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Design of the Mexico City UV monitoring network: UV-B measurements at ground level in the urban environment

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Abstract. Although there is concern for future stratospheric ozone depletion, several large urban populations are already being exposed to very high UV levels due to geographical factors. In Mexico City, ultraviolet radiation (UV) plays an important role in the generation of high levels of tropospheric ozone and other photochemical pollutants. The measurement of ultraviolet-B radiation in Mexico began in the spring 1993, as a pilot project for ultraviolet-B (UV-B) monitoring and as support for the first Hispanic public information program on the UV index through the Televisa (Mexican television network, which covers the Spanish speaking world). In 1996, based on our preliminary measurements, the Mexico City government commissioned the authors to design the Valley of Mexico UV-monitoring Network. The design of the network is presented. The preliminary measurements show that biologically active (UV-B) solar radiation can reach levels above 5 minimum erythemal dose (MED/hour) or 12 UV index units during spring and summer months. Annual UV measurements have shown seasonal variations of 40% between winter and summer months. Strong attenuation of UV-B radiation at ground level in the urban troposphere has been detected under polluted conditions. Measurements of the morphology of UV-B radiation have been taken at downtown and suburban monitoring stations, over diurnal, monthly and yearly periods. The network measurements show that the downtown UV-B levels are 20% lower than suburban levels on a seasonal basis, but differences can be greater than 40% on polluted days. The relationship between the Total Ozone Mapping Spectrometer (TOMS) total ozone column and tropospheric ozone concentrations in Mexico City is also discussed.

1. Introduction

The Mexico City metropolitan area is one of the world's largest population centers, where more than 20 million people are exposed to high solar radiation levels all year-round. The Valley of Mexico at 2500 m is surrounded by mountains and lies in the tropics at a latitude of 19°N; hence it experiences zenithal passages of the sun on May 17 and July 27.

The valley is surrounded by mountains where the pollution from intense industrial activity and more than 5 million vehicles results in large concentrations of tropospheric ozone. Figure 1 shows the monthly maximum reported tropospheric ozone concentrations for the last 10 years in parts per billion (ppb). The tropospheric ozone concentration exceeds the adopted Mexican standard for satisfactory levels of 110 ppb (hourly average) on most days.

Tropospheric ozone and other pollutants absorb ultraviolet-B (UV-B) (290-320 nm) radiation in the urban environment [*Frederick et al.*, 1993; *Liu et al.*, 1991]. Tropospheric ozone can be an important contribution to the total ozone column over Mexico City. Disregarding the respiratory diseases and potential hazards to human health coming from atmospheric pollution, UV-B attenuation by the urban environment can be considered as partial protection for the population against extreme solar ultraviolet exposure and skin damage.

To evaluate the exposure to and the attenuation of UV-B in the Mexico City environment, a monitoring program has been implemented for the long-term measurement of UV-B at ground level. The monitoring system includes UV instrumentation, computers and the development of automatic control software and analysis tools. Complementary ultraviolet-A (UV-A) and surface tropospheric ozone measurements have been conducted. This was the first integrated UV-B and UV-A monitoring system implemented in the Spanish-speaking world, with daily UV index levels and solar exposure public health reports on TV and in the press [*Televisa*, 1993]. For the pilot UV-monitoring Network, UV-B monitoring stations have been implemented and operated in downtown Mexico City since the spring of 1993, and in suburban Mexico City since the fall of 1993, along with ground measurements of ambient tropospheric ozone. UV-A has been measured since the summer of 1994. In 1996, based on the success of our

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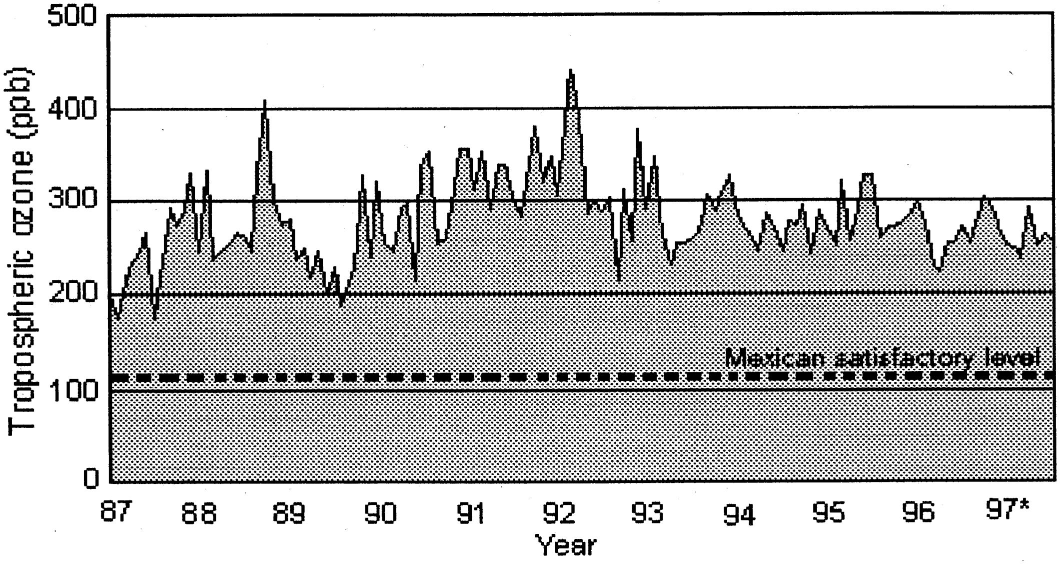

Figure 1. Maximum monthly tropospheric ozone concentrations for the 1987 to 1997 period (1997 covers only January-July period), as reported by the Mexico City Ministry of the Environment [*Secretaría del Medio Ambiente*, 1997; *Proaire*, 1996].

preliminary measurements, the Mexico City Ministry of the Environment commissioned the authors to conduct the design of the Valley of Mexico UV-monitoring Network.

2. Automatic Monitoring Systems and Facilities

Two ultraviolet automatic monitoring stations were set up and operated in the downtown and suburban Mexico City metropolitan area at similar altitudes (2220 m.); they were located 21 km apart. At each site, measurements of biologically active solar UV-B (290-320 nm) radiation and UV-A (320-400 nm) radiation were taken with Robertson/Berger (R/B) broad band analog radiometers [*Solar Light Inc.,* 1993]. The model 501A UV-B instrument simulates a *McKinlay-Diffey,* [1987] erythemal action spectrum. The UV-B detector has a wavelength sensitivity to erythemal radiation similar to human skin; 1 minimum erythemal dose (MED) is the radiation dose required to redden unprotected Type 2 skin. One MED equals an effective accumulated dosage of 21 mJ/cm^2. The model 501A UV-A instrument has the same temperature dependency and stabilization principle as the R/B sensor but measures long-wavelength UV (320-400 nm). It has a unity quantity efficiency spectral response with no weighting function. This band accounts for 90% or more of the total irradiance shorter than 400 nm reaching the surface of the Earth. The remainder of the UV irradiance is in the UV-B region, at wavelengths shorter than 320 nm.

The suburban monitoring site was placed 21 km away from the downtown monitoring site to the north, in Atizapán de Zaragoza in the state of Mexico. The site is on the periphery of the urban area. Both sites have adjacent avenues, but at the suburban site, the traffic is less dense, and there are some adjacent green areas.

Figure 2 shows the experimental concept of both UV-monitoring stations. The suburban monitoring site is far enough from downtown to be influenced by lower concentrations of ozone and other forms of atmospheric pollution. Rarely, depending on the wind direction and other meteorological conditions, higher concentrations of ozone can be detected even though there are fewer avenues and lower traffic volume in this area. Usually, the solar luminosity is higher and the sky is clearer at the suburban site than at the downtown site. A global pyranometer would complement the UV-A measurements to evaluate the absorption due to haze, aerosols, and atmospheric humidity, since both measurements are unaffected by ozone. The UV sensors were located on the roof of buildings, avoiding objects that might block or reflect the solar radiation in any season. Analog-to-digital converters were designed, developed and operated along with automatic dedicated monitoring software [*Collaboration Agreement,* 1993].

The radiometers and data loggers provided information at a sampling rate of 10 times per minute. Data were retrieved every 6 seconds and written to a file on the PC. Measurements were then averaged on a 1 minute basis. The data could then be analyzed over daily, weekly, and annual periods.

The daily data were averaged over the interval from 1000 to 1500 hours weekly to facilitate studies of changes over monthly and yearly periods. Using the same data acquisition method, tropospheric ozone measurements were taken with a UV optical chamber automatic ozone analyzer [*Advanced Pollution Administration, Inc.,* 1993] at the suburban monitoring site. The ozone sampling probe was placed 1 m above the UV instrumentation. The data were collected periodically from both monitoring stations for later processing and analysis. Total column measurements of ozone were acquired from the TOMS instrument on board the Meteor 3 satellite [*Herman,* 1995]. The UV radiometers at the downtown and suburban site were factory calibrated. At the beginning of the monitoring periods the UV-B and UV-A downtown instruments were colocated and compared against the suburban instruments; this ensured consistent UV measurements. The quartz domes were cleaned to remove dust once a week.

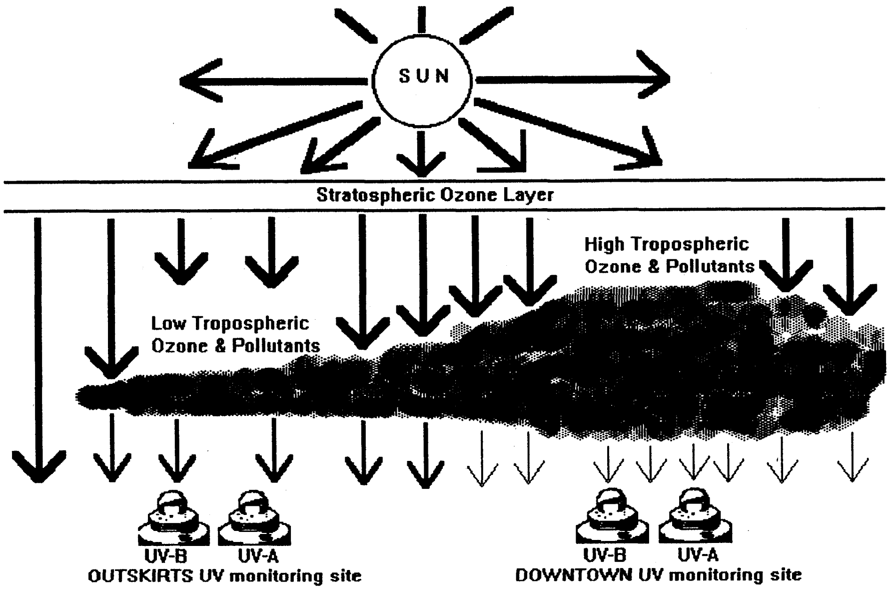

Figure 2. A diagram showing the concept of the downtown and the suburban UV-A and UV-B monitoring sites in Mexico City. Higher tropospheric ozone and atmospheric pollutants are usually found at the downtown monitoring site.

The intensity of UV-B radiation over Mexico City and its changes over time in the polluted troposphere were evaluated at the downtown and the suburban sites in Mexico City over various time periods. The tropospheric ozone concentration measurements are used as an indicator of air pollution photochemical activity.

3. Diurnal Attenuation of UV-B Radiation in Downtown Mexico City

To compare the diurnal intensity of UV-B solar radiation at the downtown site with the suburban site, data for the same day from the two simultaneous monitoring systems were compared. November 10, 1994, was selected as a clear day without significant cloud activity. The maximum UV-B measurement at the suburban site was 3.70 MED/hour while at the downtown site, the UV-B measurements reached only 2.79 MED/hour, some 30% lower. The UV-B average from 1000 to 1500 LT at the suburban site was 2.99 MED/hour, while at the downtown site, it was only 2.08 MED/hour, 24% lower. At the suburban site an average of 39 ppb of tropospheric ozone was recorded from 1000 to 1500 LT, while at the downtown site an average of 172 ppb was recorded for the same period by the Mexico City Air Quality Monitoring Network instruments [*Secretaria del Medio Ambiente*, 1994] which are distributed throughout the metropolitan area. Hence, it was concluded that there was an inverse relation between UV-B radiation and ozone at ground level.

Figure 3 shows the diurnal variation of UV-B intensity for November 10 at the downtown Mexico City site and the suburban site. The diurnal increase of UV-B due to solar elevation occurs equally at the downtown and at the suburban sites from sunrise until 0930 when the increasing tropospheric photochemical activity begins to absorb solar UV-B energy. Because of higher concentrations and a faster buildup of pollutants, the UV-B intensity at the downtown site starts decreasing relative to the suburban site UV-B intensity. At 1030, the difference from the downtown to the suburban site becomes significantly larger and increases gradually until reaching more than 1 MED/hour at 1300.

The UV-B curve at the suburban site in Figure 3 has the typical shape of a bell curve that would be expected for a clear day at a midlatitude site without clouds, haze or pollution [*Evans,* 1992], while the measurements in downtown Mexico City become distorted with UV-B absorption throughout the day until sunset. The largest UV-B diurnal difference was recorded in late morning and early afternoon, with a difference of 30% in UV-B at the downtown site, relative to suburban site (only 21 km from each other).

4. Seasonal UV-B Attenuation in Downtown Mexico City

The UV-B data from instrumentation operating simultaneously in downtown Mexico City and at the suburban site, for the year from September 1994 to September 1995, were also analyzed to study the seasonal variation of UV-B radiation for both monitoring sites. The results are shown in Figure 4; the UV-B measurements at the downtown Mexico City site are lower than the UV-B measurements at the suburban site all year-round.

Higher levels of UV-B were recorded during the spring and summer for both the downtown and the suburban monitoring sites, while lower levels were recorded during the winter months. Even in the polluted troposphere of downtown Mexico City, the yearly seasonal UV-B trend agrees with the seasonal solar zenith angle trend. The results show that the yearly standard deviation about the mean is similar for the downtown site (19%) and the suburban site (17%) UV-B measurements. This follows from the fact that both sites have similar cloud cover conditions and summer/winter seasonal cycles, however; the yearly 1000 to 1500 average UV-B radiation at the suburban was 2.72 MED/hour, while the downtown yearly

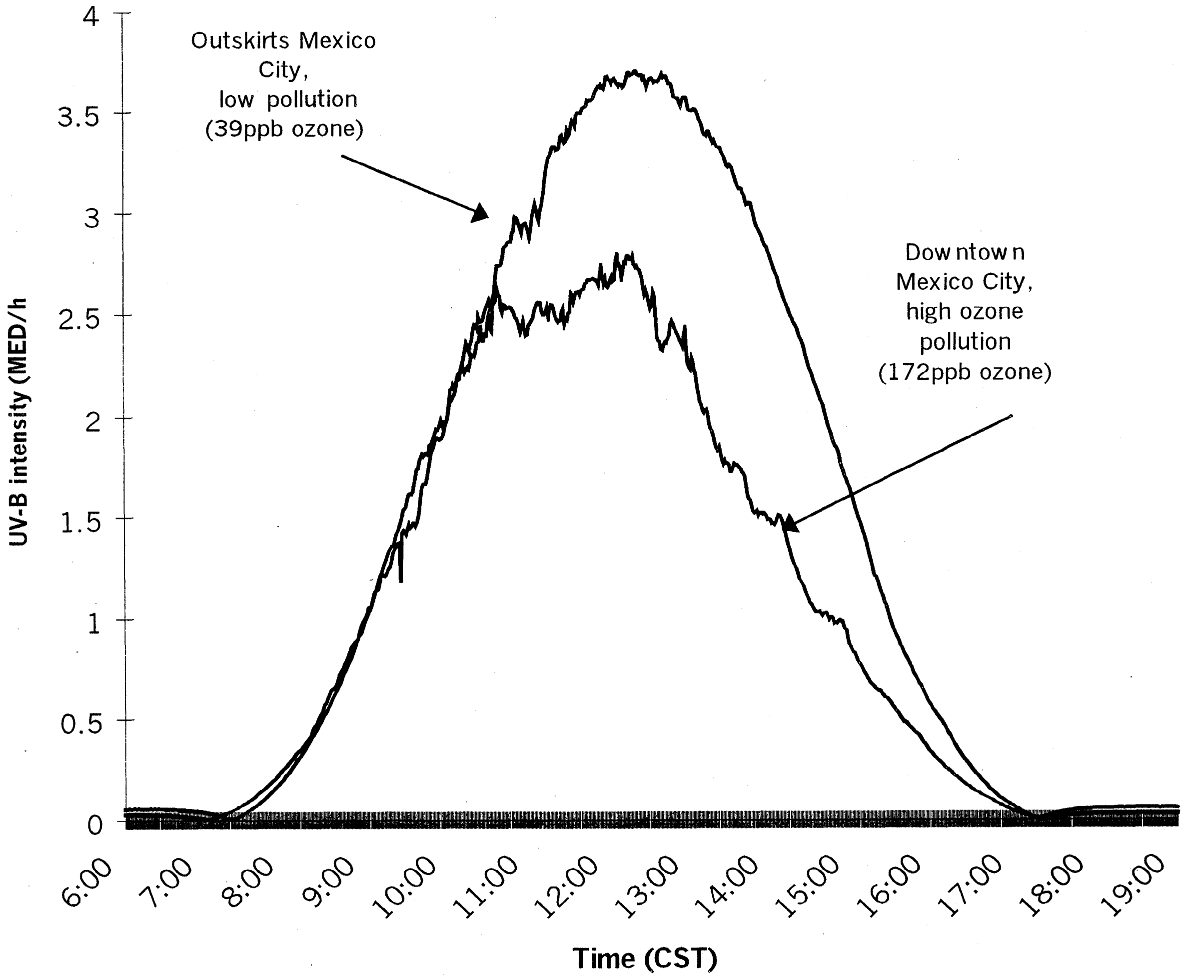

Figure 3. Diurnal UV-B measurements for November 10, 1994 (clear sunny day) at the Mexico City downtown site (bottom curve) and at the suburban (top curve) monitoring site, 21 km from each other. Significantly lower UV-B intensity is detected downtown after 1000 LT, related to higher atmospheric pollutant concentrations at the downtown site.

average was 2.17 MED/hour, 21% lower than the suburban UV-B average. The solar elevation angle at noon is plotted as the top curve in Figure 4 in order to explain the seasonal variations and the double hump occurring in May and July when the solar zenithal passage occurs in agreement with the UV seasonal intensity variations.

According to the data from the air quality monitoring network during 1994, tropospheric ozone levels above 275 ppb were reached only on 4 days, while in 1995, levels above 275 ppb were reached on six days [*Proaire,* 1996]. The yearly time series of UV-B from September 1994 to 1995 is shown in Figure 4. The UV-B difference is lower during the winter. In January the downtown UV-B was 0.18 MED/hour (9%) lower than the suburban UV-B. Larger differences between the suburban and the downtown intensities were detected in the summer. In August 1995 the downtown UV-B measurements were 1.22 MED/hour (43%) lower than at the suburban site. On average, UV-B was 0.55 MED/hour (21%) lower downtown than at the suburban site from September 1994 to 1995. This represents a significant UV-B attenuation in downtown Mexico City during the year.

The results in Figure 5 show that on most days throughout the year, UV-B is higher at the suburban site than downtown, but individual daily measurements in April 1995 show the inverse situation can be found occasionally where UV-B reaches 1 MED/hour less at the suburban site than at the downtown site. This is caused by variations in the local meteorological conditions such as local cloud cover.

Both monitoring sites, downtown and suburban, registered lower UV-B levels in winter than during the spring and summer months due solar elevation and to local tropospheric conditions, including clouds, rain, haze, and pollution.

5. Changes in Stratospheric Ozone and Tropospheric Ozone Concentrations in Mexico City

Data on Mexico City tropospheric ozone concentrations for the period from November 5 to 19, 1994, were analyzed in conjunction with UV-B and UV-A measurements. The intensity data in the UV-B and UV-A spectral bands were processed to calculate the total ozone column, using a special form of the Beer-Lambert law equation (1) as described by *Acosta* [1996].

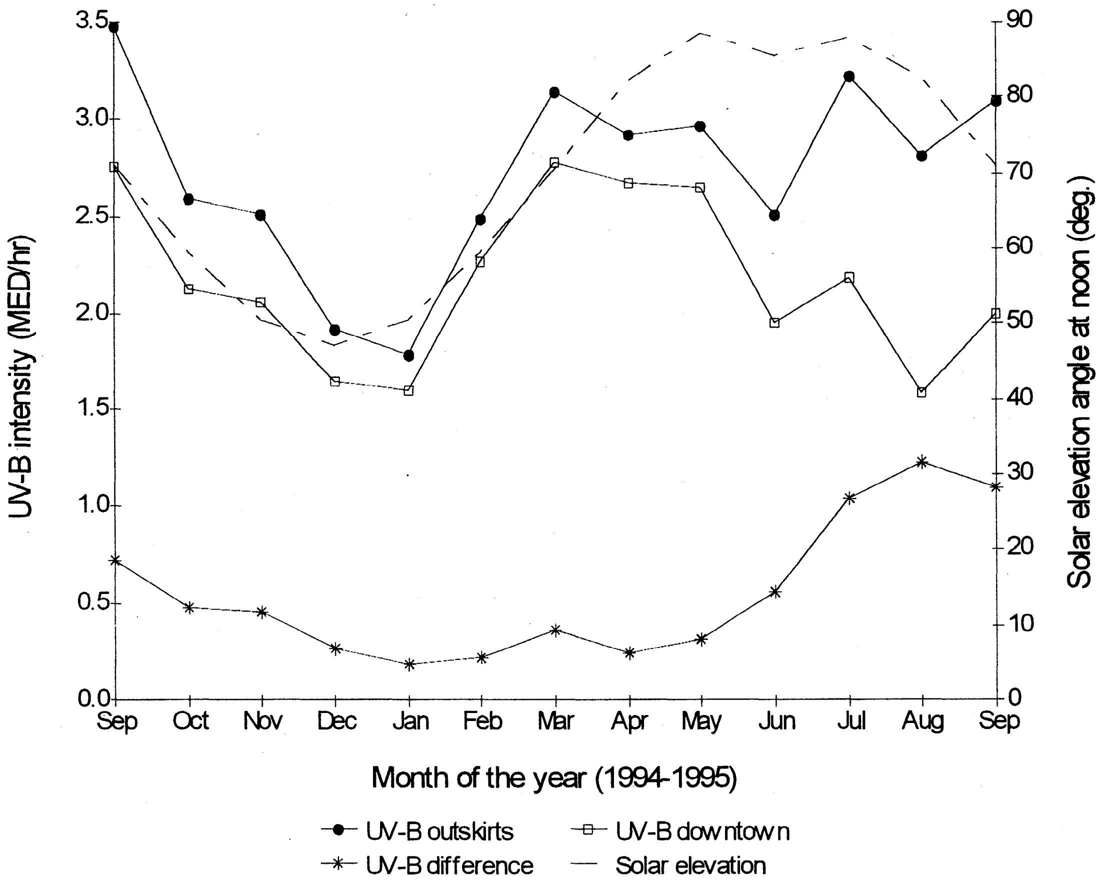

Figure 4. Monthly UV-B average of measurements from 1000 to 1500 LT at the Mexico City suburban and downtown sites. The bottom curve is the monthly average difference between the suburban and the downtown UV-B levels. The yearly average difference indicates consistently higher UV-B levels at the suburban site than in downtown Mexico City.

$$\frac{I(\lambda)}{I_0(\lambda)} = e^{-\tau} \qquad (1)$$

The UV-B intensity [I] at ground level is the radiation quantity of interest since it is absorbed by ozone. The UV-A intensity [I_0] at ground level is the selected reference quantity since it is not absorbed by ozone. Substituting UV-A for I_0 and UV-B for I, then equation (1) becomes

$$\frac{I_{\mathrm{UV-B}}}{I_{\mathrm{UV-A}}} = e^{-\tau} \qquad (2)$$

or

$$R_0 = \frac{I_{\mathrm{UV-B}}}{I_{\mathrm{UV-A}}} \qquad (3)$$

where R_o is the UV-B to UV-A ratio.

A numerical correction (0.539) was empirically determined for the UV-B to UV-A ratio. This correction is required to compensate from the fact that the two instruments record different units; UV-B in MED/hour cm^2 and UV-A in mW/cm^2. This factor was determined from an analysis of the correlation of the ozone column amount calculated from the ground level UV-B to UV-A ratio, with the Brewer spectrophotometer total ozone column measurements at Toronto [*Evans,* 1994]. The Brewer is a high-precision ground-based instrument that measures the total ozone column and is operated at Toronto in southern Ontario by Environment Canada.

If we set
$$R = 0.539\, R_o \qquad (4)$$

then R is the corrected UV-B to UV-A ratio.

The solar zenith angle (SZA) was considered in order to correct for the optical path length due to the air mass

$$\chi = \text{solar zenith angle} \qquad (5)$$

A special form of the ozone optical thickness (τ) is obtained from

$$\tau = -\frac{\ln(R)}{\mu} \qquad (6)$$

where $\mu = \sec(\chi)$.

Then solving for the vertical ozone column length from the ozone optical thickness (τ) and using an effective ozone absorption coefficient of [κ_{O_3} = 2.3 cm^{-1}]:

$$\lambda_{O_3} = \frac{\tau}{\kappa_{O_3}} \qquad (7)$$

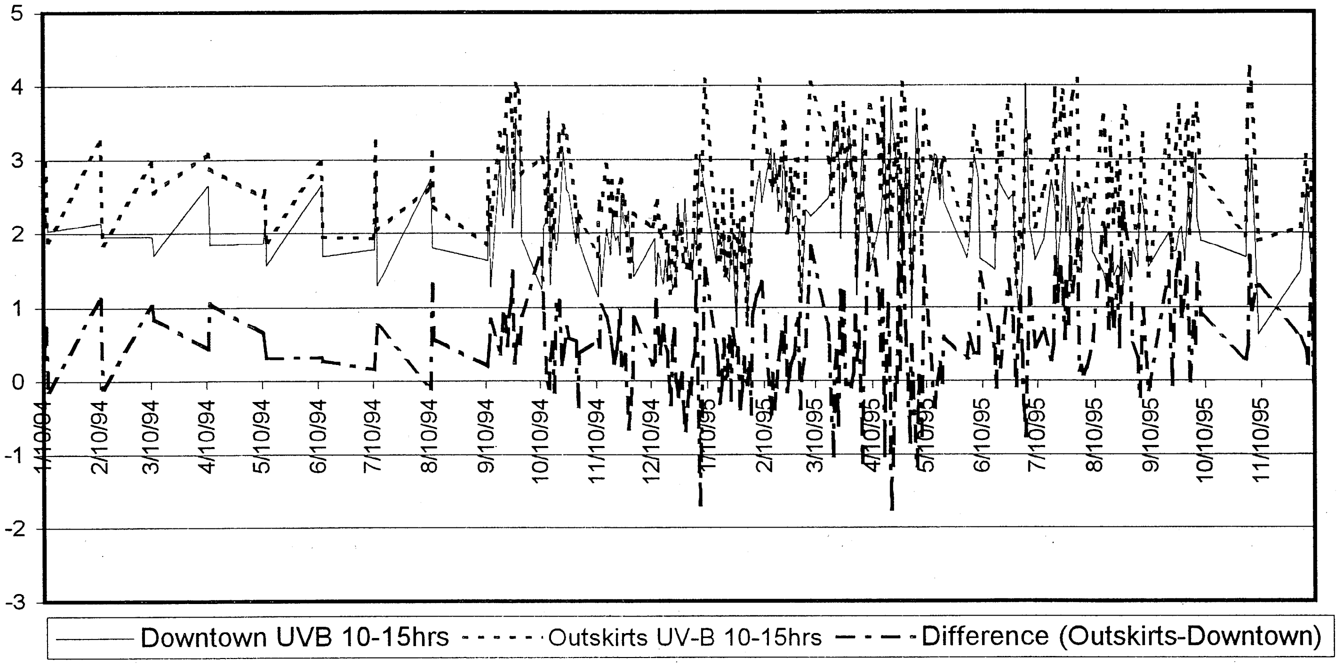

Figure 5. UV-B seasonal variation from September 1994 to 1995 taken from daily UV-B averages of measurements from 1000 to 1500 LT at the suburban site and the downtown Mexico City site. The bottom curve is the daily difference between the suburban and the downtown UV-B. The downtown UV tends to be lower year-round. There is a large variability in day-to-day changes in the UV-B intensity at ground level.

where λ_{O_3} is the vertical column thickness of the ozone layer in centimeters.

The result from equation (7) is the total ozone column length calculated from UV-B absorption relative to UV-A and is multiplied by 1000 to convert into Dobson units (DU). This procedure was incorporated in the software analysis tools described in the previous section to perform the automatic calculation of the total ozone column for every minute from the measurements of UV-B and UV-A intensities.

The difference between the calculated total ozone column thickness and the stratospheric total ozone column from the total ozone mapping spectrometer (TOMS) measurements could be compared to the measured tropospheric ozone concentrations in the Mexico City urban area.

Work is in progress to determine the accuracy and precision of the method to calculate the total ozone column. The radiometers present some advantages over alternate methods like spectrophotometers. The broad-band radiometer measures constant dose and intensity and provides long-term trend measurements for a fixed wavelength range. It detects the total irradiance over a specific UV wavelength band of interest. It has no moving parts and is simpler to operate than a spectrophotometer. A spectrophotometer resolves the UV-B band from 290-320 nm, into narrow bands. The spectral irradiance in each specific band can be measured, and the total dose can be calculated by convolving the measurements from consecutive scans, with an erythemal spectrum. The high spectral resolution scans of the spectrophotometer are also of value to the understanding of atmospheric chemistry and dynamics [*World Meteorological Organization (WMO),* 1977a] and are complementary to the broad-band radiometer measurements.

The middle curve in Figure 6 demonstrates that after Saturday, November 5, a very clear weekend, tropospheric ozone concentrations demonstrated an increasing trend from November 8 to November 19, 1994. The same increasing trend is obvious in the total ozone column calculated from UV radiation measurements as shown in the top curve. The corresponding day-to-day variations of the calculated ozone column (based on UV-B and UV-A absorption) and the measured tropospheric ozone concentrations, demonstrate that there is a direct relationship between these quantities. The measured tropospheric ozone concentrations and the calculated ozone column have the lowest values during the weekend of November 6 and the highest values on November 11, 17, and 19. Both reach local maximum and local minimum values on the same days during the 2 week analysis period.

The bottom line in Figure 6 represents the TOMS column measurements, which is dominated by stratospheric ozone. The TOMS data show small day-to-day variations, while the total ground-based measurements of ozone column show large variations that covary with the tropospheric surface ozone concentration changes. At the beginning of the comparison time period, on November 5, 1994, the difference between the TOMS ozone measurements and the calculated total ozone column thickness is close to 20 DU; on the next day, November 6, the difference goes down to 5 DU. By the end of the trend on November 19, the difference had increased to 40 DU. The close agreement within 5 DU, of the TOMS column and the measured column on November 6, when the surface ozone

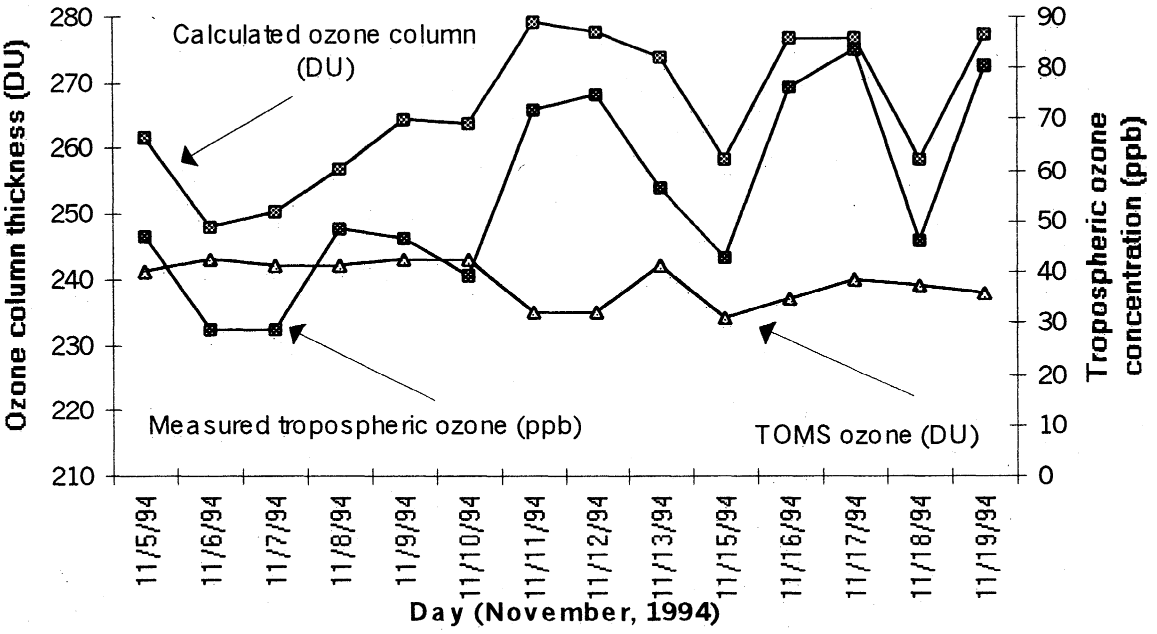

Figure 6. Calculated total ozone column thickness (Dobson units) from UV-B and UV-A band measurements, along with tropospheric ozone concentration measurements (parts per billion) for the 1000-1500 daily average over the period from November 5 to 19, 1994, at the Mexico City suburban site. The bottom curve represents TOMS column ozone measurements (Dobson units).

concentrations were low indicates that the absolute calibration of the UV-B/UV-A method is accurate within 5 DU. However, the TOMS measurements did not detect the large tropospheric ozone variations, which were measured by the tropospheric ozone analyzer and the UV-B/UV-A monitoring system during the period from November 8 to 19. This may be understood from a consideration of the properties of the TOMS measurements of tropospheric ozone column. The TOMS measurements measure stratospheric ozone with unit efficiency, but lower tropospheric ozone with only about 33% efficiency as a consequence of the radiative transfer involved. To compensate for this effect, a constant tropospheric column amount from climatology is added to the TOMS column measurement; when the actual surface ozone column matches the climatology, there is little error from this procedure [*McPeters et al.,* 1996]. The Meteor-3 TOMS measurements were taken from overpasses which occurred during early afternoon from 1300 to 1500 during the November 5-19 period (data from the TOMS web site) so that the comparison with a 1000 to 1500 average of column ozone from the ground should be reasonable. The TOMS footprint is about 40 km [*McPeters et al.,* 1996], so that the spatial averaging would tend to reduce both the high tropospheric columns and the type of fluctuations measured at our suburban Mexico City site.

Previous studies have shown that tropospheric ozone has an influence on the measurements of stratospheric ozone from terrestrial stations [*Lefohn et al.,* 1992]. In another study on the tropospheric component of the total ozone column over Mexico City, based on satellite and ground-based measurements [*Juarez et. al.,* 1995] reported 20 DU (about 10% of the total ozone column) for Mexico City. [*Portmann et al.,* 1997] estimate 28 DU for the tropospheric component of the total ozone column over central Mexico. Both studies estimate a tropospheric ozone column amount comparable with our detected variation due to tropospheric ozone in Figure 6.

The measured increases in ozone column as calculated from the ratio of UV-B/UV-A are about 30 DU from November 6 to 19; this may have contributions from UV-absorbing aerosols as well as ozone. [*Herman et al.,* 1997] have shown that these UV-absorbing aerosols are frequent in the tropics, especially near large cities such as Mexico City. Our measurements may help to evaluate the increases in the ozone column over Mexico City due to air pollution, which may partially compensate for possible future decreases in the stratospheric ozone layer over tropical latitudes.

6. The UV-monitoring Network for the Valley of Mexico

Since the spring of 1993 Sistema Internacional de Monitoreo Ambiental (SIMA) has been reporting daily UV index levels to the public on television [*Collaboration Agreement,* 1993] and in the press, inspired by the Canadian UV Index program which began in the summer of 1992 following a pilot program by Coppertone and Trent University in 1990.

In 1996 the Mexico City Ministry of the Environment commissioned SIMA to conduct the design of the UV-monitoring Network for the Valley of Mexico [*Acosta,* 1997]. The design is based on our pilot monitoring program, which has been previously described in this paper. It considers an array of UV-monitoring stations, operating alongside meteorological and atmospheric

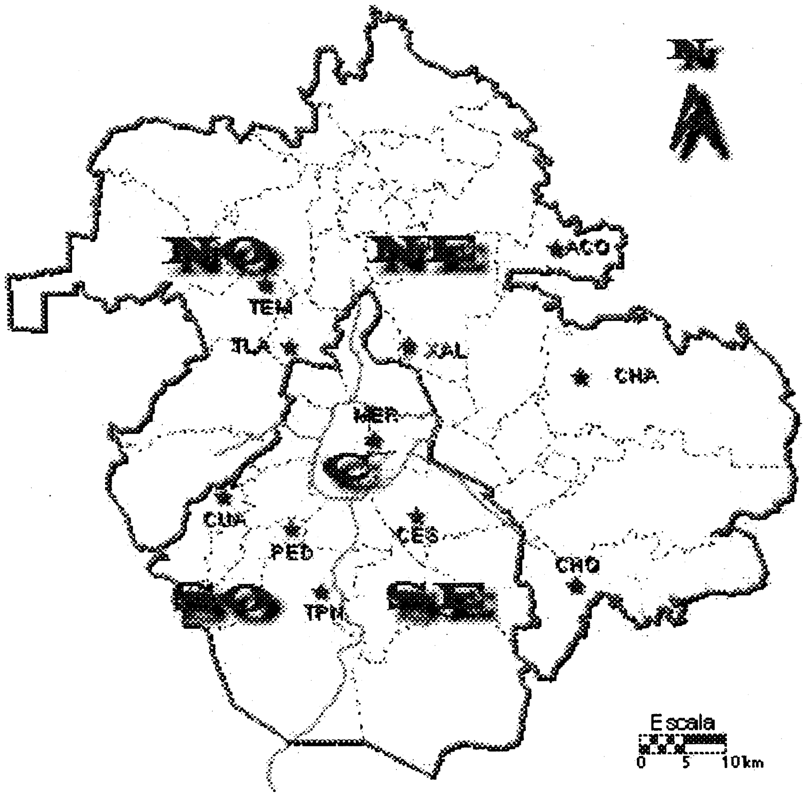

Figure 7. A diagram showing the distribution of the stations in the Valley of Mexico UV-monitoring Network [*Acosta*, 1997]. The monitoring nodes cover urban and suburban areas at each of the four cardinal points of the metropolitan area.

pollution instrumentation from the air quality monitoring network, designed to carry out long-term measurements in downtown and suburban Mexico City. Figure 7 shows the distribution of these UV-monitoring stations in the Valley of Mexico. The UV-monitoring stations were implemented in pairs to cover the urban and suburban northwest, northeast, center, southwest and southeast areas of the Mexico City metropolitan area. Five monitoring stations were distributed in the suburban perimeter of the city, while the rest were placed in the urban area, where high levels of atmospheric pollution are frequently registered. When operational, the UV network will provide valuable data to assess the tropospheric and stratospheric fractions of the total ozone column, as well as the trends in UV attenuation due to possible future increases of atmospheric pollutants.

The WMO has recommended that UV-monitoring and public information programs should be implemented in major population centers, especially in subtropical latitudes. Many UV-monitoring networks with diverse characteristics already operate around the world [*WMO*, 1997b]. In France, the Association Securite Solaire operates a UV-monitoring network based on seven solar light broad-band radiometers. One UV-B instrument was placed in each French city for public UV index reports. The U.S. National Science Foundation Monitoring Network for the Polar Regions uses the SUV-100 spectroradiometer produced by Biospheric Instruments Inc. of California [*Booth et al.*, 1994]. Canada has a network of 10 Brewer spectrophotometers [*Wardle et al.*, 1994]. Most UV networks are intended to cover large geographic areas, focusing mainly on solar radiation and stratospheric ozone measurements. What makes the design of the Valley of Mexico UV-monitoring Network unique is a higher UV-monitoring density in order to evaluate the intensity differences between different areas of the city in relation to urban atmospheric pollution, altitude, and population exposure.

7. Summary

The polluted urban atmosphere in Mexico City provides a significant attenuation of solar UV-B radiation at ground level. This attenuation factor may be applicable to other urban centers with lesser atmospheric pollution such as Toronto. Ozone is one of the most important components of urban photochemical pollution which contribute to UV-B absorption [*Juarez*, 1995].

Despite the significant attenuation factor (20% recorded attenuation for the 1994 -1995 annual average), it was found that year-round UV-B levels are still very high in Mexico City. In downtown Mexico City a yearly average of 2.17 MED/hour was found; this is equivalent to an erythema sunburn time, for skin Type 2 of 28 min. Seasonal and diurnal solar cycles are responsible for the observed variations of UV-B intensity at ground level. Changes in the local tropospheric conditions such as haze, clouds, and pollution are responsible for large daily variations of UV-B. Further research is required to assess the influence of each atmospheric component involved in the attenuation of UV-B radiation.

From this research we conclude that UV-B intensity at ground level at a particular location is driven by 1) diurnal solar apparent motion, dependent on the Earth's rotation about its axis; 2) seasonal variations of solar elevation, dependent on the Earth's motion around the Sun; 3) cloud cover and atmospheric humidity; 4) haze and tropospheric pollution; 5) thickness of total ozone column, which is dependent on tropospheric ozone concentration and the stratospheric ozone layer.

Diurnal and seasonal UV-B variations are dependent on all of the above conditions for the specific location. A similar behavior has been reported for southern Ontario [*Evans and Acosta,* 1993], although the attenuation by air pollution is smaller. Mexico City is located at a latitude of 19°N, close to the tropic of Cancer at 23°N; therefore the highest solar elevation angle is reached at solar noon during the summer and late spring, while the lowest solar elevation at noon is reached during the winter solstice.

In the suburbs of Mexico City, higher UV-B levels were detected in the spring and summer months than during the fall and winter months. The monthly average for July 1994 was 3.65 MED/hour (from 1000 to 1500). The monthly average for January 1995 was 1.79 MED/hour for the same time period, only 50% of the summer high. The yearly maximum daily average UV-B was 4.49 MED/hour (from 1000 to 1500) on August 15, while the low daily average for the same period was only 2.44 MED/hour in December 13, almost 50% below the summer maximum daily high as shown in Figure 5.

Although the solar UV-B intensity is lower in the winter than in the summer, the winter UV-B intensity still reaches levels high enough to cause important impacts on the health of humans, plants, and animals. On December 13, 1994, the recorded solar UV-B exposure of 2.44 MED/hour (average from 1000 to 1500) is equivalent to a total dose of 12.2 MEDs of erythemal dosage (total erythema dose not to be confused with UV-B intensity units or MED/hour). With 12.2 MEDs of erythemal UV-B dosage in a five hour period during the fall and winter months, the UV-B intensity is enough to cause severe sunburn to exposed individuals [*Campbell,* 1977].

Simultaneous UV-B measurements at the suburban and downtown monitoring sites demonstrated significant UV-B attenuation in the downtown intensity relative to the suburban UV-B intensity (Figure 2). A higher concentration of pollutants is normally found downtown. The UV-B measurements for Monday, November 10, 1994, showed that the mean UV-B at the downtown site can be 24% lower than at the suburban site on the same clear day (Figure 3). The daily maximum UV-B in downtown Mexico City was 30% lower than at the suburban site.

Tropospheric air pollution is linked to UV-B attenuation [*Evans and Acosta,* 1992; *Frederick, et al.,* 1993; *Liu et al.,* 1991]. The urban atmosphere in downtown Mexico City provides significant year-round UV-B attenuation, as compared to the suburban atmosphere of Mexico City. Even though both sites were very close to each other, the yearly UV solar radiation budget at ground level in downtown Mexico City is lower (Figure 4). In August, 1995, at the suburban site, the monthly average UV-B was 2.81 MED/hour equivalent to a total day dose of 14.05 sunburn erythema [*McKinlay and Diffey*, 1987], while in downtown it only reached 1.59 MED/hour - equivalent to a total day dose of 7.95 MEDs of sunburn erythemal radiation. The population in downtown Mexico City is exposed to significantly lower doses of UV-B solar radiation at ground level; Mexico City appears to have a built-in ozone layer. Aside from the respiratory diseases and potential hazards to the health of living organisms due to atmospheric pollution, the large UV-B attenuation provided by the urban atmosphere in Mexico City can be considered a protective shield for the population from extreme solar UV-B exposure damage [*Scientific Committee on Problems of the Environment,* 1992].

The total ozone column calculated from UV absorption in Mexico City was correlated with the tropospheric ozone measurements. The pollution increases from Monday to Friday. After an unpolluted weekend the tropospheric ozone measurements follow an increasing trend, similar to the calculated total ozone column from the UV-B and UV-A measurements (Figure 6). At the beginning of the week, on Sunday November 6, 1994, the tropospheric ozone was 30 ppb, and the calculated ozone column was 245 DU. By Friday, November 11, 1994, measured tropospheric pollution increased to 70 ppb, and the calculated total ozone column increased to 280 DU. The tropospheric ozone and the calculated total ozone column showed local minimum and maximum in the same days, but the relationship was not linear throughout the week.

It was found that there is an important contribution of tropospheric ozone to the total ozone column in the urban environment. There was a significant difference between the calculated total ozone column and the TOMS instrument total column ozone measurements of about 25 DU under polluted conditions. Mexico City UV-index on-line internet reports can be found at http://www.sima.com.mx or http://www.imeca.com.mx.

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