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Test of an empirical method for ozone detection in the stratosphere using two filtered broadband UV- meters

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Abstract

We describe a simple method to detect significant changes of the total ozone column from global (diffuse and direct) zenith sky measurements taken at the Earth's surface. The calculation of the total ozone column relies on measured irradiance at two wavelengths in the ultra violet part of the solar spectrum. One of these (i.e. 306 nm) are appreciable absorbed by ozone whereas the other (i.e. 360 nm) is not. The method provides measurements for clear as well as for cloudy sky conditions.

The natural logarithm of the irradiance ratio at the two wavelengths, corrected for solar elevation dependence, is assumed to be proportional to the amount of ozone in the atmospheric column. It is assumed that the two wavelengths have same properties in the atmosphere excluding the impact of ozone. Therefore variations in atmospheric conditions should cancel out in the ratio. We found a strong correlation between our calculated quantity and ozone measurements at The Danish Meteorological Institute, DMI, Copenhagen, Denmark, which is approximately 30 km away from the measuring site. The correlation coefficient, R , from linear regression had the value 0.90, and the standard deviation, S_{res} , for the residuals were 10.6 DU (Dobson Units), and the mean value was 322 DU, obtained from every day point measurements during the Swedish summer, total 67 days.

Key Words : ozone, ozone measurements, ozone detection, UV, ultraviolet radiation, UV-measurements, solar UV

1. Introduction

Ultraviolet (UV) radiation (100-400 nm) emanating from sun travels unaltered until it enters the earth's atmosphere. Here, absorption and scattering by various gases and particles modify the radiation profoundly, and by the time it reaches the terrestrial and oceanic biospheres, the wavelengths which are most harmful to organisms have been largely filtered out [1]. If the atmosphere's filtering abilities are changed in a way that the most harmful part of the UV radiation increases, detrimental effects on terrestrial life forms might occur. Skin cancer related to excessive sun tanning and the relation to ozone depletion is today a progressive research issue [2]. Recent measurements [1] also indicate a decrease of the important phytoplankton productivity associated with increased UV during passage of the ozone hole over Bellingshausen Sea.

Today ozone measurements are dedicated to special institutions. In Sweden the Swedish Meteorological and Hydrological Institute (SMHI) is responsible for monitoring ozone and UV radiation. Monitoring programs and networks are established together with the Swedish Radiation Protection Institute (SSI). Worldwide, similar programs exist and the acquisition sites are usually located in strategic positions e.g. near Polar Regions with the obvious purpose to indirectly watch ozone trends. The instrumentation needed for ozone detection, for instance Brewer Ozone Spectrophotometer, is extremely expensive and require professional staff for maintenance, operation and data interpretation.

We have investigated the possibility to use relative simple instrumentation to detect UV trends and then utilize these data to calculate a quantity which might be proportional to the ozone layer or the Dobson Unit. The hypothesis provides some assumptions and approximations to make the input data more easily accessible. The purpose of this project is to explore a simple and inexpensive ozone detection method. This report covers the practical and theoretical fundamentals how to set up a station for testing the theory and then comparing the results with conventional ozone meters e.g. Brewer Ozone Spectrophotometers.

2 Materials and Methods

2.1 Detector

It has been shown by Wester [4], that the output from the 360 nm wavelength band is proportional to UV-A irradiance (Wm^{-2}). In the same report a relationship between weighted DUV (Damaging UV) irradiance (Wm^{-2}) and a narrow wavelength band around 306 nm has also been verified, but with greater discrepancy. The greater discrepancy in the later experiment is caused by that the DUV spectrum is shifted towards higher wavelengths at low sun altitudes. The shift occurs since the relative solar spectrum is changed and this change is mainly produced by the amount of ozone. At low sun altitudes the rays from the sun geometrically have longer way to go through the atmosphere and the situation is similar to an increase of the stratospheric ozone. The spectra is only drastically changed in the UV-B region and keep its shape in the UV-A region, considering ozone variations [1].

Wester has shown [5] that filter instruments can be used to measure the ozone amount. **Figure 1** show ozone column variations measured with a dual pass-band filter radiometer in

Stockholm 1989-1991 compared to reference ozone values from SMHI, Norrköping. The method used in reference [5] is slightly different from the one described here. Wester uses an envelope technique, but the fundamental principles are the same.

One of the purpose was to use a simple measuring device to reach reasonable costs. It is an enormous trade off in initial costs between a spectro-radiometer and broadband detector systems. A problem is that the spectro-radiometer is an inevitably instrument for calibration of broadband detectors. This means that cooperation between institutions is a condition for successful research.

The detector which was used, here called the UW-detector, belongs to the category of physical broadband radiometers. The UW-detector was constructed in the laboratory by the co-author Wester and is designed with two probes, with the spectral sensitivity around 306 nm and 360 nm.

Spectral selectivity is a product of the spectral response of the detector element and the spectral transmission of the filters preceding the detector element. The instrument is designed to have no spectral sensitivity outside their measuring spectral regions. This is particularly vital for measurements in the narrow low level UV-B spectral region where the irradiance are several orders of magnitude lower than in the UV-A, visible and IR regions of the solar spectrum.

The spectral selectivity (FWHM) for the UV-B output is 5 nm at 306 nm and for the UV-A output 10-15 nm at 360 nm [4].

The detector unit have temperature controlled heating in order to avoid internal moisture and external snow and ice cover. It is also vital to keep the temperature constant, because the wavelength selectivity of the filters is sensitive to temperature changes. Moisture was reduced by placing silica gel inside the housing. The detector's two channels is connected with a computer, PC386, which samples data simultaneously for the two channels, every half second, over 5 minutes duration and then calculates a mean value. Sampling duration starts every 15 minutes.

This detector has a brilliant construction which makes a dome unnecessary because the diffuser is a part of the housing. The UW-detector has a flat Teflon diffuser for cosine angular response and to reduce the polarization effect. The detector's aluminium housing is hermetically sealed. All results considering ozone measurements in this report are achieved by the UW-detector.

2.2 Calibration

The detector should satisfy different demands. It is important to know the detector behaviour under all circumstances so no misinterpretations occur when data are analyzed. Before inter-comparisons are done with a spectro-radiometer or an already calibrated broadband detector inherent parameters should be controlled e.g. cosine response, detector response function, constant operation, temperature dependence, linearity, dark currents.

2.2.1 Cosines response

It is convenient to make the detector response proportional to the cosines of the incident angle.

We have used a slide projector, connected with the electric main, as source with unfortunately a ventilated halogen lamp (24 V 250 W 7748S EHJ, Philips). The halogen lamp consists of a tungsten filament and a silica (quartz) bulb. Quartz bulbs have the most suitable thermal properties and are also very transparent to UV [6]. The camera was aligned to the centre of rotation, COR, and placed on a sleigh which could move the camera to any angle. The detector window is positioned perpendicular to the rays at zero degrees and with its centre at COR.

Cosine measurements were performed for the UW-detector's UV A and UV B window.

2.2.2 Dark currents

Dark currents were subtracted before data processing considering the cosines test for the UW-detector. At ozone observations dark currents were neglected since they were estimated to be less than 1% of the signals magnitude.

2.2.3 Detector Response Function, Constant Operation, Temperature Dependence, Linearity

We did not make any tests for these factors. The reader is referred to reference [4] for more information.

2.3 Ozone Detection Theory

The idea is to measure two signals in the UV-range. One around 306 nm where absorption by ozone is strong, and one around 360 nm which has been found to be relatively independent of ozone variations.

The wavelength 306 nm should be a good choice for three reasons. Firstly, the irradiance of 306 nm is in the part of the solar spectrum that is greatly influenced by ozone changes, secondly the absolute irradiance level can be accurately detected, and thirdly 306 nm represents the peak value of the DUV-weighted solar spectrum, and thus can be used for public protection purposes.

The wavelength 360 nm should be a good choice for two reasons. Firstly 360 nm is in the part of the solar spectrum which does not suffer from relative variations because of ozone changes. Thirdly, 360 nm is fairly proportional to the energy deposit in the UV-A range, and thus can monitor energy deposit on earth's surface [4].

We conclude that the wavelength dependence is primarily due to ozone absorption in the interval 280-330 nm and to Rayleigh scattering at all wavelengths. Cloud cover, aerosols, and surface albedo have strong effect of the absolute value of the transmission, but do not significantly alter the wavelength distribution. Thus the UV-A signal detects the absolute changes for the whole spectra and the UV-B signal detects the spectral changes which are assumed to be proportional to the ozone column.

The irradiance E_i across the channel of the photometer is the solar spectrum weighted with the response function R_i of the detector filter.

$$E_i = \int_0^{\infty} R_i(\lambda) \cdot F(\lambda) d\lambda \quad [\text{W/m}^2]$$

where $F(\lambda)$ ($\text{Wm}^{-2}\text{nm}^{-1}$) is the solar spectral energy distribution, and the index i refers to a specific channel .

The detector element transforms E_i to a current or a voltage which gives the signal, S_i . It should be pointed out that filtered UV-meters specified for the same wavelength but with a different response function or FWHM do not have the same response for solar spectral changes. The signal from 360 nm is assumed to be proportional to UVA irradiance which is the total irradiance from the UVA range.

$$E_{UVA} = \int_{315}^{400} F(\lambda) \cdot d\lambda \approx S_{360} \cdot c_{UVA}^{-1} \quad [\text{W/m}^2]$$

The same principles apply for DUV. DUV is the solar spectrum weighted with a biological action spectrum $A(\lambda)$.

$$E_{DUV} = \int_{280}^{315} A(\lambda) \cdot F(\lambda) \cdot d\lambda \approx S_{306} \cdot c_{DUV}^{-1} \quad [\text{W/m}^2]$$

where c_{UVA} and c_{DUV} ($\text{Wm}^{-2}\text{V}^{-1}$) are average calibration constants for the UVA and DUV wavelengths intervals.

UVA and DUV (W/m^2) will fluctuate by 5 % respectively 25 % error for Swedish summer conditions [4]. It is convenient to calibrate this type of detectors at high seasonal levels of radiation, to get maximum exposure range. This report has no intention to confirm the relationships described above but to encourage thinking about the information potential of the two used wavelengths.

The four factors which mainly influence the meter reading can be described as

$$S_{360} \propto \sin^{pa}(\alpha) \cdot \left(\frac{R_0}{R}\right)^2 \cdot F_s \cdot W_A$$

$$S_{306} \propto \sin^{pb}(\alpha) \cdot \left(\frac{R_0}{R}\right)^2 \cdot F_s \cdot W_B \cdot \text{Exp}[-c_{DB} \cdot DB]$$

where:

- $\sin^p(\alpha)$ is the solar elevation dependence
- R_0 is the average sun-earth distance
- F_s is a factor for variations in solar activity
- W_A and W_B are weather constants
- DB is the ozone layer in Dobson units

Above the ozone layer in the atmosphere the UVA-B intensity has a solar elevation dependence of $\sin^p(\alpha)$ there p is depending on the measuring geometry and amount of backscattered radiation. At ground level same dependence occur but with other powers mainly due to the atmospheric scattering.

W_A and W_B are weather constants which depend on cloud cover, aerosols and surface albedo which affects the absolute value of transmission. We assume that the quote of the weather constants, W_A/W_B is constant. That the ratio W_A/W_B is constant is a consequence of the assumption that the two wavelengths have the same scattering properties in the atmosphere, excluding the impact of ozone.

The solar UV-output changes with sun-earth-distance and solar activity. Solar intensity variations of extra terrestrial radiation due to solar distance is about 6.8 % considering the square law [1] and due to solar activity changes only 0.1 % variation [7]. Solar output variations affect UVA-B relative the same, thus in calculations of $\ln Q$ it will cancel out. The major difference between the two signals is the exponential function. This function corresponds to the impact of ozone.

We want to find a quantity proportional to ozone and independent of solar elevation angle. See reference [1] for equations to calculate the solar elevation angle α .

$$A = \frac{S_{360}}{\sin^{p_a}(\alpha)} \propto \left(\frac{R_0}{R}\right)^2 \cdot F_S \cdot W_A$$

$$B = \frac{S_{306}}{\sin^{p_b}(\alpha)} \propto \left(\frac{R_0}{R}\right)^2 \cdot F_S \cdot W_B \cdot \text{Exp}[-c_{DB} \cdot DB]$$

We form the quantity Q .

$$Q = \frac{A}{B} \propto \frac{W_A}{W_B} \cdot \text{Exp}[c_{DB} \cdot DB]$$

Perform the natural logarithm.

$$\ln(Q) \propto \ln\left(\frac{W_A}{W_B}\right) + c_{DB} \cdot DB$$

Now we can form the linear relationship

$$DB = m + c \cdot \ln(Q)$$

Thus we have formed a quantity proportional to the ozone column measured in Dobson units. The detector setup measures daily curves and appropriate values of the two signals together with time of day are extracted. The time of day, longitude and latitude is needed to calculate the solar elevation angle at measurement. With a simple operation $\ln Q$ can be calculated and compared to conventional ozone measurements.

Our method is primary a relative method and will be calibrated against an absolute reading instrument e.g. Brewer ozone spectrometer. It should be mentioned that it is a risk of systematic errors when using empirical relationships, since the radiation transfer is very complex in this case. A change in the ozone height distribution that is different from the one used for the development of the relationship can cause such an error [8].

2.4 Data Evaluation

The UV-detector was positioned for zenith sky geometry. Data was sampled, every half second, during 5 minutes every 15 minute. After 5 minutes sampling a mean value was calculated and restored in the acquisition system. Values extracted from plots followed a few criteria:

- 1) Values were primarily taken around *noontime* because to get maximal signal and least impact of ozone due to maximal solar elevation angle.
- 2) *Daily point measurement*: Only one measured value of irradiance from each day was used in the calculations. Daily curves were plotted to extract appropriate parts with minimum of rapid cloud movements which result in an icicle pattern. To avoid great

signal changes under measure, values were extracted from a period with relative constant input. This means in principle that three values (45 minutes time period) with almost same magnitude were considered and the middle one of these was extracted. Does not have to be around noon time.

- 3) *Noon time mean value measurement:* Around noon time or at 9 a clock to 11 a clock GMT, eight readings were used. The mean value of eight $\ln Q$ calculations was used.

Finally when enough data had been sampled $\ln Q$ is calculated for the summertime period. Ozone values from DMI, Copenhagen were plotted against $\ln Q$ to find the linear relationship. Our measurements were not synchronized with Copenhagen except that we measured the same day.

3. Results

3.1 Calibration

The UW-detector was tested for cosines response by a collimated source. **Figure 2** shows the cosines response versus incident angles, for the UVA and UVB window.

3.2 Ozone Detection

When the UW detector had operated from 1994-06-09 - 1994-08-14 data were evaluated. For cloud free days or blue sky condition, curves shown in **figure 3A** were obtained. Theoretically a power function of sinus is added in the plot. It is a good agreement between power functions of sinus and the daily measured curve. To show the scatter of the choice of power from other days, other curve-fits are included in the graph. Powers are chosen from curve fits based on linear regression of a.m. and p.m. part of the curve and a mean value were used. Powers for actual curve can be found in **table 1** for both the a.m. and the p.m. part of the day. **Table 1** shows ozone data for the actual day and the day before and after the actual day, to demonstrate if a big ozone layer variation is going on. A statistical evaluation of **figure 3A** can be found in **table 2**.

The normalized measured values were plotted against the theoretical values, which in the ideally case would result in a perfect line with slope value one. Problems arise when you try to evaluate curves with icicle pattern as shown in **figure 3B**. If we assume a constant ozone column between 12:00 and 14:00 Swedish summer time for a blue sky day and a cloudy day with icicle pattern, $\ln Q$ should have almost constant values, but $\ln Q$ makes dips due to cloud effects, see **figure 3B**. **Figure 3C** shows $\ln Q$ over a blue sky day (July 4). $\ln Q$ is here relatively constant over the day. When sun is under the horizon $\ln Q$ has no meaning and falls in magnitude.

The geographical localization of the measuring sites which this report concern are shown in **table 3**. The geographical distance between Lund and Copenhagen is approximately 30 km. Calculated $\ln Q$ for observations made in Lund versus the amount of ozone in Dobson Units measured in Copenhagen, for the summer period 940609-940814 are plotted in **figure 4A**. The straight line is obtained by linear regression.

Table 4 shows the statistical result from linear regression for noon time mean value measurements and daily point measurements. Ozone data from Copenhagen and Norrköping

has been used. **Figure 5A** shows the difference between Norrköping and Copenhagen. Same data as in **figure 4A** but only for the 24 most cloud free days taken into account are plotted in **figure 4B**. Statistical output from linear regression can be studied in **table 4**. **Figure 5B** shows measured ozone values in Copenhagen compared with the calculated curve, based on our linear model with $\ln Q$ as the variable. All calculations are made in Microsoft XL sheets of version 5.0.

4. Discussions

4.1 Calibration and Setup

Cosines response is a good standard for these kind of detectors, and which allows inter-comparisons with other detectors. The UW detector shows good cosines response. Inexactness of the geometry of the experimental setup should explain the small discrepancy. Therefore a statistical evaluation of the cosine response has no meaning.

4.2 Ozone Detection

A correlation can be seen in **figure 4A** and **figure 5B**. Hypothetically a better correlation is expected for good weather conditions (**figure 4B**). However a somewhat lower correlation and a better or lower standard error for the residuals were found, see **table 4**. The worse correlation can be explained by that for the 24-days case the ozone layer did not range very much in magnitude. It can be concluded that different weather conditions do not affect the correlation much, according to these curves, which was one of the assumptions in the theory. The spread can probably partly due to other complex atmospheric conditions not taken into account here and to inherent detector factors.

Perhaps the model contains a theoretical artefact which might explain the spread. $\sin^p(\alpha)$ corrects measured values and eliminate the solar angle dependence. This means that if it is constant ozone over a day no matter which time or solar angle you chose to measure the calculated value should be the same, see **figure 3C**. The constancy lies in the choice of p_b and p_a (**table 1**). To explain the spread of the calculated values an ozone dependence in the power p is easily imaginable. Different ozone columns modify the solar spectra and lower or raise UVB signals. The straight path through the atmosphere gives the effective ozone layer, $(L_{O_3})_{eff}$.

$$(L_{O_3})_{eff} = \frac{L_{O_3}}{\sin(\alpha)}$$

where L_{O_3} is the length of the ozone column.

If we consider simple attenuation

$$S_{306} \propto \text{Exp} \left[- \frac{L_{O_3}}{\sin(\alpha)} \cdot c \right]$$

This exponential dependence affects the shape of the UVB curve. A variation of ozone would lead to different shapes of the UVB curve which are the same as a change in the power p in our theory.

We studied the effects of a drastic change in our theory. The curve of $\ln Q$ versus time of a day with constant ozone would be either convex or concave instead of constant if pb is over or under estimated. From **table 1** it might be possible to verify if pb has a strong ozone dependence. For higher ozone values pb should increase and result in a more conical curve profile, for the daily UVB-curve.

In the theory a ozone dependence of pb will result in a nonlinear dependence between $\ln Q$ and the ozone layer.

$$V = \frac{S_{360}}{S_{306}} \propto c3 \cdot \frac{\sin(\alpha)^{1.48}}{\sin(\alpha)^{2.86 \cdot DB \cdot c1}} \cdot \text{Exp}[c2 \cdot DB]$$

where $c1$, $c2$ and $c3$ are only calibration constants and will be determined empirically.

$$\ln[V] \propto 1.48 \cdot \ln[\sin(\alpha)] + DB \cdot (c2 - 2.86 \cdot c1 \cdot \ln[\sin(\alpha)]) + \ln[c3]$$

$$\ln[V] = m + c \cdot DB$$

$$m = \ln c3 + 1.48 \cdot \ln[\sin(\alpha)]$$

$$c = c2 - 2.86 \cdot c1 \cdot \ln[\sin(\alpha)]$$

The variable $\sin(\alpha)$ affects both slope and interception in a way that cannot be corrected to get the linear dependence. Anyhow, **table 1** might provide us with information about the topic.

If a major ongoing change of ozone occurs over a day, an asymmetric UV-B curve should be the result. Difference in p between a.m. and p.m. part of the curve should indicate this change. In **table 1** we can see that UVA shows no big variation in agreement with theory. UVB powers indicate a change at 25th of June and 5th of August. But according to measured values in Copenhagen ozone values for 24/6 and 26/6 are 329 respectively 307 and, 4/8 and 6/8 gives ozone values 294 respectively 294. This change of the UV-B curve's shape cannot be explained by ozone changes. Changes of the curve shape might have to do with other atmospheric conditions. From **table 2** we can see that the choice of the powers is not very critical.

When the sun is obscured of a cloud the detector sees only diffuse radiation. **Figure 5B** shows dips of $\ln Q$ during a day with strong variations in exposure. This could be explained by the fact that the shorter wavelength, 306 nm, is more diffuse than the longer one, 360 nm and therefore they do not suffer equally in signal magnitude when sun is behind a cloud. The effect of cloud scattering will not exactly cancel because the cloud optical depth will affect the two wavelengths differently [9] (although assumed wavelength independent). The irradiance ratio between scattered and global irradiance is dependent of optical depth and solar zenith angle, as a consequence of wavelength dependence of ozone scattering and molecular scattering.

To extract values from days like June 30, **figure 3B**, it should be most convenient to pick peak maximums. Unfortunately, our evaluation criteria taking the middle value of three relatively constant readings, does not include the detection of signal peaks. This may have contributed to a worse correlation in the results. The correction of solar angle is in a way based on clear day conditions with both diffuse and direct radiation which forms the $\sin^p(\alpha)$ dependence.

Finally the curve in **figure 4A** gives a correlation coefficient, $R=0.90$, $Se=10.6$, $p=0.000$, which strongly indicate that this method is applicable. A quote between UVA and UVB should follow a sort of exponential law, in relation to ozone layer thickness, according to simple attenuation of radiation which usually follow an exponential function $\text{Exp}[-x]$. **Figure**

5B shows measured ozone values in Copenhagen compared with the calculated curve, based on our linear model with lnQ as the variable. A correlation can be seen and the overall trend is the same between the both measurements.

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Tables

Table 1. Powers of sinus functions from curve fits of almost cloud free days. Daily curves have been separated to a.m. and p.m. parts. $\text{Sin}(\alpha)^p$ (powers used in the ozone calculations were $p_a=1.48$ and $p_b=2.86$).

Powers p	UV-A, p_a		UV-B, p_b		Ozone (DU)*		
	a.m.	p.m.	a.m.	p.m.	Day no.	(Day before, and after)	
Jun 25	1.52	1.46	3.01	2.76	176	295	(329,307)
Jul 04	1.53	1.43	2.94	2.83	185	308	(310,304)
Jul 25	1.44	1.70	2.86	2.82	206	312	(315,327)
Aug 05	1.40	1.45	2.71	3.10	217	292	(294,294)
Aug 11	1.41	1.49	2.72	2.86	223	296	(304,309)
Average	1.46	1.49	2.85	2.87			
Av.am/pm	1.48		2.86				

* Ozone data from Copenhagen

Table 2. Statistical evaluation of the curves in **figure 2A**. The curves are normalized to the point which corresponds to maximum solar elevation angle. The measured curve are tested against different theoretical sinus curves, shown in **figure 2A**. The normalized measured values were plotted against the theoretical values. Linear regression is used. The day of measurement was July 4 and the most appropriate powers can be obtained by the mean value of a.m. and p.m. part given in **table 1**.

Power, p	Correlation coefficient R	Slope, k	σ_{Slope}
1.48	1.00	1.007	0.009
1.53	1.00	1.024	0.010
1.40	1.00	0.978	0.010
2.88	1.00	1.006	0.005
3.10	1.00	1.025	0.006
2.71	1.00	0.989	0.004

Table 3. Geographical localization of the measuring sites.

Site	Lund	Copenhagen	Norrköping	Stockholm
Longitude	13.2E	12.6E	16.2E	18.0E
Latitude	55.7N	55.7N	58.6N	59.4N

Table 4. Results and statistics from linear curve-fits between lnQ and the ozone layer, (DU). Linear regression is made with use of powers from **table 1**.**Regression against Copenhagen** ($p_a=1.48$ and $p_b=2.86$)

LnQ values are calculated from the average value of 8 lnQ measurements each day (noon time mean value measurement).

1-Whole summer

LnQ values are calculated from 1 irradiance measurement each day (point measurement).

2-Whole summer**3-24 Best days****Regression against Norrköping** ($p_a=1.48$ and $p_b=2.86$)

LnQ values are calculated from 1 irradiance measurement each day (point measurement).

4-Whole summer**5-24 Best days**

Regression	1	2	3	4	5
R	0.88	0.90	0.83	0.712	0.365
R-sq	0.78	0.81	0.69	0.51	0.133
Standard Deviation, S_{res} , SD, (for residuals), [DB]	11.5	10.6	5.8	18.3	13.45
Observations N	67	67	24	67	24
Intercept, m	-1125	-1163	-697.3	-931.6	-291.0
SE Intercept	96.4	89.5	143.8	154.4	332.4
p-value Intercept	0.000	0.000	0.000	0.000	0.391
Slope, c	200.0	204.4	139.9	174.3	84.79
SE slope	13.3	12.4	19.9	21.3	46.1
p-value Slope	0.000	0.000	0.000	0.000	0.079
Mean Value, [DB]	321.6	321.6	312.3	330.9	320.9

Figures

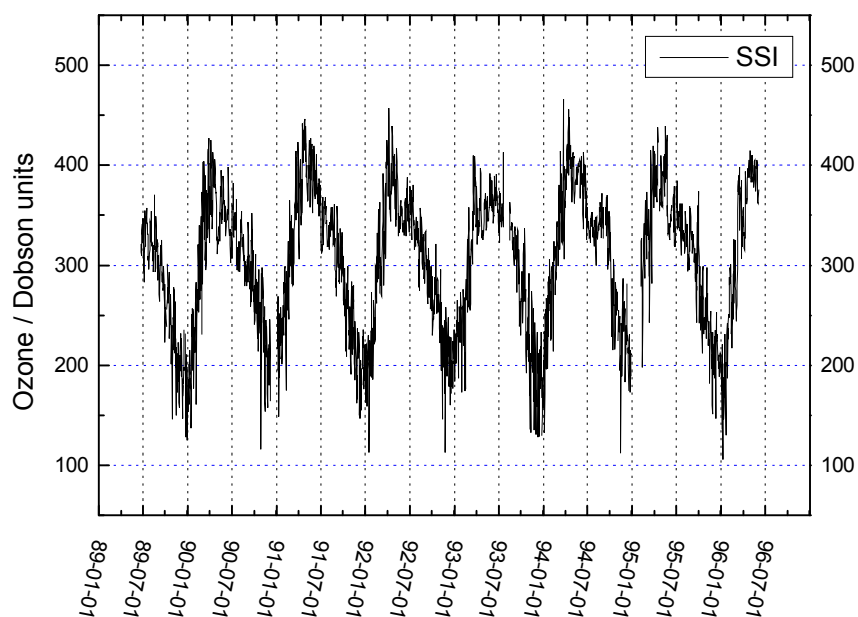


Figure 1a
Ozone column variations 1989-1996 measured with a dual passband radiometer in Stockholm (SSI).

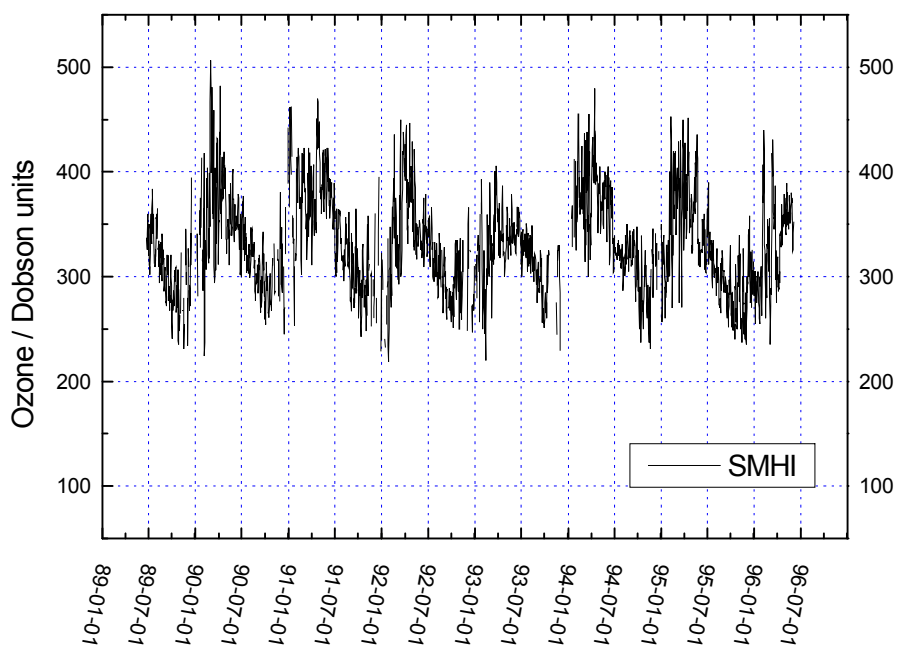


Figure 1b
Ozone column variations 1989-1996 measured with a dual pass-band radiometer in Norrköping (SMHI)

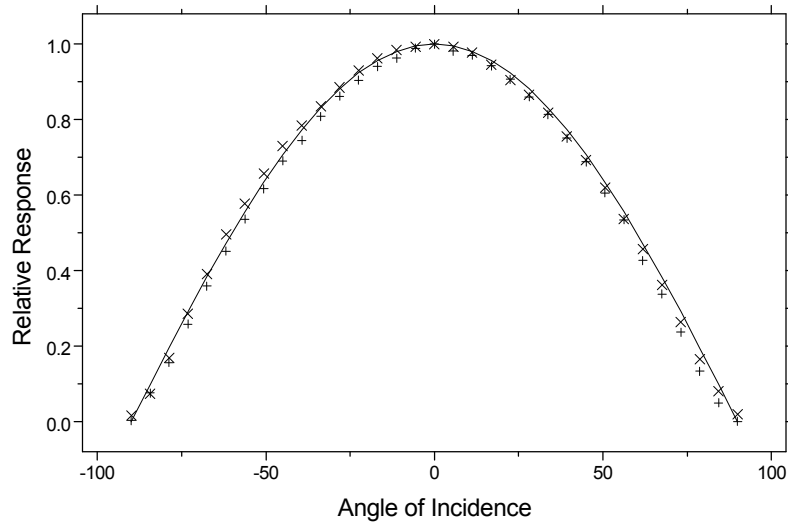


Figure 2. Cosines response as function of incident angle for the UW-detector's UVA and UVB windows. Solid line, cosines function; cross (x) line, UVA window; cross (+) line, UVB window.

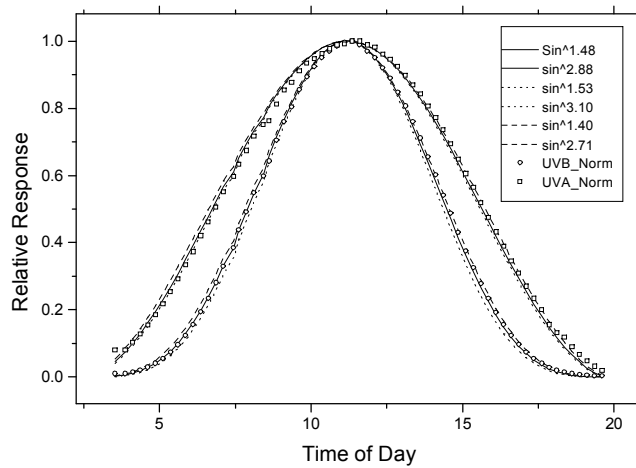


Figure 3A. Normalized daily curve of July 4, with blue sky and no clouds, for 306 nm (inner solid line) and 360 nm (outer solid line). Curve-fit is made for the current day and curve-fits from other cloud free days are included in the graph to show the scatter in the choice of the power. Powers are referred to **table 3**. The label shows the used functions. Statistical evaluation of this graph is shown in **table 5**.

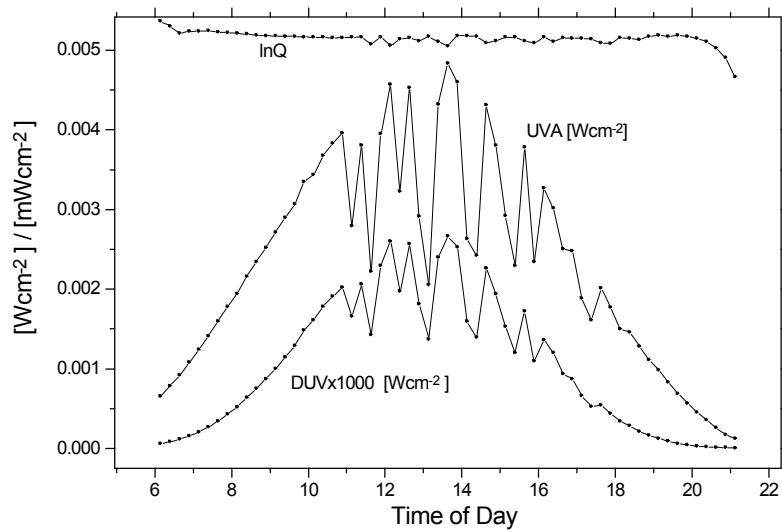


Figure 3B. Daily curve for June 30, with clouds, for 306 nm (scaled to fit absolute levels for UVA irradiance) and 360 nm. Calculated $\ln Q$ are scaled to fit absolute UV- levels. Y-axis represents irradiance for UVA and DUUV.

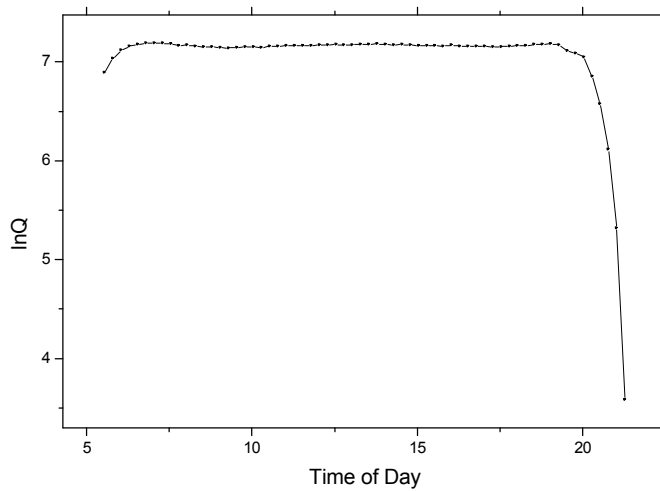


Figure 3C. Calculated $\ln Q$ over a cloud free day with relative constant ozone layer. The figure shows the constancy of $\ln Q$. Powers are $p_b = 2.86$ and $p_a = 1.48$.

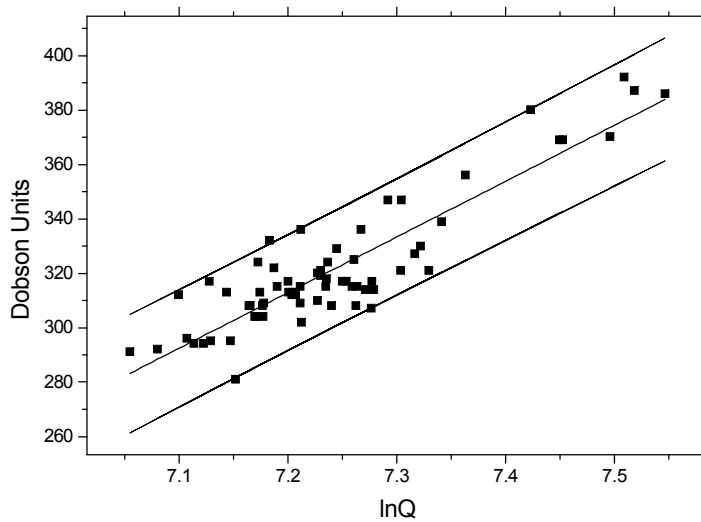


Figure 4A. Dobson units measured in Copenhagen versus calculated/measured values in Lund the same day (daily point measurements). The line is obtained by linear regression and 95 % prediction bands are included. Data: Time period = 1994 06 09 - 1994 08 14, $p_a = 1.48$, $p_b = 2.86$, Correlation coefficient = 0.90, Standard deviation, residuals = 10.6 DU. Line parameters and statistics can be found in **table 6**.

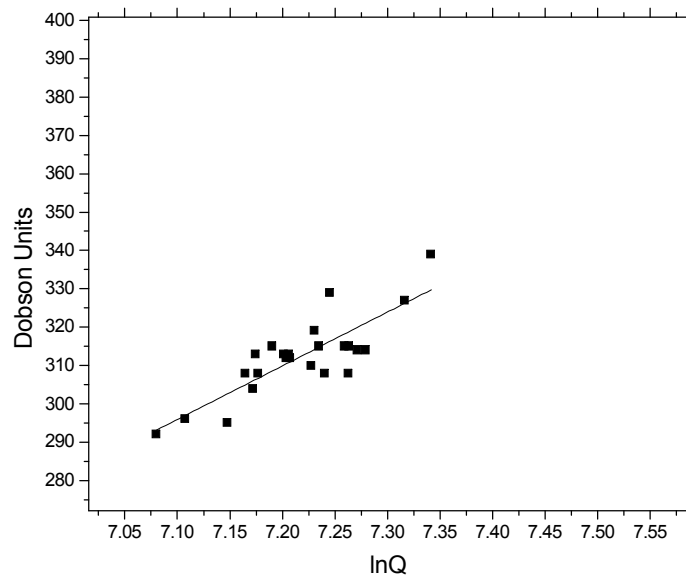


Figure 4B. Only the 24 most cloud free days have been chosen and a linear regression have been made (daily point measurements). Data: Time period = 1994 06 09 - 1994 08 14, $p_a = 1.48$, $p_b = 2.86$, Correlation coefficient = 0.83, Standard deviation, residuals = 5.8 DU. Line parameters and statistics can be found in **table 6**.

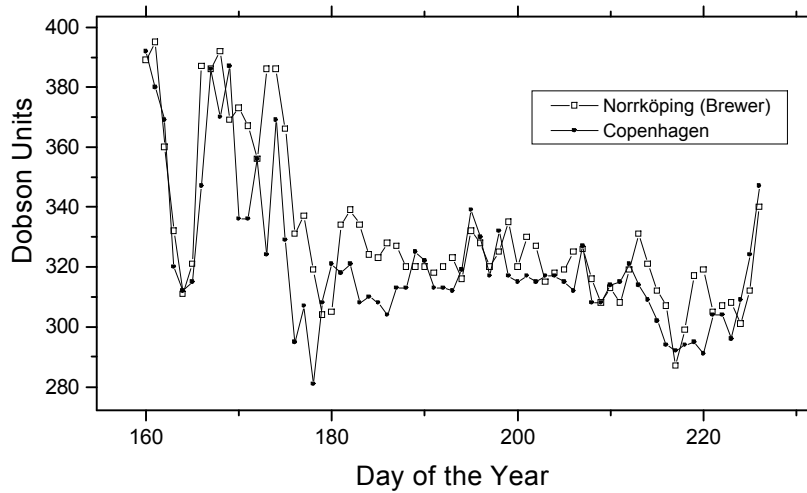


Figure 5A. Ozone measurements in Norrköping and in Copenhagen, 1994. Day number 159 corresponds to June 9 and day 225 to August 14. (if January 1 corresponds to day 0).

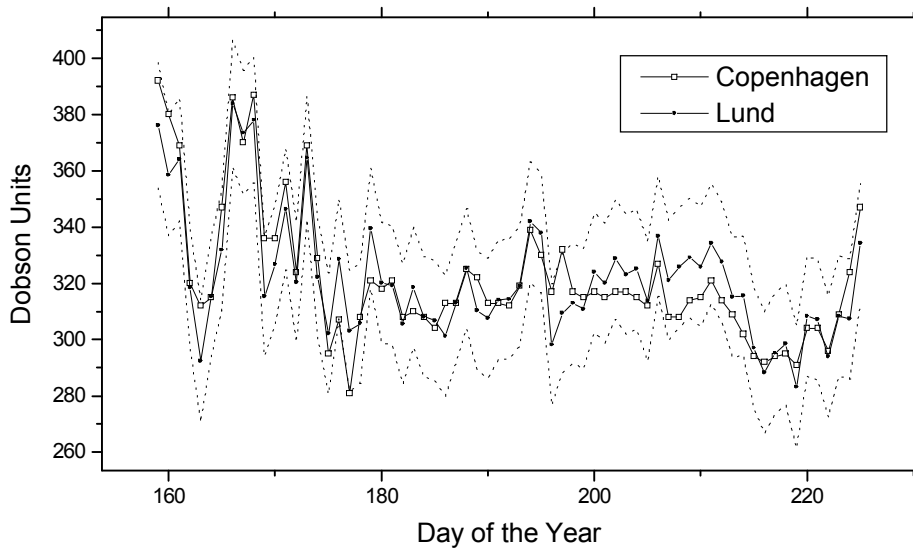


Figure 5B. Curve obtained after linear regression (figure 5A, table 6) together with ozone measurements in Copenhagen. Day number 159 corresponds to June 9 and day 225 to August 14 (if January 1 corresponds to day 0). Dashed line corresponds to 95 % prediction band. Data: Time period = 1994 06 09 - 1994 08 14, $p_a = 1.48$, $p_b = 2.86$, Correlation coefficient = 0.90, Standard deviation, residuals = 10.6 DU, mean value = 322 DU.