Computing the Radiation Amplification Factor RAF using a sudden dip in Total Ozone Column measured at Diekirch, Luxembourg

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1. Introduction

Ozone is an absorber of UVB radiation; this propriety is used by a variety of ozone sensors: Brewer and Microtops for instance for measuring the total ozone column (TOC) or Teledyne API for measuring ambient ozone concentrations. A recurrent question is "what is the influence of a thinning of the ozone layer on erythemal UVB irradiance?". Knowing the radiation amplification factor RAF allows to give at least an approximate response.

The relationship between cause (variation of TOC) and effect (variation of UVB) is non linear, and can be expressed as in many absorption phenomena by an exponential law:

$UVB = C * TOC^{-RAF}$ [eq.1]

Clearly this expression is not valid for TOC = 0; the constant C represents among other parameters the influence of total solar radiation **[1]**. Taking 2 situations denoted by the indices 0 and 1, equation 1 can be written as:

$$\frac{UVB_1}{UVB_0} = \left(\frac{TOC_1}{TOC_0}\right)^{-RAF} \quad \text{[eq.2]}$$

Which gives, taking the logarithm on both sides of the equation:

$$-RAF = \frac{\ln\left[\frac{UVB_1}{UVB_0}\right]}{\ln\left[\frac{TOC_1}{TOC_0}\right]}$$ [eq.3]

There are a couple of serious problems in this seemingly easy equation. The vertical total ozone column is what is given by the readings of the sensor, but the sunlight goes through the slanted column, and the different measurements may well have been done under conditions of different sun positions. So one first precaution should be to normalize the TOC's by dividing by the cosine of the solar zenithal angle (which gives a slanted TOC greater than the vertical one; see **[1]**).

The RAF's found in the literature extend over a large interval, from approx. 0.79 to about 1.7. This means that the RAF varies with time and location, and one should not expect a numerical value valid over the whole planet and for every day of the year. The calculation done in this paper has the sole modest aim to deliver a RAF for the location of Diekirch, Luxembourg (approx. latitude 50° N, longitude 6° E) by exploiting a rather brutal dip in TOC from the 22th to the 23rd April 2013 shown in the following figures.

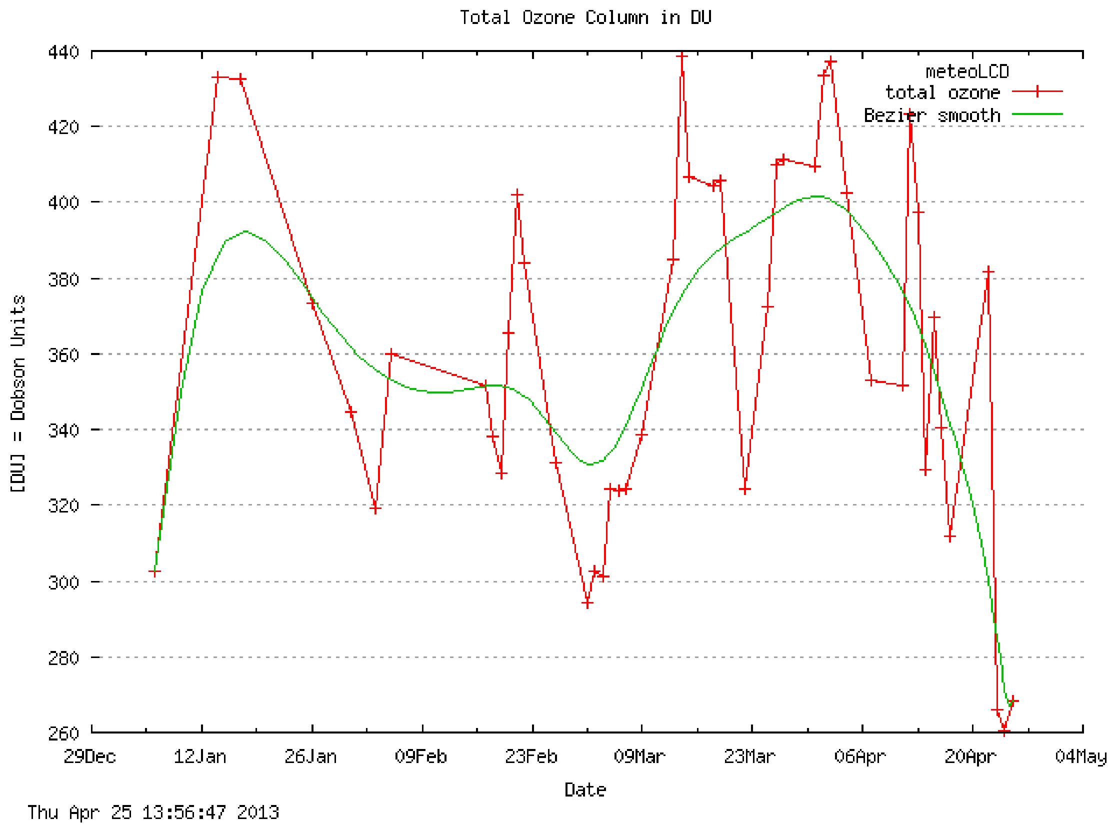

Fig.1 Plunge in TOC at Diekirch, 22 April 2013 ***[5]***

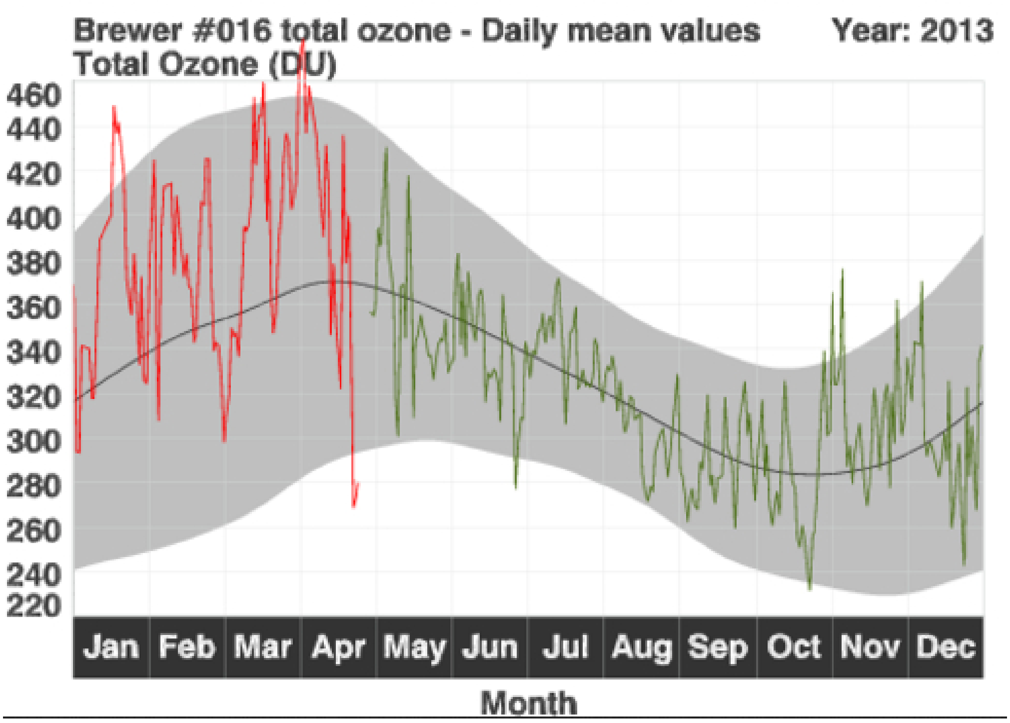

Fig.2 Same variation of TOC measured at Uccle (Belgium), 22 April 2013 ***[6]***

2. The important dip in TOC observed during the 22 and 23 April 2013

TOC, water column and AOT is measured by a Microtops II (average of 4 to 6 measurements), total solar irradiance by a Kip CM21 pyranometer and eff. UVB by a Solar Light 501 biometer.
Fig.3. shows the plots of solar irradiance in W/m^2 and effective UVB in mMED/h (1 MED = 250 J/m^2); measurement rate is 2 per hour.

During these days, the overall situation concerning atmospheric transparency (mostly described by the water column) and atmospheric turpitude (given by the atmospheric optical thickness AOT) are nearly identical. The TOC makes a spectacular dip from approx. 382 DU down to 266 DU, i.e. by - 30 %; the eff. UVB increases from 1550 to 2230 mMED/h i.e. by 44%. The peak values of total solar irradiance (blue curve, measured by a CM21 pyranometer) are practically the same, but the more irregular curve during the 23th April show that there are some passing clouds (Fig.4).

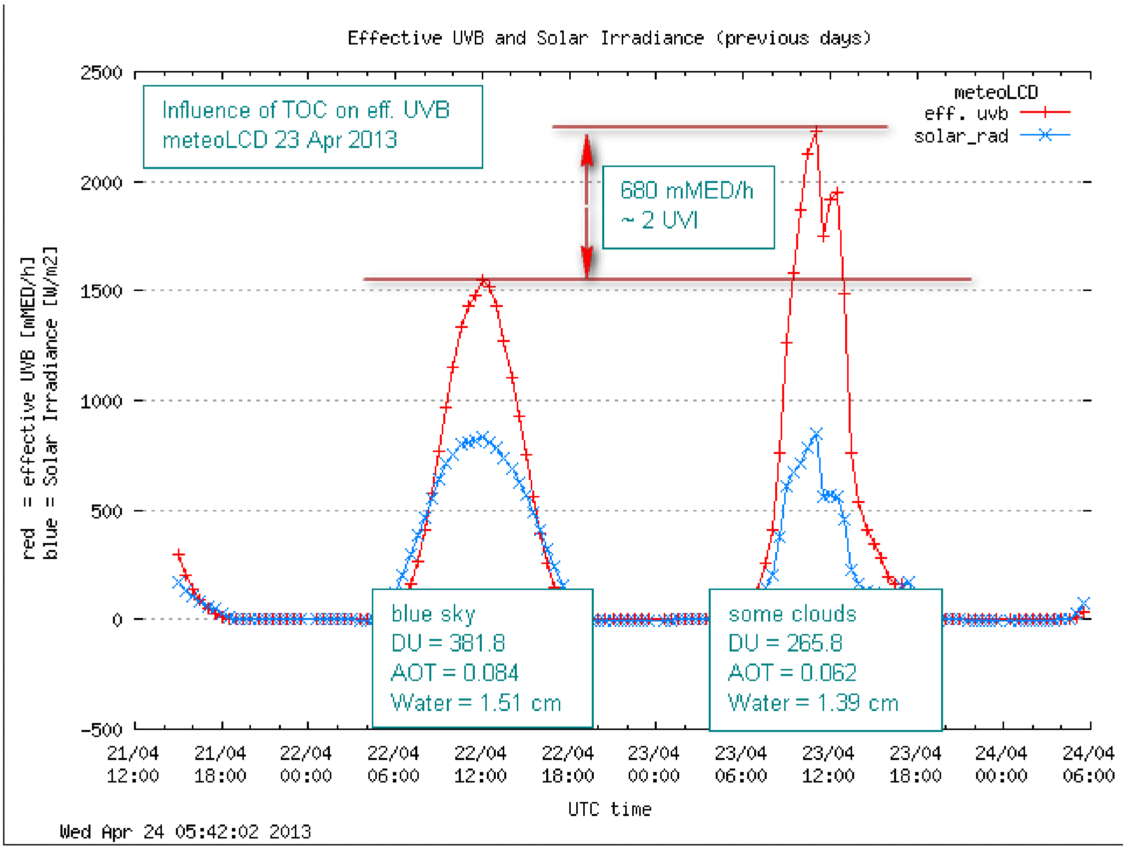

Fig.3. Total solar irradiance and erythemal UVB during the 22 and 23 April 2013 at Diekirch, LU.

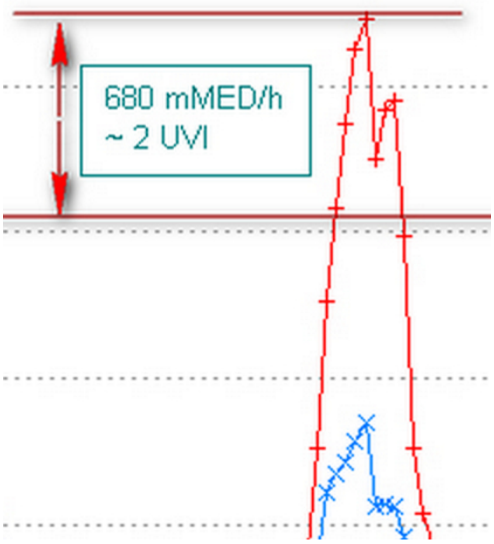

Fig.4. Zoom on secondary UVB peak (red curve) caused by partial cloud cover

This day the 12:00 peak solar irradiance value falls rapidly down to a small plateau, whereas the UVB readings (red curve) show a second peak during this interval where the total solar irradiance remains practically constant. This is the well known effect that a partial cloud cover can increase UVB irradiance (see **[2]**, **[3]**, **[4]**). Here this increase is about 200 mMED/h or +11% during one hour.

Neglecting any correction for the slanted ozone column, a first quick calculation applying eq.3 gives:

$$RAF = -\frac{\ln\left[\frac{2230}{1550}\right]}{\ln\left[\frac{266}{382}\right]} = 1.005 \cong 1$$

This is a value well situated in the usual range found in the literature. Applying to eq.2 gives:

$$\frac{UVB_1}{UVB_0} = \left(\frac{TOC_1}{TOC_0}\right)^{-1} = \frac{TOC_0}{TOC_1}$$

$$UVB_1 = \frac{TOC_0}{TOC_1} * UVB_0 \qquad \text{[eq.4]}$$

So the amplifier-factor for UVB (or for the UV index UVI which is proportional to UVB) is the fraction TOC_0/TOC_1. A dip of 50% of the TOC would increase the UVI by a factor of 2; a down by 10% would rise the UVI by a factor of 1.11, i.e. by 11%.

3. Using the measurements of the 4 days 22 to 25 April 2013.

The fine weather period terminated the 25th April with a sunny, blue-sky day. Fig.4 shows the plot ot total solar and eff. UVB irradiance, together with the readings of TOC and other parameters. Most Microtops data are averages of 4 to 6 consecutive manual measurements; the other parameters are from the meteoLCD sensors and represent the average of 30 minutely measurements.

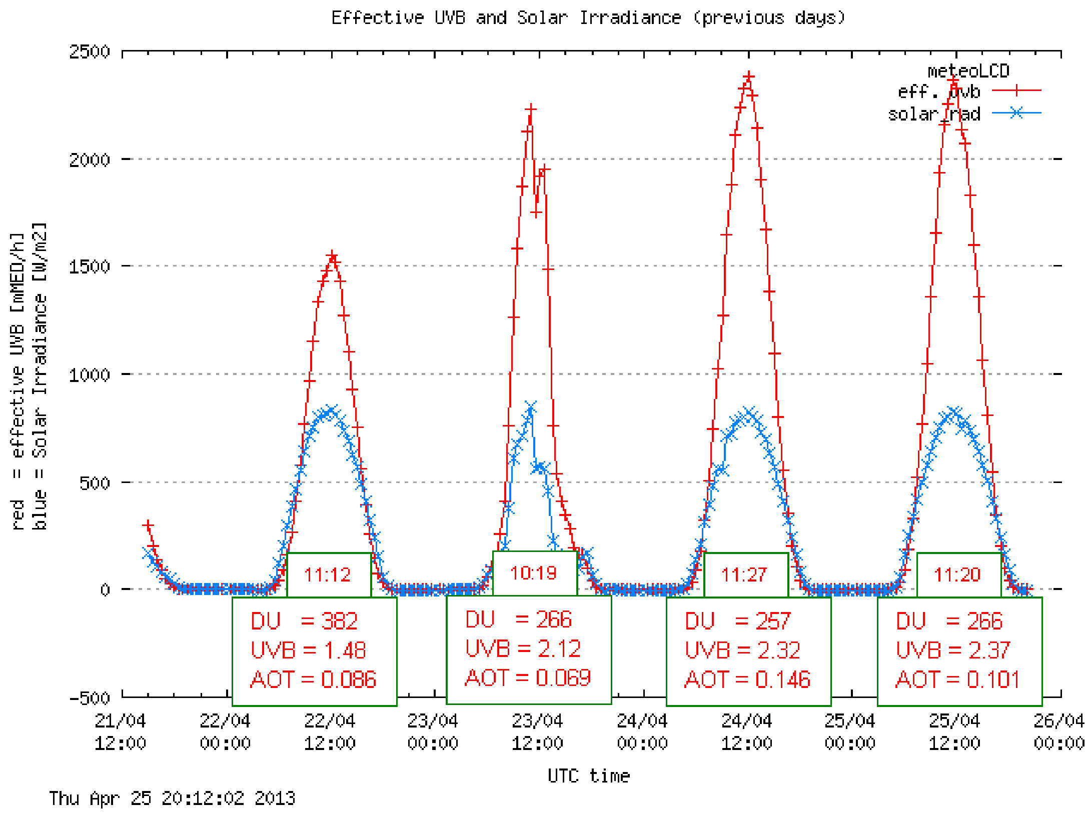

Fig.5. TOC, UVBeff and other parameters during the 4 days 22 to 25 April 2013.
Time is UTC. UVB in [MED/h] with 1 MED = 250 J/m^2 eff. UVB.
1 MED/h = 2.8 UVI. The data do not all correspond to the peak valuesof the day!

We will use a total of 10 averages (22/04: 1, 23/03:1, 24/04:4, 25/04: 4) to compute the radiation amplification factor RAF. The available series have been restricted by omitting:

- data where AOT > 0.200
- data where time of measurements is not between 10:00 and 12:30 UTC.

The relevant solar zenithal angles (SZA) extent from 36.6° to 40.5° and are very close.

Eq. 3 can be rewritten as:

$$\ln\left[\frac{UVB_i}{UVB_0}\right] = RAF*(-1)*\ln\left[\frac{TOC_i}{TOC_0}\right] \qquad \text{[eq.5]}$$

where the index 0 denote the measurement data of the 22th April and index i those of the following days. Eq.5 is the equation of a line whose slope is RAF. We will calculate the RAF by a linear regression, and do this calculation first using the “raw” TOC’s and second, using the “slanted” TOC’s = TOC/cos(SZA).

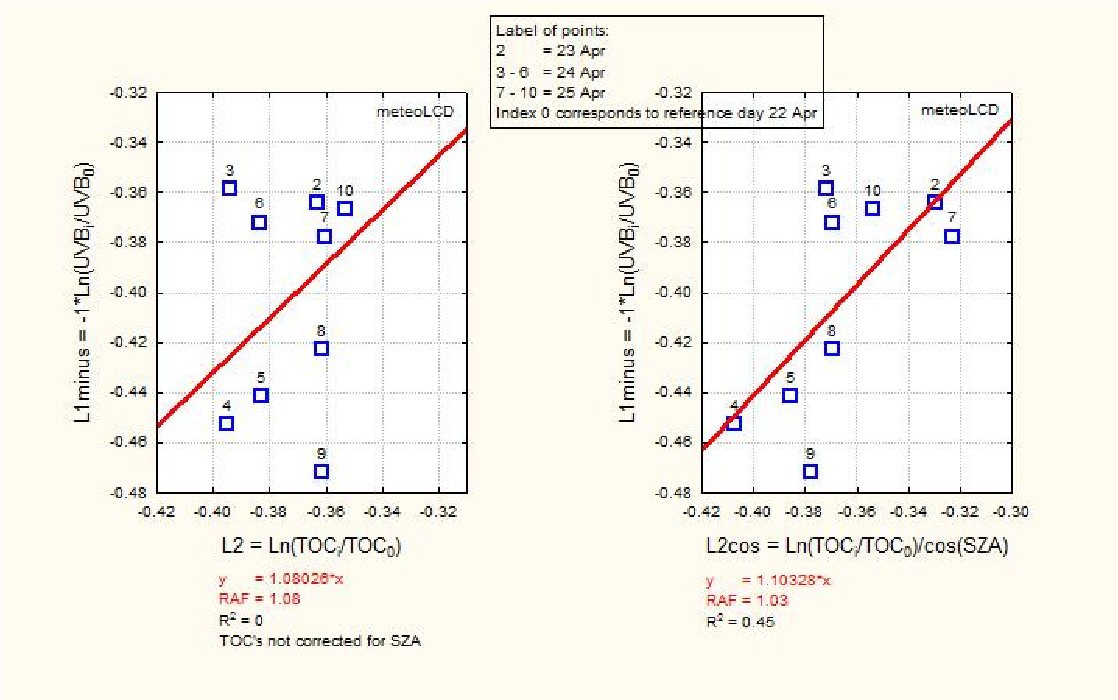

Fig.6. Log-Log plot with RAF = slope of regression line.

Visibly the use of the slanted TOC's gives a "better" picture, with considerably less scattering. The R^2 factor which represents the portion of variability explained by the linear model is 0 in the first case, and an acceptable 0.45 (45%) for the second.
The results of calculating the averages, standard deviations and range are given by the next table:

RAF from table of measurements	average	standard deviation	range avg +/- std
"normal" TOC	**1.083**	0.122	0.961 … 1.205
"slanted" TOC"	**1.103**	0.088	1.015 … 1.191

4. A model including the surface solar irradiance

Kudish et al. **[7]** propose an empirical expression for UVB which contains the solar irradiance, TOC, the air mass and the atmospheric optical thickness. They conclude that "*the atmospheric optical depth had a relatively minor effect on the UVB radiation intensity*".
In the previous calculations, the air mass is included in the slanted TOC, designed *TOCslant* in the next equation. Only a slight change is needed to equation 1 to include the influence of the solar irradiance:

$$UVB = a * Solar^{b} * TOCslant^{-c} \qquad \text{[eq. 6]}$$

Using the Statistica software package, the non-linear estimation delivers the following expression with a very high $R^2 = 0.95$:

$$UVB = 1856.6 * Solar^{0.94} * TOCslant^{-1.05} \qquad \text{[eq. 7]}$$

All parameters are significant at the 95% level, except a.
The +/- 1 sigma confidence interval for the RAF = 1.05 is given as [0.936 … 1.164].

The largest error between predicted and observed UVB is 94 mMED/h, less than 4.5%

5. Conclusion

The exceptional large dip in TOC during one single day in April 2013 represented a welcome occasion to investigate the increase of erythemal UVB at ground level in response to the thinning of the ozone layer. The radiation amplifier factor found was close to 1.1. Using the slanted TOC changed the result by a relatively small margin (from 1.08 to 1.10) but betters the goodness of the fit by 0.45. Incorporating the solar irradiance at ground level makes a big improvement in the model as R^2 increases from 0.45 to 0.95. The resulting RAF of 1.05 nevertheless remains close to the previous values.

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[6] http://ozone.meteo.be/meteo/view/en/113200-ajaxcontroller.html/1569014/image.jpg

[7] Kudisch A.I. , Evseev E.G.: The analysis of solar UVB radiation as a function of solar global radiation, ozone layer thickness and oerosol optical thickness. Renewable Energy **36** (2011), p. 1854-1860

History:

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Version 1.01 changed invalid comment on costant C in eq.1.. 27 Apr 2013