The effect of varying ozone concentration on surface UV-B radiation: a Fiji perspective

K Koshy, M Maata, A H Q Samad, G Sami, J Tabudravu
Division of Chemistry, The University of the South Pacific, Fiji

ABSTRACT

Projects studying the effect of column ozone levels on UV-B radiation reaching the surface of the Earth as part of a wider global observation of vertical profiling were initiated by NASA/NOAA in the 1990s. A comparison of the changes in UV-B radiation as a function of ozone concentration revealed a negative correlation. We have shown for the first time in Fiji that a similar trend exists but with more scatter. Previous studies at this site (USP) have shown that the atmospheric concentration of aerosols varies seasonally and this may have a bearing on the scatter of the results.

1 INTRODUCTION

The halide (chlorine and bromine from chlorofluorocarbons (CFC)) catalysed destruction of ozone has been responsible for the reduction in the ozone levels in the polar stratosphere. Over Antarctica, the reduction is 50% in the column and 100% at some altitudes (Brasseur *et al*. 1999). As a result, the levels of UV-B (280 - 315 nm) and UV-C (<280 nm) entering the biosphere are enhanced. Unlike the polar stratosphere, the tropical stratosphere does not have the conditions for halide-catalysed ozone destruction (Hamill and Toon 1991; Hofmann *et al*. 1997; Leun *et al*. 1995).

Stratospheric ozone levels in both the polar and non-polar regions are near their lowest point since measurements began in the 1970's. Current UV-B radiation levels show increases relative to the values in the 1970's (UNEP 1998).

The UV region (200 - 400 nm) of the solar radiation spectrum accounts for a small fraction of the total solar energy that reaches the Earth's surface. Wavelengths shorter than 280 nm (UV-C) are important for atmospheric photochemistry, but they are completely absorbed in the atmosphere by ozone and other oxygen and nitrogen species (Baird 1995). The remaining UV spectrum is further subdivided into UV-B and UV-A radiation. The UV-B component (280 - 315 nm) is of particular interest because it is strongly absorbed by ozone, and it increases at the surface when the atmospheric ozone decreases (EPA 1998). The main sink for ozone in the stratosphere is photochemical reactions, thus preventing the entry of excessive UV-B radiation into the lower atmosphere.

$$O_3 + h\nu \rightarrow O^{\bullet} + O_2$$

Although the UV radiation splits the ozone molecule, ozone can reform through the following reactions resulting in no net loss. At wavelengths less than 240 nm, ozone is formed.

$$O_2 + h\nu \rightarrow O^{\bullet} + O^{\bullet}$$
$$O^{\bullet} + O_2 \rightarrow O_3 \qquad \text{(Sparling 1999)}$$

Reductions in atmospheric ozone over New Zealand by 5-10% since 1970 resulted in a 10% increase in UV-B radiation over the region (Marks and McKenzie 1997). The maximum UV-B radiation measured at Mauna Loa, Hawaii was 51.3 $\mu W\ cm^{-2}$ on July 27, 1995 when the total ozone column was 257 Dobson Units (DU) (Newman 2006; McKenzie *et al*. 1991). This was 20% greater than the highest value previously recorded. Over Hawaii, an increase of 7% in UV-B at 295 nm for every 1% loss of ozone was recorded by Bodhaine *et al*. (1997).

The relationship between the UV radiation and the changing ozone column observed at Antarctica is illustrated in Figure 1. McKenzie *et al*. (1991) confirmed this inverse relationship between the ozone levels and the surface UV-B radiation at Lauder (NZ). During the 1980s, ozone levels varied by ±1% seasonally and the UV-B response to this was between 5 - 6% in magnitude. Apart from total column ozone, aerosol content and cloud cover are important parameters governing the magnitude of UV-B radiation reaching the Earth's surface (Lubiin and Jensen 1995).

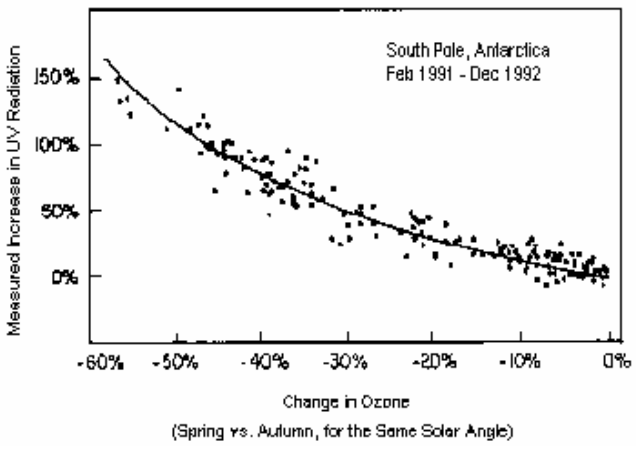

Figure 1. The relationship between ozone and the penetrating erythermal UV radiation observed at the South Pole (UNEP, 1999).

Clouds and lower tropospheric aerosols can also have a slight effect on the magnitude of UV-B radiation reaching the surface. The variations observed were influenced by the nature (concentration, physical and chemical makeup like soot, sulfate haze, dust, seawater aerosol, etc.) of the aerosols. Anthropogenic sulfate aerosols associated with fossil fuel burning were observed to decrease surface UV-B irradiance by a maximum of 5 - 18% in highly industrialized regions of the Northern Hemisphere (Li *et al*. 1995; Long *et al*. 1996; UNEP 1998). Despite these natural means of reducing the levels of UV-B radiation

from reaching the Earth's surface, there are sufficient rays penetrating these obstacles to cause harm to life.

1.1 BIOLOGICAL EFFECTS OF INCREASED UV-B RADIATION AT THE EARTH'S SURFACE

A major health risk associated with ozone depletion is the result of increased UV-B radiation in the environment. The impact of increases in ambient UV-B levels has caused serious concerns.

UV-B rays have a significant impact on important biomolecules, such as deoxyribonucleic acid (DNA) and proteins, and therefore, on living organisms. The stratospheric ozone does not filter out the UV-A rays. Although the photons of the UV-A rays (>315 nm) are less energetic than the UV-B rays, they do have biological effects. Both UV-A and UV-B radiation have important effects on various materials and chemical processes on the Earth's surface and in the atmosphere (WMO 1998; Voytek 1990).

Humans have three major organ systems whose cells and tissues are commonly exposed to sunlight: the eye, the immune system and the skin. UV-B radiation has a huge impact on these three systems. Some of the effects are cataract formation, skin cancer (melanoma) and suppression of the immune system amongst other effects which impact on plants and other animals. Despite this, some animals are known to be UV-B tolerant (Callaghan *et al*. 2004). Over 34,100 people suffered from melanoma in the USA alone since 1973 and these cases are increasing by 4% each year (Long *et al*. 1996; UNEP 1998).

In 1935, the chances of developing skin cancer in the USA were 1 in 1500. In 1991, it increased to 1 in 150 and by the year 2000, skin cancer cases are predicted to be as many as 1 in 75 people. In Australia, the skin cancer rate is very high with a larger percentage of people estimated to develop cancer. New cataract cases are predicted to reach 1.6 million/year worldwide before the year 2000 (Geocities 1997).

In Fiji, the number of skin cancer reports particularly amongst the fair skinned, European and Chinese, have increased relative to previous years (Ministry of Health 2000). Any correlation to possible increases in UV-B radiation reaching the biosphere has not yet been studied. This applies to UV-B increases predicted on the basis of the scenario that most favours ozone depletion. Ozone depletion would increase due to incomplete compliance with phasing out the ozone depleting substances which have enormous lifespans and ozone depleting potentials in the stratosphere (UNEP 1994).

In response to the increasing UV-B radiation entering the atmosphere, the number of monitoring sites for UV-B and ozone (stratospheric and tropospheric) has increased enormously during the 1990's throughout the world (UNEP 1994). One such site is our Suva based ozonesonde/UV-B monitoring site which started in 1997.

2 METHODOLOGY

2.1 FIJI MEASUREMENTS OF UV-B AND OZONE

2.1.1 UV-B LEVELS

A Delta-T device (model PD104B-cos) was used in determining the quantity (intensity) of UV-B radiation reaching the surface. The UV sensor was mounted on a horizontal surface (2 m above the ground) at the Suva site. The specifications of the Delta-T device are given in Table 1.

The UV-B sensor has made continuous surface radiation measurements at the Suva site. The surface mounted device detected the UV-B radiation reaching the surface quantitatively. The UV-B data was recorded as hourly averages and hourly maxima during the period June 1998 to the end of 1999.

Table 1. Specifications of the UV-B meter used for surface radiation measurements.

Sensor Type	Peak Sensitivity	Detector Sensitivity	Accuracy
UV-B	313 nm	1 mV = 10 W m^{-2}	± 7.5%

The UV-B radiation reaching the surface, measured during the time of ozonesonde launches (11-12 am), were correlated to the total column ozone above the Suva site (see below). The reducing effects of mainly cloud cover and aerosols were not considered. The inverse (qualitative) relationship between total column ozone and UV-B radiation reaching the surface at the Suva site was determined.

2.1.2 OZONE LEVELS

The vertical profile of ozone was measured on a weekly basis using balloonborne electrochemical concentration cell (ECC) ozonesondes (Komhyr *et al*. 1995a; Komhyr *et al*. 1995b; Saltzman and Gilbert 1959). Measurements started in conjunction with the PEM-Tropics project in February 1997. The ozonesondes were launched at the Suva site (Geographical location: 18.10S, 178.20E), which is based at the University of the South Pacific.

3 RESULTS AND DISCUSSION

3.1 OZONE EFFECTS ON UV-B

The variation of UV-B with the changing total column ozone is shown in Figure 2.

The expected increase in UV-B radiation as a result of decreasing total column ozone was seen on most days during the 1998 - 1999 period. The reducing effect of ozone increases on the UV-B radiation reaching the ground did not however, show any quantitative relationship. That is, the varying magnitude of UV-B changes with fluctuating ozone levels indicated the presence of other influencing factors.

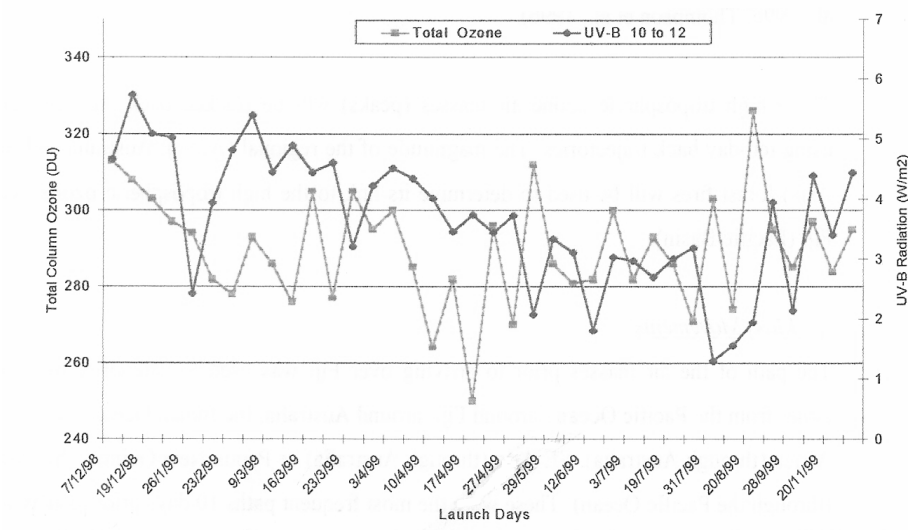

Figure 2. UV-B radiation variations as a result of changing total column ozone during 1998 and 1999.

The correlation between UV-B radiation and total column ozone shows an inverse relationship as seen in Figure 3. The negative slope indicates a possible inverse relationship between UV-B radiation and total column ozone. The poor correlation ($R^2 = 0.0016$) is indicative of the presence of other variables (cloud cover and aerosol content of the atmosphere) in the relationship which were not accounted for in this study.

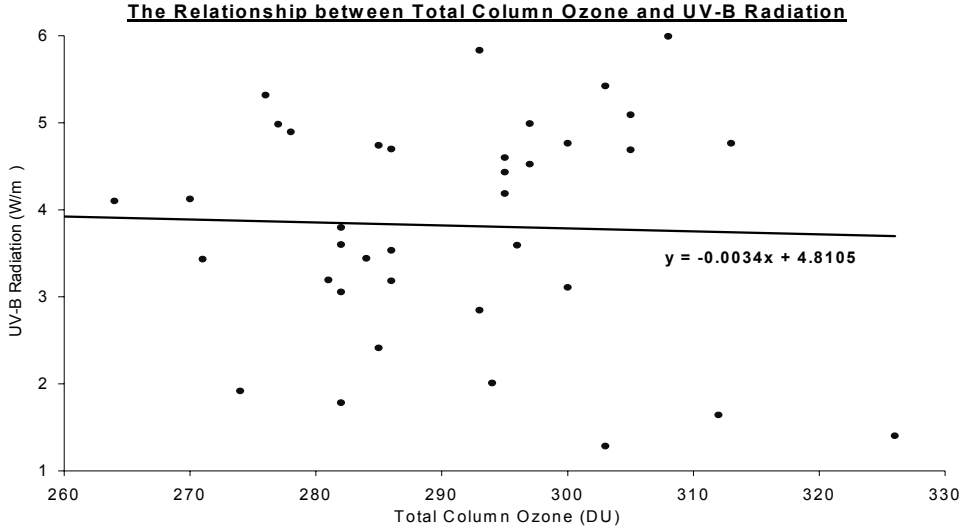

Figure 3. Correlation between total column ozone and UV-B radiation reaching the ground during 1998 and 1999.

3.2 CLOUD/AEROSOL EFFECTS

UV-B studies have shown the effects of cloud cover on the magnitude of UV-B radiation reaching the ground to vary from 70% reductions with dense heavy clouds to an increasing effect with broken clouds (Long *et al*. 1996; McKenzie *et al*. 1997). The effects of clouds (cloud type and percentage cover) on the UV-B radiation are essential in determining its relationship to the total column ozone.

Studies have shown atmospheric aerosols to have a reducing effect on the UV-B radiation reaching the ground. The effects varied within 5 - 18% in industrialised regions (UNEP 1998). Collectively, the clouds and aerosol content of the troposphere have previously shown reducing effects by up to 88% and ranging to an increasing effect with broken clouds. The effects of these are possible contributors to the poor correlation observed at the Suva site.

The levels of suspended particles at the ground level were monitored using high volume sampler techniques and micro-balance weighing, over Suva during May 1998 to June 1999. The total suspended particles ranged from 8.9 to 46 μg m^{-3} varying throughout the Suva area. This varying suspended particle content of the atmosphere may be making a contribution to the changing UV-B radiation reaching the ground (Kumar 2000), but this needs greater investigation. The effects of clouds and the aerosol content of the atmosphere are essential in determining a quantitative relationship between total column ozone and UV-B radiation reaching the ground.

4 CONCLUSION

The global observation of a negative correlation between ozone and UV-B has been further supported by our studies in Fiji. However, there are complicating factors in tropical island situations which have resulted in the wider scatter of the correlated ozone/UV-B data.

REFERENCES

Baird, C. 1995. Environmental Chemistry. W.H. Freeman and Company, New York. 484 p.

Bodhaine, B.A., Dutton, E.G., Hofmann, D.J., McKenzie, R.L. and Johnson, P.V. 1997. UV measurements at Mauna Loa. July 1995 to July 1996. *Journal of Geophysical Research* **102(D15),** 19265-19273.

Brasseur, G.P., Orlando, J.S. and Tyndall, G.S. (editors). 1999. Atmospheric Chemistry and Global Change. Oxford University Press, New York. 654 p.

Callaghan, T.V., Björn, L.O., Chernov, Y., Chapin, T., Christensen, T.R., Huntley, B., Ims, R.A., Johansson, M., Jolly, D., Jonasson, S., Matveyera, N., Panikov, N., Oechel, W., Shaver, G., Elster, J., Jonsdottir, I. S., Laine, K., Taulavuori, K., Taulavori, E. and Zöckler, C. 2004.

Responses to Projected Changes in Climate and UV-B at the Species Level. *Ambio* **33(7),** 418-435.

5. 5.EPA. 1998. 1997 National air quality: status and trends. Online. Available :http://www.epa.gov/oar/aqtrnd 97/brochure/stratoz.htm

Geocities. 1997. Impacts on humans. On line. Available: http://www.geocities.com/rainforest/vines/4030/impacts. html.

Hamill, P. and Toon, O.B. 1991. Polar stratospheric clouds and the ozone hole. *Physics Today* December: 34-42.

Hofmann, D.J., Oltmans, S.J., Harris, J.M., Johnson, B.J. and Lathrop, J.A. 1997. Ten years of ozonesonde measurements at the South Pole: Implications for recovery of springtime Antarctic ozone. *Journal of Geophysical Research* **102(D7),** 8931-8943.

Komhyr, W.D., Barnes, R.A., Brothers, G.B., Lathrop, J. A. and Opperman, D.P. 1995a. Electrochemical concentration cell ozonesonde performance evaluation during STOIC 1989. *Journal of Geophysical Research* **100(D5)**, 9231-9244.

Komhyr, W.D., Connor, B.J., McDermid, I.S., McGee, T.J., Parrish, A.D. and Margitan, J.J. 1995b. Comparison of STOIC 1989 ground-based lidar, microwave spectrometer and Dobson spectrophotometer umkehr ozone profiles from balloon-borne electrochemical concentration cell ozonesondes. *Journal of Geophysical Research* **100(D5),** 9273-9282.

Kumar, S. 2000. Unpublished Data, Physics Department, School of Pure and Applied Sciences, The University of the South Pacific, Suva, Fiji.

Leun, J.C.V.D., Tang, X., Tevini, M., Andrady, A., Amin, M.B., Hamid, H., Hu, X. and Torikai, A. 1995. Environmental effects of ozone depletion: 1994 assessment. *Ambio* **24(3),** 138-196.

Long, C.S., Miller, A.J., Lee, H.T., Wild, J.D., Przywarty, R.C. and Hufford, D. 1996. Ultraviolet index forecasts issued by the National Weather Services. *Bulletin of the American Meteorological Society* **77(4),** 729-748.

Lubiin, D. and Jensen, E.H. 1995. Available. On line: http://www.iisd.ca/linkages/journal/low.html. Effects of clouds and stratospheric ozone depletion on ultraviolet radiation trends. *Nature* 377: 710-711.

Marks, C.P. and McKenzie, R. 1997. UV index forecasts and data for New Zealand on the Internet. *Water and Atmosphere* **5(4),** 13-14.

McKenzie, R.L., Mathews, W.A. and Johnston, P.V. 1991. The relationship between erythermal UV and ozone, derived from spectral irradiance measurements. *Geophysical Research Letters* **18(12),** 2269-2272.

McKenzie, R.L., Paulin, K.J. and Kotkamp, M. 1997. Erythemal UV irradiances at Lauder, New Zealand: Relationship between horizontal and normal incidence. *Photochemistry and Photobiology* **66(5),** 683-689.

Ministry of Health, Fiji, Statistical Department. 2000. Cancer Cases: Annual Table for each Year.

Newman, P. 2006. Ozone Facts: What is a Dobson Unit? Online. Available: http://ozonewatch.gsfc.nasa.gov/facts/dobson.html

Saltman, B.E. and Gilbert, N. 1959. Iodometric microdetermination of organic oxidants and ozone. *Analytical Chemistry* **31(11),** 1914-1920.

Sparling, B. 1999. Basic chemistry of ozone depletion. Online. Available: http://science.nas.nasa.gov/services/ educ…sources/teacherwork/ozone/ozone_chem.html

UNEP, 1994, Environmental effects of ozone depletion: 1994 assessment.

UNEP, 1998, Environmental effects of ozone depletion: 1998 assessment.

UNEP, 1998, Scientific assessment of ozone depletion: 1998, Volume 2.

UNEP. 1999. Common questions about ozone. On line. Available: http://www.unep.org/ozone/faq7.html.

Voytek, M.A. 1990. Addressing the biological effects of decreased ozone on the Antarctic environment. *Ambio* **19(2),** 52-61.

WMO. 1998. Scientific assessment of ozone depletion: 1998. Global ozone research and monitoring project-Report No. 44.