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An assessment of the stray-light in 25 years Dobson total ozone data at Athens, Greece

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Abstract

In this study, we investigated the susceptibility of the Dobson spectrophotometer No. 118 to stray-light interference. In this regard, a series of total ozone content measurements were carried out in Athens, Greece for airmass values (μ) extending up to $\mu = 5$. The monochromatic-heterochromatic stray-light derived by Basher's model was used in order to evaluate the specific instrumental parameters which determine if this instrument suffers from this problem or not. The results obtained indicate that the Athens Dobson instrument appears to have an insignificant stray-light error. The comparison of the values of the same parameters measured 15 years ago with the present ones indicates the good maintenance of the Dobson spectrophotometer No. 118. This fact is of crucial importance because the variability of the daily total ozone observations collected by the Athens Dobson Station since 1989 has proved to be representative to the variability of the mean total ozone observed over the whole mid-latitude zone of the Northern Hemisphere. This stresses the point that the Athens total ozone station, being the unique Dobson station in south eastern Europe, may be assumed as a ground-truth station for the reliable conversion of the satellite radiance observations to total ozone measurements.

1 Introduction

The Dobson spectrophotometer was the very first instrument developed in the early 1920s by G. M .B. Dobson to study the circulation in the upper atmosphere through the ozone movements (Dobson, 1957, 1968a). Since the first instrument was constructed, a number of instruments were placed around the world in selected stations and began to be used to measure total ozone content (TOC) on a daily basis. Since then, a long time series of TOC data was created. A worldwide network of instruments was established during the International Geophysical Year (July 1957 to June 1958) in order to better understand and study the atmospheric ozone (Broennimann et al., 2003).

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Even though newer and more sophisticated instruments were created such as Brewer spectrophotometer, the Dobson spectrophotometer is still used and is considered a key part of the ground-based monitoring system of the ozone layer (Bojkov and Balis, 2009; Varotsos et al., 2012a).

The fact that the earliest studies and the preliminary data records of TOC were made using the Dobson spectrophotometer makes this instrument the reference device for TOC data obtained by other ground-based and satellite borne instrumentation. As a result, any new device, on board a satellite or ground-based, that is constructed for TOC measurements is calibrated against Dobson which is considered as a standard instrument (Cracknell and Varotsos, 2012; Varotsos et al., 2014). So, it is important to understand and study all the sources of errors that could lead to a false measurement or miscalculation of TOC.

In brief, the Dobson spectrophotometer uses the differential absorption between two wavelengths of the solar ultraviolet spectrum, which together compose one bandpair. One of the wavelengths of each bandpair is being absorbed (e.g. beam i) by the ozone in the atmosphere, while the other is not (e.g. beam j). Within the instrument the two beams i and j follow different optical paths. At first, total solar light enters the instrument and is directed to a monochromator so that the two beams i and j can be isolated. Beam i is then driven directly to another monochromator and then to a photomultiplier. Beam j follows a slightly different path. After the first monochromator, the beam j passes through an optical wedge which has a different absorption factor at each point and its position is controlled by the user through a graduated dial. Then, the beam j follows the same path as the beam i and arrives at photomultiplier. When the pulsating electric current, that the photomultiplier generates, is zero the beam j has been absorbed by the wedge exactly as the beam i has been absorbed by the ozone in the atmosphere. Knowing the exact position of the wedge the TOC in the atmosphere can be calculated. A detailed description of the principles of measurement and the operation of the instrument is available elsewhere (Cracknell and Varotsos, 2012; Komhyr and Evans, 2008).

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Apart from the absorption of radiation passing through the atmosphere by ozone there is also the scattering (Varotsos et al., 2012b) by aerosol particles and Rayleigh scattering. The effect of the latter on the radiation is corrected by using appropriate factors during the processing of the measurements. In order to eliminate the attenuation caused by aerosol particles, two bandpairs are used for a single measurement of TOC. More details of the procedure can be found elsewhere (Komhyr and Evans, 2008). The band pairs that are used most widely and hence for the experiment presented in the next sections are A and D, where the A bandpair consists of 305.5 and 325.0 nm beams, while the D bandpair consists of 317.5 and 339.9 nm beams.

In the whole world almost 100 Dobson instruments constitute the ground-based network operating under the auspices of the World Meteorological Organization. In order to maintain these instruments and ensure their continuing well-functioning they are involved in regular validation/calibration campaigns. During these campaigns, among other activities, these instruments are used for taking simultaneous measurements with a reference Dobson (Christodoulakis et al., 2008; Tzanis et al., 2009). The goal is to evaluate the performance of a particular Dobson instrument against the reference one. Beside these campaigns there are also other tests conducted on a regular basis at each station, to determine whether the instrument is operating reliably.

There are circumstances though in which an instrument fails to determine accurately the amount of total ozone, not because of a malfunction but rather from the limitations of the instrument (Dobson, 1968b). Specifically, high solar zenith angle measurements are problematic. Major problems can be triggered by the following sources:

– Unwanted sky light from around the sun that could enter the instrument (sky light error).

– The light of long wavelengths that is scattered within the instrument could be combined with the light of short wavelength used for the measurement (internal stray-light error).

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– Apart from the direct sunlight (used for the measurement), the light component by multiple scattering in the atmosphere (atmospheric scattered light error) (Dobson, 1968b; Evans et al., 2009).

Focusing on the stray-light, its presence in the Dobson instrument leads to lower TOC values as the airmass increases (e.g. Labow et al., 2004; McPeters and Labow, 1996). More specifically, if airmass reaches the value 3 then the stray-light results in the underestimation of the TOC measurements. This underestimation in TOC becomes stronger under conditions of high optical path length (e.g. high TOC).

It is worthwhile to note that the slit widths adopted by Dobson (1931) were not very narrow thus preventing stray-light of other wavelengths from falling on the photomultiplier. According to Basher (1982), for direct AD measurements, errors of 1, 3 and 10 % may be present at airmass values of 2.5, 3.2 and 3.8, respectively. This is a permanent problem for instruments operating in high latitudes but also affects ozone vertical profile (Umkehr) measurements performed by using the Dobson spectrophotometer (e.g. Petropavlovskikh et al., 2009, 2011).

The term stray-light describes the part of the radiation in a beam, which was not part of it from the beginning, but has contaminated it due to scattering. It should be stressed that this extra radiation may be due to scattering outside the instrument (external) or scattering within the instrument (internal). The external stray-light includes both wavelengths which are measured from the instrument and wavelengths different from the desired ones (homochromatic and heterochromatic stray-light, respectively). The internal stray-light is due to the large number of the optical surfaces (twenty eight or thirty two optical surfaces, depending on the instrument), which are used in a Dobson spectrophotometer and consists mostly of heterochromatic radiation (Basher, 1982). In other words, the stray-light effect varies from instrument to instrument and each Dobson instrument has a unique signature to stray-light (Olafson and Asbridge, 1981).

Basher (1982) created a monochromatic, heterochromatic stray-light model in order to estimate stray-light levels present in the measurements of a particular instrument. This model uses two parameters that determine whether an instrument suffers or not

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from this problem. This model has been employed in the present paper and it is presented in more detail in the next sections along with the experiments and the analysis performed in order to address the question of whether or not the Dobson spectrophotometer No 118 installed in Athens since 1989 suffers from stray-light error. It is worthwhile to note that this instrument was also checked for stray-light levels about 15 years ago (Varotsos et al., 1998). The combination of the new levels of stray-light with the previously detected ones will enable the reduction of the inaccuracies of the Athens Dobson Station, which according to the literature (e.g Chandra et al., 1996) tracks the seasonal trends derived from the zonally-averaged data of the mid-latitudes of the Northern Hemisphere.

2 Basher's model and other efforts

The stray-light contribution mainly affects the short wavelength beam of the band pairs measured by a Dobson spectrophotometer. This causes the log intensity ratio vs. airmass function to deviate from linearity. The latter generates two errors which are schematically presented in Fig. 1 (Basher, 1982). The first error (referred to as ΔX) is the reduction of the log intensity ratio with airmass which results in reduced TOC values. The second error (referred to as ΔETC) is the overestimation of the extraterrestrial constant (ETC) that should be determined using log intensity ratio vs. airmass data. This error makes the residual curvature in the data to seem small and the TOC measurements to be constant with airmass, but this may conceal a systematic negative error in the TOC measurements (Basher, 1982).

In order to investigate the aforementioned errors Basher (1982) proposed a monochromatic, heterochromatic stray-light model. According to this model stray-light levels are determined by calculating two parameters R_0 and α. R_0 is defined as the ratio of the energy of the monochromatic stray-light source to the energy of the desired band and would be measured for zero airmass. Its values range from 10^{-5} to 10^{-3} and the smaller it is, the less affected the instrument is to stray-light interference.

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α is the ratio of the attenuation coefficient of the stray-light band to that of the desired band. Its values range from 0.7 to 1.2 and the greater it is, the influence of stray-light on TOC measurements is greater.

The equations for the estimations of ΔETC and ΔX are:

$$\Delta \text{ETC} = \frac{1}{\mu_2 - \mu_1} \log \frac{(1 + R_0 10^{\mu_2 \alpha})^{\mu_1}}{(1 + R_0 10^{\mu_1 \alpha})^{\mu_2}} \quad (1)$$

$$\Delta X = \frac{-1}{\mu \Delta \alpha} (\Delta \text{ETC} + \log(1 + R_0 10^{\mu} \alpha)) \quad (2)$$

where μ_1 and μ_2 are the abscissas of the points where the straight line used for determining ETC intersects the log intensity-air mass curve and $\Delta\alpha$ is the bandpair's ozone absorption coefficient (the values of μ_1 and μ_2 used in this study were 1.0 and 2.5, respectively). The μ_1 value is the theoretically smallest value of the airmass, while μ_2 value is considered as the largest value of airmass for which the most reliable bandpairs A and D can be used (Dobson, 1957).

The procedure for using this model in order to specify the parameters R_0 and α for a particular Dobson spectrophotometer is firstly to make a series of observations for a range of values of airmass (experimental data). Then, ΔETC and ΔX are calculated using Eqs. (1) and (2) for different values of R_0 and α. Afterwards, the obtained ΔX values are added to the TOC value of the particular day. These theoretical results are compared with the experimental data in order to estimate the values of R_0 and α for which the best fit is achieved.

There has been another study published recently in order to investigate stray-light within the Dobson spectrophotometer by Evans et al. (2009). The main idea behind this study was presented by Dobson who suggested that if the stray-light component of the current can be measured, then the obtained measurements can be corrected using an appropriate formula (Dobson, 1968b). Evans and his team figured that in order to apply this correction procedure, they should remove the desired wavelengths measured by the instrument using external filters. In order to conduct the experiment,

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a Dobson instrument was modified in a way that only the short wavelength beam of the bandpairs used could be seen by the photomultiplier when a slit mask was pushed in place from outside the instrument.

3 Measurements and results

For the needs of the experiment, we obtained TOC measurements using Dobson spectrophotometer No. 118 for five days; employing AD bandpairs for a wide range of airmass (μ), for details see Table 1.

In Fig. 2 the theoretically estimated errors due to stray-light as a function of airmass for various values of parameters R_0 and specific values of α, of the Basher model are shown. It is obvious from these figures that as R_0 reduces all the curves, even in the case of large α, tend to zero. So we can infer that the smaller the parameter R_0, the more able the specific spectrophotometer is to reject the scattered radiation. As far as the parameter α, is concerned we conclude, based on the same figure, that as its value increases, the influence of the stray light in the TOC measurements increases too.

In Fig. 3 the experimental data along with theoretical values calculated using Basher's model for all the experimental days are given.

In order to evaluate Basher's model parameters for Dobson No. 118 the following analytical steps were accomplished:

1. For each day TOC observations were conducted for various airmass values. The measurements obtained constitute the experimental TOC values (referred to as X_{trend}).
2. The ΔX values were calculated by using the Basher's model for R_0 ranging from $10^{-3.3}$ to 10^{-5} and α ranging from 0.7 to 1.2. In Table 2 are given ΔX values for the case of 5 September 2012 for $R_0 = 10^{-3.8}$ and all α values.
3. Then adding previous ΔX values to the TOC value as measured that day are listed in a table. These TOC values are the theoretically expected values of real

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TOC field if there was no stray-light effect (referred to as X_{true}). An example of this table is given in Table 3 for the same day as Table 2 and for the same R_0 and α values.

4. From the aforementioned values a new average of TOC value for each particular day is calculated, which is referred to as True Ozone Value (see Table 3).

5. Then three different statistical tools (Pearson correlation coefficient, Root Mean Square Deviation (RMSD), Pearson's Chi-square test (CHI SQ.)) are employed in order to estimate the goodness of fit between the experimental data and the theoretical values. This is a mandatory step so that we can identify the values of parameters R_0 and α which best describe Dobson spectrophotometer No. 118 behavior.

Pearson correlation coefficient measures the linear dependence between two parameters, ranging from −1 to 1. When the coefficient equals 1 (−1) it means that the two parameters are absolutely correlated (anti-correlated) while the value 0 indicates that there is no correlation between the parameters. A detailed description of the calculation of Pearson correlation coefficient is available elsewhere (Pearson, 1920). In our case, the two parameters are X_{trend} and X_{true} values. Pearson correlation coefficients were calculated for all R_0 and α pairs. So for each day 66 correlation coefficients (11 values of $R_0 \times$ 6 values of α) (statistically significant at 99 % confidence level) have been obtained. The coefficients among all the experimental days range from 0.881 to 0.998. In order to distinguish the "good" from the "bad" results the average value for each particular day was calculated. The coefficients which were lower from their average value for each specific day, and hence the pairs of R_0 and α, were rejected. In Table 4 are given the obtained correlation coefficients for the case of 5 September 2012. For that day the mean value of all correlation coefficients was calculated to be 0.974. The bold values in the table are the ones which are less than this mean value. The pairs of R_0 and α which correspond to those bold values were rejected.

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Next, a new table calculating the RMSD between X_{true} values and the X_{trend} values for all R_0 and α pairs for the whole range of airmass values (i.e. for all μ values) has been created. RMSD measures the "distance" between simulated values and experimentally obtained values. Actually, it represents the standard deviation of the differences between the simulated and experimentally obtained values. So it is frequently used for evaluating a model. In order to distinguish the "good" from the "bad" results the average value for each particular day was calculated. Values which were greater from their average value, and hence the pairs of R_0 and α, were rejected. In Table 5 are given the obtained RMSD values for the case of 5 September 2012. For that day the mean value of all RMSD values was calculated 25.36. The bold values in the table are the ones which are greater than this mean value. The pairs of R_0 and α which correspond to those bold values were rejected.

Finally, CHI SQ. test to calculate test statistic χ^2 for $X_{trend} - X_{true}$ values (calculated for all R_0 and α pairs) has been employed. In this test experimentally obtained values are compared with theoretical values. It is actually a null hypothesis test. In our case the null hypothesis is that experimental and theoretical values have no difference. In order to decide whether or not to reject the null hypothesis the test statistic χ^2 is computed and compared to a critical value. The determination of this critical value is based on the degrees of freedom engaged in each particular day. Values of χ^2 which were greater than the critical value, according to degrees of freedom for each case and for 95 % significance level, and hence the pairs of R_0 and α, were rejected. In Table 6 are given the obtained χ^2 values for the case of 5 September 2012. For that day the degrees of freedom were 18 so for 95 % significance level the critical value was 28.869. The bold values in the table are the ones which are greater than this critical value. The pairs of R_0 and α which correspond to those bold values were rejected.

Subsequently, the pairs of the parameters R_0 and α that fulfilled the criteria of the above mentioned three statistical tests gathered in a new table for each particular day. For the case of 5 September 2012 the results are presented in Table 7. The rejected pairs of R_0 and α were scored with 0 while the not rejected were scored with 1.

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Then, by taking into account the pairs of values that were the predominant for all the days, the values of the parameters of the Basher model best suiting Dobson spectrophotometer No. 118 have been identified. Repeating this procedure for all experimental days we get the final scorecard which is given in Table 8. In this table, row "SUM" includes the total score obtained for each value of parameter α while column "SUM" includes the total score obtained for each value of parameter R_0. Considering the greatest SUMS for each parameter we conclude that parameter R_0 ranges from $10^{-3.8}$ to $10^{-3.6}$ and parameter α ranges from 0.7 to 0.9.

Athens Dobson Station performs total ozone content measurements of airmass values up to 2.5. For that range of μ, Basher model results introduce a mean underestimation of Dobson No. 118 measurements of about 3.5 DU. In Fig. 4 Dobson measurements along with satellite observations performed by Total Ozone Mapping Spectrometer (TOMS), on board Nimbus-7 and Earth Probe satellites, as well as Ozone Monitoring Instrument (OMI), on board Aura satellite, in Athens, Greece during 1991–2014 are presented. Applying Wilcoxon's test to these data it was found that Dobson underestimates the total ozone with respect to TOMS (Nimbus-7), TOMS (Earth Probe) and OMI by 5, 2 and 5 DU, respectively. These results may be attributed to the plausible underestimation of Dobson measurements due to stray-light effect.

4 Conclusions

The main conclusion drawn from the above mentioned analysis is that the Dobson spectrophotometer No. 118 does not suffer from stray-light interference. In more detail, the parameters R_0 and α of the Basher's stray-light model range from $10^{-3.8}$ to $10^{-3.6}$ and 0.7 to 0.9, respectively. These values are almost equal (R_0: $10^{-3.5}$ to $10^{-3.4}$, α: 0.6 to 0.9) which were calculated about 15 years ago, when a similar check was made on this instrument (Varotsos et al., 1998). This demonstrates that the Athens Dobson instrument remains in a very good condition although it is used daily. It is therefore of great importance to stress that this TOC Station may continue to be considered as

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the ground truth station for the satellite observations over the mid-latitude belt of the Northern Hemisphere.

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Table 1. Dates of the experiment and airmass ranges.

Date	Airmass range
5 Sep 2012	1.174–3.894
24 Sep 2012	1.281–5.045
29 Sep 2012	1.344–5.048
30 Sep 2012	1.327–4.358
31 Oct 2012	1.626–4.058

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Table 2. ΔX values calculated by Basher's model for the case of 5 September 2012 for $R_0 = 10^{-3.8}$ and all α values ($\mu_1 = 1.0$ and $\mu_2 = 2.5$).

ΔX values (DU)						
μ	α					
	1.2	1.1	1	0.9	0.8	0.7
1.174	−25.3	−14.6	−8.4	−4.7	−2.6	−1.5
1.186	−25.1	−14.5	−8.3	−4.7	−2.6	−1.4
1.187	−25.1	−14.5	−8.3	−4.7	−2.6	−1.4
1.290	−23.4	−13.6	−7.8	−4.4	−2.5	−1.4
1.293	−23.3	−13.6	−7.8	−4.4	−2.5	−1.4
1.480	−21.2	−12.4	−7.1	−4.1	−2.3	−1.3
1.484	−21.1	−12.3	−7.1	−4.1	−2.3	−1.3
1.885	−19.7	−11.6	−6.8	−3.9	−2.2	−1.3
1.894	−19.7	−11.6	−6.8	−3.9	−2.2	−1.3
2.262	−23.2	−13.6	−7.8	−4.5	−2.5	−1.4
2.277	−23.4	−13.7	−7.9	−4.5	−2.6	−1.4
2.619	−33.9	−19.4	−10.9	−6.0	−3.3	−1.8
2.640	−34.9	−19.9	−11.1	−6.1	−3.3	−1.8
3.158	−74.4	−42.3	−22.6	−11.6	−5.8	−2.9
3.190	−77.9	−44.4	−23.7	−12.1	−6.1	−3.0
3.431	−107.6	−63.4	−34.1	−17.1	−8.2	−3.9
3.468	−112.6	−66.8	−36.0	−18.1	−8.6	−4.0
3.847	−166.8	−107.4	−61.4	−31.1	−14.4	−6.3
3.894	−173.6	−113.0	−65.2	−33.2	−15.3	−6.7

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Table 3. X_{trend} and X_{true} values for the case of 5 September 2012 for $R_0 = 10^{-3.8}$ and all α values ($\mu_1 = 1.0$ and $\mu_2 = 2.5$).

μ	X_{trend} (DU)	X_{true} (DU)					
		α					
		1.2	1.1	1	0.9	0.8	0.7
1.174	284.8	314.0	303.3	297.1	293.4	291.3	290.2
1.186	288.9	313.8	303.2	297.0	293.4	291.3	290.1
1.187	288.7	313.8	303.2	297.0	293.4	291.3	290.1
1.290	291.4	312.1	302.3	296.5	293.1	291.2	290.1
1.293	291.3	312.0	302.3	296.5	293.1	291.2	290.1
1.480	293.2	309.9	301.1	295.8	292.8	291.0	290.0
1.484	292.7	309.8	301.0	295.8	292.8	291.0	290.0
1.885	294.3	308.4	300.3	295.5	292.6	290.9	290.0
1.894	295.5	308.4	300.3	295.5	292.6	290.9	290.0
2.262	293.8	311.9	302.3	296.5	293.2	291.2	290.1
2.277	295.5	312.1	302.4	296.6	293.2	291.3	290.1
2.619	292.5	322.6	308.1	299.6	294.7	292.0	290.5
2.640	290.2	323.6	308.6	299.8	294.8	292.0	290.5
3.158	264.2	363.1	331.0	311.3	300.3	294.5	291.6
3.190	263.8	366.6	333.1	312.4	300.8	294.8	291.7
3.431	237.2	396.3	352.1	322.8	305.8	296.9	292.6
3.468	231.8	401.3	355.5	324.7	306.8	297.3	292.7
3.847	215.6	455.5	396.1	350.1	319.8	303.1	295.0
3.894	213.2	462.3	401.7	353.9	321.9	304.0	295.4
True Ozone Value		343.0	321.5	307.1	298.3	293.5	291.1

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Table 4. Pearson correlation coefficients among X_{trend} and X_{true} values obtained for the case of 5 September 2012. Bold values are less than the obtained mean value.

Pearson correlation coefficients		α					
		1.2	1.1	1	0.9	0.8	0.7
R_0	$10^{-3.3}$	0.985	0.988	0.987	0.982	0.979	0.979
	$10^{-3.4}$	0.987	0.989	0.985	0.980	0.977	0.978
	$10^{-3.5}$	0.989	0.988	0.983	0.978	0.976	0.977
	$10^{-3.6}$	0.989	0.987	0.981	0.975	0.974	0.977
	$10^{-3.7}$	0.989	0.985	0.978	**0.973**	**0.973**	0.976
	$10^{-3.8}$	0.988	0.982	0.974	**0.971**	**0.972**	0.976
	$10^{-3.9}$	0.986	0.978	**0.971**	**0.969**	**0.971**	0.975
	$10^{-4.0}$	0.984	0.975	**0.968**	**0.967**	**0.970**	0.975
	$10^{-4.5}$	**0.962**	**0.956**	**0.956**	**0.961**	**0.968**	0.974
	$10^{-4.9}$	**0.945**	**0.946**	**0.952**	**0.960**	**0.967**	0.974
	$10^{-5.0}$	**0.942**	**0.944**	**0.951**	**0.959**	**0.967**	0.974

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Table 5. RMSD values among X_{trend} and X_{true} values obtained for the case of 5 September 2012. Bold values are greater than the obtained mean value.

RMSD		α					
		1.2	1.1	1	0.9	0.8	0.7
R_0	$10^{-3.3}$	**46.46**	**29.24**	16.64	16.38	22.49	**27.04**
	$10^{-3.4}$	**42.54**	**25.60**	15.32	17.81	23.84	**27.79**
	$10^{-3.5}$	**38.43**	22.20	14.92	19.40	25.05	**28.41**
	$10^{-3.6}$	**34.25**	19.26	15.39	20.98	**26.10**	**28.92**
	$10^{-3.7}$	**30.13**	16.98	16.47	22.49	**26.99**	**29.34**
	$10^{-3.8}$	**26.19**	15.59	17.92	23.85	**27.75**	**29.69**
	$10^{-3.9}$	22.60	15.17	19.52	25.07	**28.38**	**29.97**
	$10^{-4.0}$	19.55	15.64	21.11	**26.12**	**28.90**	**30.20**
	$10^{-4.5}$	17.10	22.81	**27.10**	**29.35**	**30.38**	**30.81**
	$10^{-4.9}$	23.06	**27.20**	**29.39**	**30.38**	**30.81**	**30.99**
	$10^{-5.0}$	24.36	**27.93**	**29.73**	**30.53**	**30.87**	**31.01**

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Table 6. χ^2 values among X_{trend} and X_{true} values obtained for the case of 5 September 2012. Bold values are greater than the obtained critical value.

χ^2		α					
		1.2	1.1	1	0.9	0.8	0.7
R_0	$10^{-3.3}$	**183.88**	**61.70**	17.58	18.98	**35.42**	**49.59**
	$10^{-3.4}$	**150.78**	**45.83**	15.15	22.60	**39.44**	**52.06**
	$10^{-3.5}$	**119.80**	**33.37**	14.86	26.74	**43.16**	**54.17**
	$10^{-3.6}$	**92.23**	24.38	16.33	**31.07**	**46.49**	**55.94**
	$10^{-3.7}$	**68.87**	18.65	19.12	**35.38**	**49.42**	**57.41**
	$10^{-3.8}$	**50.07**	15.81	22.80	**39.46**	**51.94**	**58.62**
	$10^{-3.9}$	**35.82**	15.37	26.99	**43.22**	**54.08**	**59.61**
	$10^{-4.0}$	25.83	16.82	**31.38**	**46.58**	**55.88**	**60.41**
	$10^{-4.5}$	20.43	**36.26**	**49.77**	**57.43**	**61.05**	**62.62**
	$10^{-4.9}$	**36.97**	**50.13**	**57.57**	**61.08**	**62.62**	**63.26**
	$10^{-5.0}$	**40.96**	**52.57**	**58.76**	**61.61**	**62.84**	**63.35**

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Table 7. Scorecard of all R_0 and α pairs for the case of 5 September 2012.

		α					
		1.2	1.1	1	0.9	0.8	0.7
R_0	$10^{-3.3}$	0	0	1	1	0	0
	$10^{-3.4}$	0	0	1	1	0	0
	$10^{-3.5}$	0	0	1	1	0	0
	$10^{-3.6}$	0	1	1	0	0	0
	$10^{-3.7}$	0	1	1	0	0	0
	$10^{-3.8}$	0	1	1	0	0	0
	$10^{-3.9}$	0	1	0	0	0	0
	$10^{-4.0}$	1	1	0	0	0	0
	$10^{-4.5}$	0	0	0	0	0	0
	$10^{-4.9}$	0	0	0	0	0	0
	$10^{-5.0}$	0	0	0	0	0	0

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Table 8. Final scorecard for all R_0 and α pairs and for all experimental days.

		α						SUM
		1.2	1.1	1	0.9	0.8	0.7	
R_0	$10^{-3.3}$	0	0	1	1	2	2	6
	$10^{-3.4}$	0	0	1	2	2	2	7
	$10^{-3.5}$	0	0	1	2	2	2	7
	$10^{-3.6}$	0	1	1	2	2	2	8
	$10^{-3.7}$	0	1	1	2	2	2	8
	$10^{-3.8}$	0	1	2	2	2	2	9
	$10^{-3.9}$	0	1	1	1	1	2	6
	$10^{-4.0}$	1	1	1	1	1	2	7
	$10^{-4.5}$	1	0	0	0	0	1	2
	$10^{-4.9}$	0	0	0	0	0	1	1
	$10^{-5.0}$	0	0	0	0	0	1	1
SUM		2	5	9	13	14	19	

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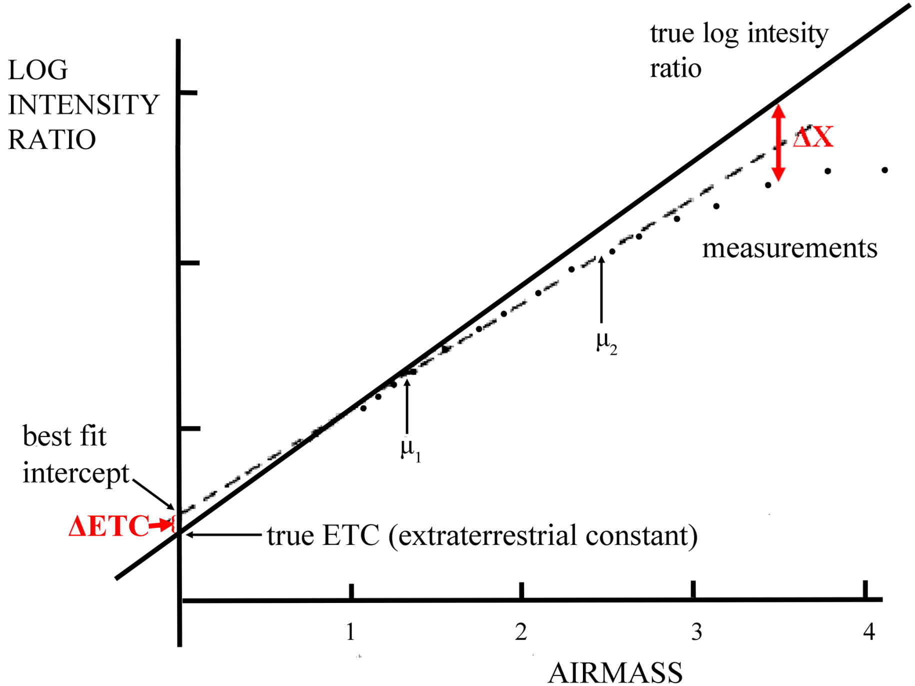

Figure 1. Schematic presentations of the stray-light errors induced on log intensity ratios (ΔX) and on the determination of extraterrestrial constants (ΔETC) (Basher, 1982; modified).

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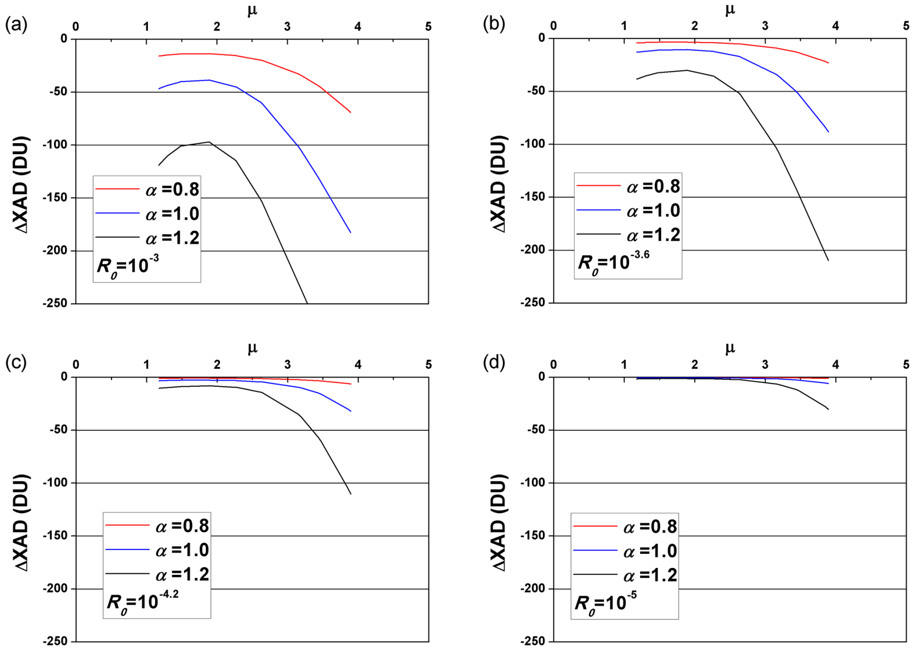

Figure 2. Variation of ozone error ΔXAD as a function of airmass μ, for various values of parameters R_0 and α of the Basher model and for airmasses μ_1 = 1.0 and μ_2 = 2.5.

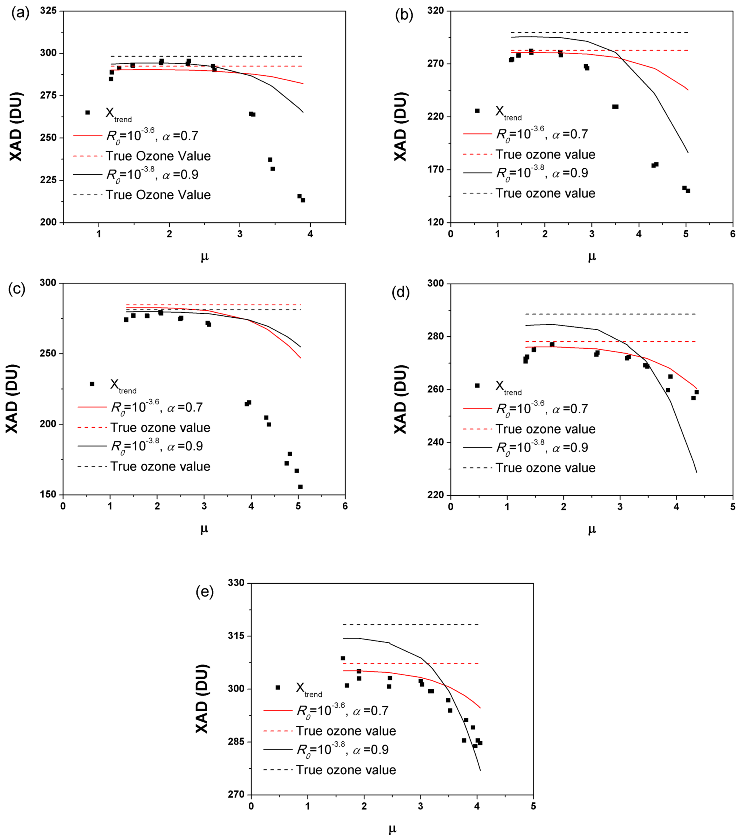

Figure 3. Comparison of experimental data (black dots) with stray-light model applied for two different sets of parameters R_0 and α (solid lines) along with the corresponding True Ozone Values (dashed lines). **(a)** 5 September 2012, **(b)** 24 September 2012, **(c)** 29 September 2012, **(d)** 30 September 2012 and **(e)** 31 October 2012. Model was executed for values of airmass $\mu_1 = 1.0$ and $\mu_2 = 2.5$.

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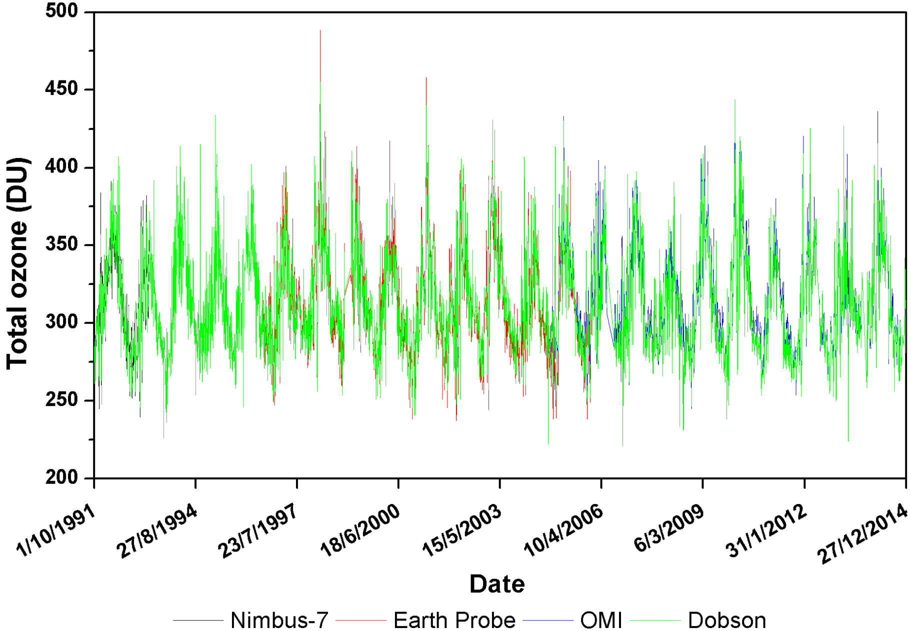

Figure 4. Total ozone content daily observations performed by satellite-borne instruments and Dobson spectrophotometer No. 118 in Athens, Greece during 1991–2014.

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