APPROACH OF UV CLIMATOLOGY IN BELGIUM BY MONITORING ULTRA VIOLET IRRADIANCE AT THE SURFACE OF THE EARTH : THE BELGIAN NETWORK

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The observation and monitoring of solar irradiance, in general, and UV (Ultra Violet) irradiance, in particular, is important due to its impact on human health and environment on regional and global scale. The UV irradiance, hence, the UV index (UVI), is affected by various atmospheric parameters, e.g., the solar zenith angle, the ozone overhead column and other atmospheric absorbers and scatters such as clouds and aerosols.

In order to investigate the modifications induced by the UV irradiance on human environment, it is important to quantify the various factors affecting the UV irradiance, UV-B (280-315 nm) and UV-A (315-400 nm).

In Particular, clouds are responsible for a great deal of the observed irradiance variability that in turn requires the examination of extensive observation data sets by detailed radiative transfer models using co-located meteorological and ozone measurements together with satellite based estimations.

These factors are continuously monitored over Uccle, Belgium, since 1993 by means of ground based station producing spectral measurements of UV irradiance together with UVI computation. Today, six stations represent the contribution of Belgium in the European UV network.

Our measurements give a good insight into the trend of UV irradiance and associated atmospheric parameters over Belgium. We present here some of the recent results from observations and radiative transfer modelling, e.g., the relation between the cloudiness, uncertainty in the cloudiness due to measurements and UVI, ozone trend and UVI, among others. It is seen that since 2000, despite of a stable ozone concentration, UV irradiance continues to increase. Modelling studies show that ozone and

UVB trends are anti-correlated (1% of ozone reduction implies 2% of UVB increase). Aerosols reduction, as a consequence of improvement of air quality policy could be another important factor to explain the observed UV trend.

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1. INTRODUCTION

The solar irradiance reaching the surface of the Earth, ranging from the ultraviolet (UV) to the infrared (IR) wavelength of the electromagnetic spectrum, has various effects on the Earth’s atmosphere and ecosystem. At the same time, there are several applications of solar irradiance on the surface of the Earth, namely, climatic, environmental, hydrological, agricultural, biological, solar energy and engineering applications, among others (Meek 1997).

Together with the advantage of solar irradiance in the visible spectrum (420-700nm), the UV wavelength of the solar irradiance (280-400nm) reaching the surface of the Earth affects human health and the environment in many ways (Bano *et al.*, 2013; Pandey (2012); Peng *et al.*, 2015). The UV irradiance plays an important role in building and maintaining human bones (Bryant, 1997). In spite of its advantages on humans, an excess of UV irradiance has harmful and acute effects on humans, namely, damage to DNA (Diffey, 1992), effects on human skin and eye damage (Vanicek *et al.*, 2000), among others.

UV irradiance plays an additional significant role in Earth’s atmospheric chemistry, via actinic flux (Calbo et al, 2005; Kylling *et al.*, 2003; Monks *et al.*, 2004; Webb *et al.*, 2002), which becomes complex under varying condition of cloudiness (Van Weele, 1996).

UV irradiance is also affected by various factors, namely, solar zenith angle (SZA), total column ozone-including stratospheric and tropospheric ozone, clouds, aerosols, albedo, among others (Calbo *et al.*, 2005). One of these factors, ozone, is a crucial one, having a seasonal variation in its total column value. An anticorrelation between stratospheric ozone and UV irradiance has been found (Kondratyev and Varotsos, 2000). Ozone gains attention also due to various anthropogenic impacts on it, which resulted in ozone hole, which in turn affects the UV irradiance (Madronich *et al.*, 1998; WMO, 2003, 2010).

Therefore, the measurement of UV irradiance is very important. Thus, already since a long time there have been several studies dedicated to the UV irradiance measurements, e.g., Bech *et al.* (2015), Martinez-Lozano *et al.* (2012), McKenzie *et al.* (2008), Peng *et al.* (2015) and Zerefos *et al.* (2014), among many others. Together with the ground-based measurements, there have been several reports on studying the UV irradiance using model-based approach (Chubarova, 2008; Leal *et al.*, 2011; Lindfors *et al.*, 2007; Stamnes *et al.*, 1988; Burrows, 1997). At the same time, remote sensing satellite-based techniques have also been used to study UV irradiance (Herman *et al.*, 1996; Herman, 2010; Ziemke *et al.*, 2000).

Identifying the importance of UV irradiance, several long-term measurements are carried out for climatological studies that have also been used for cross validation with other approaches (Fioletov *et al.*, 2004; Luccini *et al.*, 2006; Taalas *et al.*, 2000). Driven by the Antartic ozone depletion in 1980s, one of the ground-based UV irradiance measurement site was established in Uccle, Brussels, Belgium, which is now providing a long-term climatological characteristic of local UV irradiance and associated measurements. Brussels being the capital of Belgium that hosts several national and international institutions, thus, it accommodates a large population that is exposed to an urban atmosphere. This UV irradiance measurement site commenced the foundation of UV ground-based measurement network of Belgium. The data from this network has already been used in several studies (Gillotay *et al.*, 2010; Pandey *et al.*, 2012; Moreau *et al.*, 2010; Zerefos *et al.*, 1997).

In this study, we present the ground-based UV network of Belgium that features in the European UV measurement network. The long-term database of Brussels is used to analyze the climatology of UV irradiance and associated parameters by studying the yearly variations. Attention is also given to two more stations in Belgium -a northern and a southern station- in analysing the trend of UV irradiance over the course of measurements. Subsequently, the effect of varying aerosol is also expressed by conducting a simple radiative transfer modelling approach.

2.1 THE BELGIAN UV NETWORK

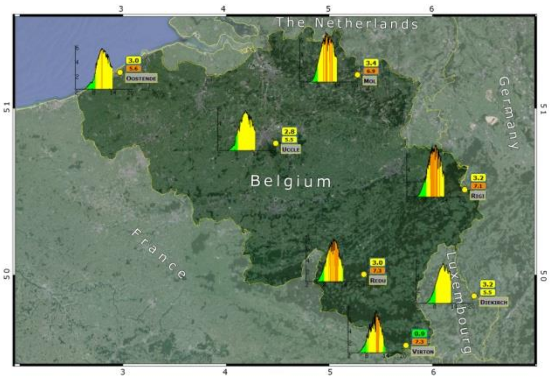

Figure 1. Location of the ground-based Ultraviolet (UV) irradiance measurement sites in Belgium and Luxemburg.

The Belgian Institute for Space Aeronomy (BISA) has developed and deployed a fully automatic network for the measurements of solar irradiance (UV and visible) and ancillary parameters as meteorological data, clouds, sunshine duration, among others. The initial measurements started in 1993.

The Belgian UV network comprises of six stations. There is an additional station in Luxemburg as a result of collaboration between Belgium and Luxemburg. Figure 1 shows the locations of all these stations. However, the focus in this study is on the Belgian network.

The first station was deployed in 1993 on the rooftop (100 m amsl-above mean sea level) of the Belgian Institute for Space Aeronomy in Uccle, south of Brussels-a green suburban area. The second station, Redu, was established almost a decade after the first one, that is in 2004, in the Belgian Ardennes. The Redu measurement station is at an altitude of 450 m amsl in the proximity of heavy traffic. The third station was established in 2006 in Ostend (in Dutch it is written as Oostende and in French as Ostende), which is a coastal city. The measurement site is located 200 m away from the sea at an altitude of 10 m amsl. The fourth station is at Virton, a small town, since 2007, at an altitude of ~250 m amsl. The fifth station was deployed in 2008 in the northern part of Belgium, Mol, which has a drier and warmer climate. The station is located at an altitude of ~75 m amsl. The most recent station was deployed in 2011 in Mont-Rigi at an altitude of ~700 m amsl, which is almost the highest peak in Belgium. All the sites were chosen in a way to take into account the aspect of varying background climatology together with a better coverage of the field of view. Table 1 summarises the characteristics of various sites of the Belgian ground-based UV network.

Name	Latitude (°N)	Longitude (°E)	Altitude (amsl m)	Year of deployment	Climatological characteristics/environment
Uccle	50° 48’	4° 21’	100	1993	Urban area
Redu	50° 00’	5° 09’	450	2004	Forest (close to highway)
Ostend	51° 14’	2° 56’	10	2006	Coastal
Virton	49° 34’	5° 32’	250	2007	Little township
Mol	51° 13’	5° 05’	75	2008	Forest
Mont-Rigi	50° 31’	6° 05’	700	2011	Forest and peat-bogs

Table 1: Summary of the Belgian ground-based UV network sites.

2.2 DATA AND MEASUREMENTS

The first ground-based UV observations made at Uccle were the spectral measurements. They were made by means of a modified Jobin-Yvon HD10 double spectro-radiometer. The home-made modification pertaining to the spectro-radiometer concerned especially the improvement of its scanning mechanism in order to increase the scanning stability in atmospheric conditions. The modification also pertained to the design of new slit and grating supports, which allowed more accurate alignment of the double monochromator. An additional modification was the entrance optics, which offered a nearly perfect cosine response. Following which, the instrument is fitted inside a thermostatic container flushed with dry nitrogen. The modification is completed by fitting a quartz dome that highlights the entrance optics.

The scanning frequency of Jobin-Yvon HD10 double spectro-radiometer is fixed to 15 minutes. The spectral measurements is completed by the addition of broadband UVB meter, UVA meter, pyranometer and narrow band filter radiometers. The measurement frequency of these instruments is fixed to 1 mean value every minute.

Presently, Uccle is equipped with two double monochromators, (Modified Jobin-Yvon HD10 and BenthamTM300, since 2004), broadband instruments (UVB, UVA and total solar pyranometer), filter radiometers (GUV 2511, UVMFR-7, MFR-7 and SPUV-10) and ancillary instruments to measure the meteorological parameters (EOLE-200), the cloud fraction and ceiling (CIR-4 and CIR-13) and the sunshine duration (SDM MS-093).

Main characteristics of the instruments are presented in Table 2a and 2b.

The measurement at Uccle invoked the idea of developing a ground-based network in Belgium. Over the ten years of the measurement at Uccle and its maintenance, an adequate choice of various instruments were made and were deployed at other sites sequentially. All the other ground-based stations of the current UV network of Belgium are equipped with following instruments: (a) Filter radiometer, (b) broadband UV-B meter, (c) broadband UV-A meter, (d) broadband pyranometer, (e) cloud infrared radiometer (CIR-4), (f) sunshine duration meter and (g) meteo station Eole 200 that can measure temperature, dew point temperature, pressure, relative humidity, wind speed & direction and rainfall.

Instrument	Modified JY-HD10	Bentham DTM300
Focal length	100 mm	300 mm
Gratings	1200 gr/mm holographic concave	200 gr/mm holographic plane
FWHD at 300 nm	0.49 nm	0.25 nm
Usual range	280-600 nm	280-500 nm
Wavelength step	0.3 nm	0.5 nm
Scan duration	400 sec	840 sec
Detector	PMT Hamamatsu R292	PMT DH 10 Te
Dark current	Automatically removed	Automatically removed
Stray light	Undetectable	Undetectable
Field of view	2π sr (nearly perfect cosine response)	2π sr (nearly perfect cosine response)

Table 2a. Main characteristics of the double monochromators

2.3 OPTICAL CHARACTERISATION? ABSOLUTE CALIBRATION AND MAINTENANCE.

A full optical characterization of an instrument is performed prior to its deployment. The optical characterization mainly includes the measurement of the relative response curve and/or the band path of each channel by means of monochromatic light generated by a double spectro-radiometer, verification of the linearity, determination of the angular response at different fixed wavelengths and the verification of the stray light, among others. The process of optical characterization is followed by the absolute calibration of the instrument by means of at least three FEL 1000W NIST (National Institute of Standards and Technology) certified standard lamps.

Instrument	Type	Wavelength range	Measurement	Frequency
UV-B meter	Broadband	280-330 nm; max at 294 nm	Global	1 / min
UV-A meter	Broadband	300-380 nm; max at 330 nm	Global	1 / min
Pyranometer	Broadband	300nm-3µm	Global	1 / min
UVMFR-7	7 Narrow bands shadowed	300, 305.5, 311.5, 317.5, 325, 332.5, 368 nm FWHM ~2 nm	Global + diffuse	1 / min
MFR-7	7 Narrow bands shadowed	415, 500, 615, 673, 870, 940 nm + PAR FWHM ~10 nm	Global + diffuse	1 /min
GUV2511	6 Narrow bands	305,313,320,340,380 and 395 nm FWHM ~2 nm	Global	1 / min
SPUV-10	10 Narrow bands	300, 310, 318, 368, 500, 610, 675, 778, 862, 1050 nm FWHM ~ 2 nm in UV FWHM ~ 5nm in Visible FWHM ~ 10 nm in IR	Direct	1 / min

Table 2b: Characteristics of broadband, filter radiometer

The determination of irradiance level, together with associated parameters, from different type of measuring instruments (spectral, narrowband and broadband), permits to verify the coherency of these instruments. In case of a difference of more than 2.5% between two instruments for the same measuring value, the instrument is replaced by a freshly calibrated spare instrument. Thus, a recalibration of instruments is performed regularly at our laboratory. A periodical maintenance is indispensable to maintain the quality of the produced data sets. Thus, every ground-based station undergoes a periodical maintenance on a bimonthly basis by cleaning the entrance optics of the instruments, replacing drier cartridge-if any, among others.

2.4. DATA MANAGEMENT AND DATA PROCESSING.

The data recorded by the different instruments are stored on their respective computers, and thereafter sent to the main data base in Uccle, Brussels, every five minutes, by automatic ftp procedure. These 'level 0' data are used to generate 'real time' information to the public, displayed on our website: http://uvindex.aeronomie.be .

Once the data is transferred to the main data base, it is reprocessed. The spectral data is verified by a quality control procedure developed under the EU SUVDAMA project (den Outer and Slapper, 1998) in order to remove potential wavelength shifts. Correction of the response curve of the broadband instrument is applied to take into account the temperature dependence. At the same time, no correction is applied on the angular response of the instruments. Their optical characterization shows nearly perfect cosine response curve up to SZA = 80°. Thereafter, the ‘level 1’ data is generated and thus, submitted in Flextore format to the EUVDB (European UV data base) every month. The ‘level 1’ data can also be downloaded by users directly from our web-site.

3. RESULTS AND DISCUSSION.

3.1 DAILY CUMMULATIVE UVB, UVA AND TOTAL SOLAR IRRADIANCE.

Since Uccle, in Brussels, is the station that has the longest ground-based UV irradiance measurement, the prime focus of this study remains over the measurements carried at Uccle. The observation at Uccle comprises the measurements done by spectral, narrow band and broadband instruments. Uccle, Brussels, can also be considered as a representative of the center of Belgium.

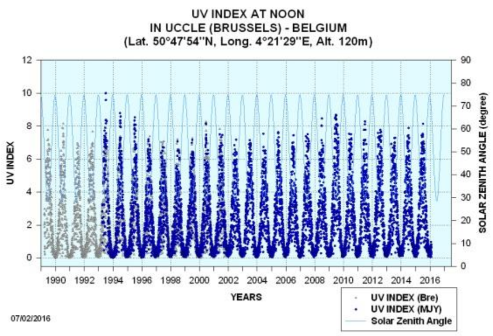

Figure 2. Time-series of UVI during the period 1989-2015 as measured at Uccle, Brussels.

Figure 2 shows the time-series of the UV Index (UVI) as observed at Uccle from 1989 till 2016. It can be seen that the UVI values are lower in the beginning and end of each and every calendar year, which is marking the winter months, as less irradiance is measured at the surface. Whereas, during the middle of the calendar year the irradiance values are higher, this corresponds to the summer months.

The ground-based UV observation in Belgium with a longer term record following Uccle, is at Redu. It can be considered as a representative of Southern Belgium, which has uneven terrain. The time-series of at Redu are shown in Figure 3.

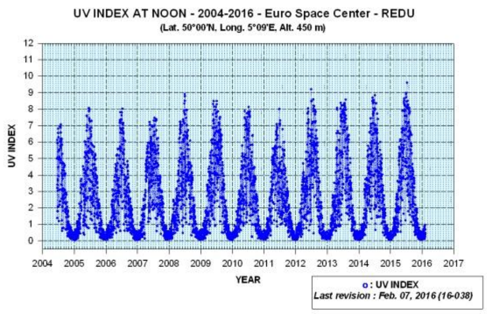

Figure 3. Time-series of UVI during the period 2004-2016 as measured at Redu.

The first year of measurement has partial records of observation. The year-to-year variation, together with the variation in summer and winter months, can be seen very well too.

The other station that has the longer term UV observation in Belgium is Ostend, since 2006.

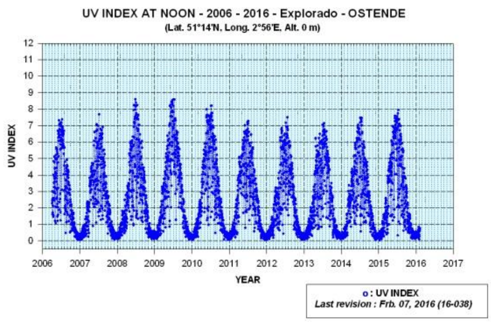

Figure 4. Time-series of UVI during the period 2005-2016 as measured at Ostend.

It was established as a representative of the northern Belgium that also captures the coastal climate. Figure 4 shows the time-series of the UVI, as observed at Ostend. Like other two stations -one in the southern Belgium and other in the central Belgium- Ostend measurements also exhibits year-to-year and seasonal variations in the observations. A comparison of Redu (southern Belgium) and Ostend (northern Belgium) measurements exhibit that the yearly variations are prominent at Redu than at Ostend. This implies that there are differences in the amount of solar irradiance reaching the northern, central and southern part of Belgium.

3.2 COMPUTATION OF UVI

A major outcome of the measurements is the UV index (UVI)-as a service to public interest. Thus, this section describes the computation of UVI from the raw signal of the instruments. A raw signal from spectral measurement is counts/second at each wavelength, whereas, for the broadband and narrow band instruments, it is volts or amperes. These raw signals are converted in irradiance, W m^{-2} nm^{-1} or W m^{-2}, by applying the calibration coefficients determined in the optical laboratory. The wavelength scale is determined by means of a series of hollow-cathode lamps. Some of the calibration coefficients, especially for the UVB meter, slightly depend on the solar zenith angle, which is taken into account during the signal to irradiance conversion. Conversion coefficients provided by the manufactures are always verified in our optical laboratory.

The effective UV is obtained by the weighted solar spectra measured at the ground level by the CIE action spectrum (McKinlay and Diffey, 1987). Following which, the UVI at noon, between 11:30-12:30 UTC, is computed as following:

$$\boldsymbol{UVI_{noon}} = \overline{\boldsymbol{UVI}}_{\boldsymbol{11.30UTC}}^{\boldsymbol{12.30UTC}}$$

where, $\boldsymbol{UVI = K_{ery} \int_{250nm}^{400nm} E_\lambda S_{ery}(\lambda)\, d\lambda}$

where, $\boldsymbol{K_{ery}}$ **= 40 m^2/W**

$\boldsymbol{E_\lambda}$is the solar irradiance in W m^{-2} nm^{-1} at wavelength λ

$\boldsymbol{S_{ery}(\lambda)}$ is the CIE action spectrum

3.3 LONG-TERM VARIATION OF EFFECTIVE UVB AND TOTAL OZONE COLUMN.

The last two decades of measurements of solar irradiance in Belgium allows us to study the trend with respect to the factors modulating the irradiance. In this section we focus on the long-term variation of effective UVB (*UVB$_{eff}$*), as it is directly linked with the UVI, and total column ozone, which is one of the major factors affecting the *UVB$_{eff}$*.

In order to study the trend of *UVB$_{eff}$* over two decades of measurements, we computed a 6ormalized difference of monthly mean from the long-term mean of the particular month over all the years. Hereafter this quantity is referred as Normalised Difference of monthly Mean –NDM (%), for the sake of simplicity of expression. NDM of *UVB$_{eff}$* is computed in the following way:

$$\boldsymbol{NDM_{UVB}}\,(\%) = \left[\left(\overline{\boldsymbol{UVB_{eff,i}}} - \overline{\textstyle\sum_{j=1995}^{2014} \boldsymbol{UVB_{eff,i,j}}}\right) \Big/ \overline{\textstyle\sum_{j=1995}^{2014} \boldsymbol{UVB_{eff,i,j}}}\right] \times \boldsymbol{100} \qquad \textbf{(1)}$$

where, NDM_{UVB} = Normalised difference of monthly mean of *UVB$_{eff}$* from the long-term mean of *UVB$_{eff}$* for the particular month over all the years, *i* = the month- January, February, March, …, December, $\overline{UVB_{eff,i}}$ = monthly mean of *UVB$_{eff}$*, $\overline{\sum_{j=1995}^{2014} UVB_{eff,i,j}}$ = long-term mean of *UVB$_{eff}$* for a particular month from 1995 till 2014, which is computed by employing the method of monthly means (Hart 1922). It is computed by obtaining the arithmetic mean of *UVB$_{eff}$* for a particular month over the two decades of measurements.

The $NDM_{UVB}$from 1995 till 2014 is shown in the Figure 7. In general no trend is evident as such, however, a linear regression -shown by the solid red line- exhibits a positive slope

In order to study the total column ozone trend over Belgium, the ozone values that were being obtained since 1978 using satellite observations are put to use. Level 3 total column ozone values from the Ozone Monitoring Instrument (OMI) and the Total Ozone Mapping Spectrometer (TOMS) are extracted over 51N and 4.5E as a representative of the centre of Belgium. It is noteworthy, that the spatial variability of total column ozone over Belgium is very little, thus, this value is a good approximation over Belgium.

The normalized difference of monthly mean of total column ozone observations from the long-term mean of total column ozone of the particular month over all the years of observations is computed in the similar manner as (1). This value is denoted by NDM_{ozone} in percentage.

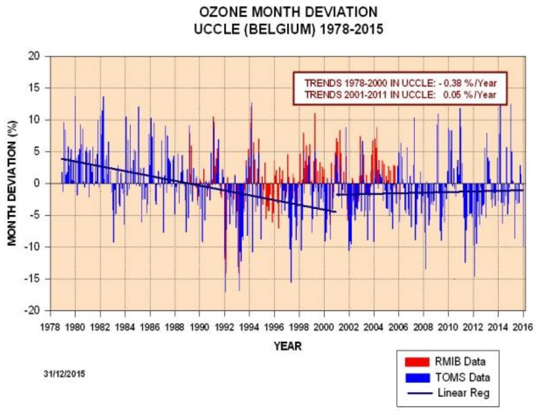

Figure 5. Trend of total column ozone over 51N and 4.5E as computed from the Level 3 data of Ozone Monitoring Instrument (OMI) and Total Ozone Mapping Spectrometer (TOMS) during the period 1979-2015. Two linear regression curves (solid red line) correspond to the change point, representing recovery of ozone, of total column ozone.

Figure 5 exhibits the NDM_{ozone} from 1978 till 2015, where two solid lines shows two liner regression curves by following the trend of De Bock *et al.* (2014). They showed that the end of 90's experienced a change point in the time-series of the ground-based measured columnar ozone over Uccle. Therefore, we also show two regression curves showing the trend of NDM_{ozone} over Uccle as monitored by satellites. Until 2000, the regression is negative whereas, beyond the change-point, it is almost constant, which implies that columnar ozone has remained almost constant since end of 90's till date. This could very well correspond to the fact of impact of various protocols put to practice that could have facilitated the ozone recovery.

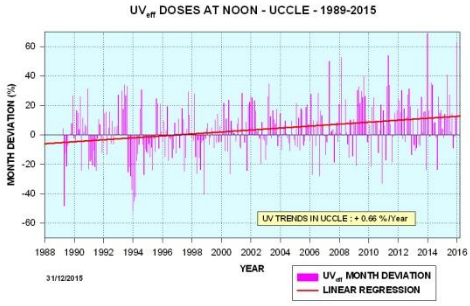

Figure 6. Trend of effective UVB (UVB_{eff}) at Uccle between 1989 and 2015. A linear regression is shown using the solid red curve.

Figures 6 and 5 in conjunction exhibit a striking feature: columnar ozone trend is stable since around 2000, whereas, the trend in UVB shows a positive increase. This could imply that the contribution of ozone in the UVB irradiance measured at Uccle has disappeared or the UVB irradiance is affected by some other factor. This needs to be studied in detail in future by means of ground-based and satellite-based measurements, together with a radiative transfer modelling approach. However, it is well known that along with columnar ozone, clouds and aerosols play a major role affecting the UVB irradiance (Calbo *et al.*, 2005). One of the reasons of this continuous increase in UVB trend, despite of a constant total columnar ozone trend, could be related to the aerosol concentration. During the course of measurement of past two decades, the aerosol concentration around the measurement site evolved as a result of changing pattern of traffic emission, emission type, type of vehicular engines, the usage of a different kind of domestic heating fuel (e.g., desulfurised fuel), policies to improve the air quality, among others. These evolutions could be a reason for decrease in aerosol concentration, which thereafter, could explain the positive trend in UVB at Uccle, centre of Belgium, despite of a constant total columnar ozone trend. The impact of pollution on UV irradiance has also been reported in the past (McKenzie *et al.*, 2008).

Following the UVB trend in central Belgium, the UVB trend in the south of Belgium is

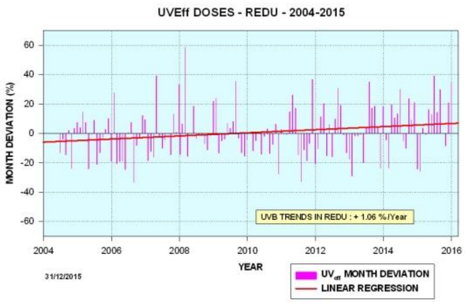

Figure 7. Trend of effective UVB (UVB_{eff}) at Redu between 2004 and 2015. A linear regression is shown using the solid red curve.

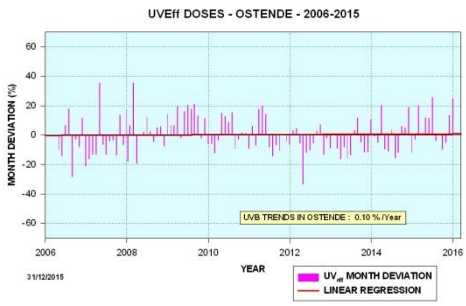

Figure 8. Trend of effective UVB (UVB_{eff}) over Ostend between 2006 and 2014. A linear regression is shown using the solid red curve.

shown in Figure 7 by means of the NDM_{UVB} as observed at Redu, a representative of southern Belgium. A linear regression -the solid red curve- has a positive slope, implying that there is an increase in the UVB trend. This trend is similar to the observations made in the centre of Belgium-Uccle. Therefore, a reason for this increasing UVB trend could also be similar to those as for the Uccle. However, for Redu the traffic emission could have played a major role. As the measurement site is close to a highway the emission is mostly from traffic. But, since the policies to improve the air quality in-and-around Belgium has been effective in reducing the Sulphur dioxide, the UV absorbing aerosols, the concentration of these aerosols could have lowered. Thus, an increase in the UVB trend.

In order to study the UVB trend in the north of Belgium, the NDM_{UVB} at Ostende is shown in Figure 8. The linear regression -solid red curve- exhibits a decreasing trend of UVB. Although, the decrease in the UVB trend is very low for Ostend, it can even be said as unchanged since the measurements, yet, this is strikingly different than the central and southern Belgian stations that experienced an increase in UVB trend. This difference in trend could be associated with the type of climate Ostend experiences. The Ostend measurement station experiences maritime aerosols, unlike urban/sub-urban aerosols. As the station is located very close to the coast -a pristine location, the maritime aerosols from natural origin mostly remain constant, as they are not linked with anthropogenic activities.

It is noteworthy that the hypotheses proposed to explain the varying trend of UVB have to be examined. There could very well be other reason, e.g., associated with the effect of cloud or a combination of cloud and aerosols. Nevertheless, here we propose the hypotheses based on a preliminary approach that are subjected to a detailed future studies.

3.5 Effect of aerosols on the UVI

This section presents a preliminary approach

Type of aerosol	UVI with TCO = 306 DU													
	SZA = 25°							SZA = 70°						
	AOT (τ_{aer})							AOT (τ_{aer})						
	0	0.1		0.2		0.3		0	0.1		0.2		0.3	
	Ref	Est	Δ	Est	Δ	Est	Δ	*Ref*	Est	Δ	Est	Δ	Est	Δ
Maritime	8.50	8.25	*3*	8.07	*5*	7.91	*7*	0.79	0.70	*11*	0.67	*15*	0.66	*17*
Continental	8.50	8.16	*4*	7.87	*8*	7.62	*10*	0.79	0.69	*13*	0.65	*18*	0.63	*20*
Urban	8.50	7.75	*9*	7.08	*17*	6.47	*24*	0.79	0.64	*19*	0.57	*28*	0.52	*34*

to the above proposed hypothesis of aerosols playing a crucial role in varying UVB, hence UVI, during the course of measurements in Belgium. In order to have an estimate of the effect of aerosols on the UVI, the discrete ordinate radiative transfer (DISORT) model (Stamnes *et al.*, 1988) is put to use. It is configured for a plane-parallel atmosphere, with one nm wavelength step ranging from 280 to 600 nm. The background albedo is assumed to be 0.1 with 306 DU as the total columnar ozone. It is configured for a clear sky condition, i.e., cloud optical thickness (τ) as zero. The impact of three different kinds of aerosols - maritime, continental and urban- on the UVI is computed for two solar zenith angles, 25° and 70°, by varying the aerosol optical thickness (AOT, τ_{aer}). It has been observed by the AErosol RObotic NETwork (AERONET, http://aeronet.gsfc.nasa.gov/)that τ_{aer}, on average, ranges between 0 and 0.3 over Uccle, Belgium. Thus, we vary τ_{aer} from 0 to 0.3 in steps of 0.1.. The UVI for τ_{aer} = 0, is referred as the reference value (*Ref*), whereas the UVI with other values of τ_{aer} is referred as the estimated value (*Est*). Making use of the *Ref* and *Est*, following is computed:

Δ (%) = [(*Ref* – *Est*) / *Ref*] x 100

This, Δ, indicates the normalised difference of the τ_{aer} with respect to the *Ref* τ_{aer} for the specific solar zenith angle, expressed in percentage. Table 3 shows the effect of varying τ_{aer} on the UVI at Uccle, Belgium, for three different types of aerosols. It can be seen that an increase in τ_{aer} implies a decrease in UVI. This reduction in UVI, for a lower solar zenith angle, is highest for urban types of aerosols than the continental type, with a minimum impact on maritime aerosols. A similar trend is observed for a higher solar zenith angle (70°). In this case, the Δ is higher than the respective Δ of the lower solar zenith angle, implying that the impact of increase in τ_{aer} in decreasing the UVI is bigger for a solar zenith angle of 70° than that of a 25°. However, it can be clearly seen that the urban aerosols play relatively a bigger role than the continental or maritime aerosols in decreasing the UVI. It can be said in another way that the relative effect - reduction or increase- of maritime aerosols on UVI is less pronounced than urban aerosols.

A detailed future study is aimed, which takes into account previous studies, e.g., Cheymol and De Backer (2003), Pandey *et al.* (2012), Serrano *et al.* (2014), Gillotay *et al.* (2005), among others, to investigate the relation between the Belgian ground-based UV observations, aerosol properties and cloud properties.

Table 3. Effect of Aerosols on UV index (UVI) for different aerosols types at varying aerosol optical thickness (AOT, τ_{aer}) and solar zenith angles (SZA)

4. **CONCLUSIONS AND OUTLOOK.**

In this study we presented the Belgian ground-based ultraviolet (UV) irradiance measurement network. Together with the evolution of the entire network, the yearly variation of UVB, UVA and total solar irradiance (TSI) from a northern (Ostende), central (Uccle) and southern (Redu) Belgian station is shown. The central Belgian station, Uccle, enjoys the longest ground-based UV and associated measurements –20 years. Thus, a detailed seasonal -summer and winter months- variation of irradiances, together with the long-term irradiance variation, hence, the UV index (UVI) is shown primarily based on measurements at Uccle.

The trend of UVB, which is directly associated with UVI, is studied. We found that for the central (Uccle) and southern (Redu) Belgian stations the UVB trend is positive over the course of measurements, whereas, for the northern Belgian station, Ostende, the UVB trend is not positive or can be addressed as slightly negative. As total column ozone is a major modulator of UVB, among other factors, a satellite based long-term trend of total column ozone is considered for a preliminary investigation in conjunction with long-term UVB trend. A change point in the total column ozone is observed, following which, the long-term total column ozone trend is positive -a sign of ozone recovery. It is found that the UVB trend in Uccle and Redu is positive too, even for the duration when total column ozone trend is positive.

We speculate that this behaviour could be explained by the role of aerosols and hence, a preliminary radiative transfer modelling study is conducted to open doors for detail future investigation. The use of a radiative transfer model (RTM) illustrated the role of aerosol optical thickness is playing a role on reduction of UVI at the coastal station (Ostende) and increase of UVI at Uccle and Redu.

This study also lays the background for future detail studies related to the ground-based UV network data together with satellite-based and model-based studies.

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