual variations has appeared since 1980.Graphicallyin the SH the periodicity brakes down and transforms to a double peak from 1985 and on. It can be considered that this effect is due to the hemispheric impact of the ozone hole at the South Pole. Between 2005 and 2008 OMI have recorded this disturbance unequivocally, with average relative differences of 0.696%. We conclude that the disturbance in the SH TCO interannual variations is a sign of an irreversible modification in TCO behavior.

With respect to the typical TCO values of 0.3 atmosphere cm or 300 DU, this work show that for the period 1978-1994 this value was representative, but it isn't for the period 1998-2014, because the mean value for the SH is on the order of 25 DU under the typical value.

This work reveals that there is no standard way to analyze ozone trends and try to highlight the importance of satellite measurements.

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