ERYTHEMAL UV AT 45°S: LONGITUDINAL AND SECULAR VARIABILITY

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ABSTRACT

A single layer model for calculating clear-sky global ultraviolet (UV) irradiance is used to investigate the zonal variation in erythemal UV along the 45°S parallel. Daily total column ozone data from the Total Ozone Mapping Spectrometer (TOMS) experiment together with geographic location and day number provide the required inputs to the UV model. Monthly averages of total ozone during the years of 1979 (the first complete year of TOMS data) to 1992 (the last complete year of TOMS data) are used to model surface UV irradiance providing an indication of the variations that can be expected over a 13 year period. Although an increase in surface UV is evident in the results, spatial variations may exceed temporal variations at 45°S. In addition, coefficients from a statistical model of global ozone variation have been used to provide an estimate of weekly average total column ozone along 45°S for the years 1979, 1992 and 2000. These data, when used as input to the UV model, indicate a sustained increase in surface UV at these latitudes. Results based on such future projections should be treated with caution due to unforeseen future perturbations to the total column ozone trends.

INTRODUCTION

Since stratospheric ozone is the primary absorber of incident UV radiation, it can be expected that decreases in total column ozone will result in increases in the surface irradiance. However, lack of a global empirical UV data set has resulted in few quantitative results on the dependence of UV on total ozone. Many UV measurement programs are now underway in order to remedy this problem (McKenzie et al., 1993). Care must be taken when selecting a site for the measurement of surface UV for purposes of investigating UV/ozone dependences. Prime requisites for such a site include large annual variability in total column ozone, stable meteorological conditions (many cloudless days) and good visibility (low tropospheric aerosol loading). Following the breakup of the Antarctic vortex in late spring, large masses of chemically processed air move away from the continent possibly causing ozone deplention at lower latitudes (Sze et al., 1989). Therefore, proximity to the Antarctic may be an added advantage for a surface UV measurement site.

The South Island of New Zealand provides a prime location in the Southern Hemisphere for surface UV measurements. Not only is it one of the three countries closest to the Antarctic, but it also experiences the largest annual variation in total column ozone. This large variability in total column ozone makes trend detection more difficult, but facilitates studies of the effects of ozone changes on UV. Figure 1 shows the amplitude of the annual variation in total column ozone for 30°S, 45°S and 60°S obtained from a statistical model of the global

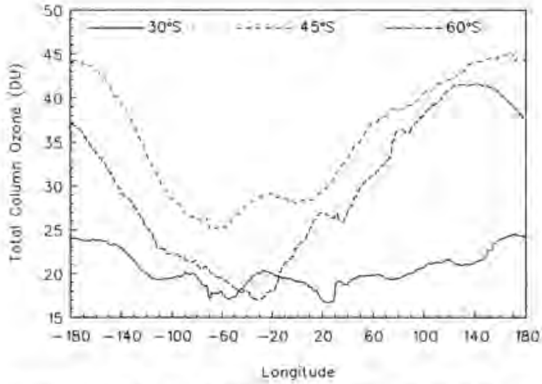

Figure 1: Amplitude of the annual variation: 1979 to 1992.

ozone variation (Bodeker, 1994). The model indicates that the maximum annual variability occurs near the latitude line of 45° and near New Zealand longitudes. The typical annual peak-to-peak amplitude in monthly mean total column ozone at 45°S, 170°W is 90 DU.

In order to investigate the past and possible future UV environment of New Zealand, use is made of a simple model (McKenzie, 1991) to calculate the clear-sky global ultraviolet (UV) irradiance received on a horizontal surface at local noon. The model inputs required are total column ozone and day number (to calculate solar zenith angle and eccentricity of the Earth's orbit). Ozone data were obtained from TOMS on board the Nimbus 7 satellite. This experiment provides, on a daily basis, the global distribution of total column ozone. Each data point represents a mean taken over an average cell size of 60 km x 60 km as determined by the field of view of TOMS. Recent improvements to the TOMS data reduction algorithm have led to a new calibration drift correction of the TOMS instrument, such that the data at the end of the record are precise to 1.3% (2σ) relative to the data at the beginning of the record (Herman et al., 1991). These data are of sufficiently high quality to allow for long-term trend determination.

TOTAL COLUMN OZONE AT 45° SOUTH

The data set used in this analysis is the 'Version 6' GRID-TOMS product spanning the period 1 January 1979 to 31 December 1992. These data consists of daily global maps of total column ozone, measured in Dobson Units (DU), at a resolution of 1.25° longitude by 1° latitude. The data set has been used in a previous study (Bodeker, 1994) to develop a high spatial resolution statistical model of the global total column ozone variation. Monthly average data in each of the 288 x 180 TOMS cells were calculated from 1979 to 1992. A long-term linear trend is obtained using regression analysis while four sinusoidal terms are fitted using a robust least squares fit method to provide 14 coefficients which characterise the total column ozone variability over this period. Two of the coefficients characterise the mean value and trend, and the remaining 12 are the amplitude, phase and period of four sinusoidal functions corresponding to an annual variation, a Quasi-Biennial variation (QBO), a solar cycle variation and a semi-annual (6 month) oscillation. The model has been shown to accurately track total column ozone variations at low latitudes although the increased variability at higher latitudes results in reduced model performance.

Not only do the model coefficients make it possible to regenerate monthly average TOMS ozone distributions from a more compressed data set, but they have the potential to predict future changes in total column ozone. However, extreme care must be taken when using the statistical model in a predictive capacity since future non-linear trends in total ozone could result in large discrepancies between model results and measured data. Furthermore, the timing of the breakdown of the southern hemisphere vortex can result in large interannual variability in monthly average total column ozone for the months of September, October and November. Differences between model predicted values and measured data tend to maximize during these months.

Figure 2 shows a plot of annual mean total column ozone along the latitude line of 45°S from 180°W to 180°E at a resolution of 1.25° longitude. Measured data (solid line) are shown for the years 1979 and 1992 (the extremes of the available TOMS data set) while model data are plotted for 1979, 1992 and 2000. Differences between measured data and model output do not exceed 6 DU, providing confidence in the validity of the forward projection to the year 2000. Data during 1992 are consistently below the model predicted values. Previous analysis (Gleason et al., 1993) has shown that global ozone during 1992 reached record low levels and can be expected to fall below statistical model estimates. At 45°S these departures were within their normal range of variability.

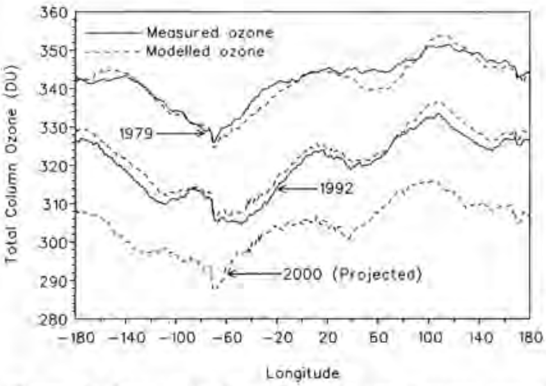

Figure 2: Longitudinal variation in total ozone annual mean at 45°S.

The longitudinal variability in the plots of Figure 2 is maintained from year to year where a minimum is reached near 60°W (South America) and a maximum is reached near 110°E (Western Australia). This morphology is thought to result from planetary wave number one forcing during the winter which tends to establish a zonal minimum in ozone along the Antarctic peninsula and South America and a zonal maximum south of Australia. Note the steep gradients in the zonal profiles near 70°W and 170°E. This occurs at the only two major mountain ranges that intersect this latitude. Possible causes of the features are:

1) Incorrect tropospheric estimates in the TOMS data reduction algorithm since TOMS does not measure lower tropospheric ozone with full sensitivity (Klenk et al., 1982).
2) Albedo changes from the high lee wave clouds formed above these mountain ranges may result in an underestimate in the TOMS data retrievals (Thompson et al., 1993). The algorithm used to correct for cloud effects is based on the measured reflectivity and a climatological cloud top height and uses an assumed tropospheric ozone column below clouds.
3) Possible real changes in total column ozone arising from tropographically forced upwelling of ozone poor air.

CALCULATING THE VARIABILITY IN UBV

In order to provide a more meaningful interpretation of these data, we investigate the effects of the longitudinal changes in ozone on erythemally weighted UV (McKinlay and Diffey, 1991). The dependence of surface erythemal irradiance on total ozone is generally expressed in terms of a radiative amplification factor (RAF). For a fixed solar zenith angle (SZA), incremental changes in ozone ( ) lead to incremental changes in surface erythemal irradiances (I) according to:

$$\frac{d\Omega}{\Omega} = - R_{sza} \frac{dI}{I} \qquad (1)$$

where R_{sza} is the RAF. Previous analyses (McKenzie et al., 1991) have indicated that RAF values of approximately 1.2 can be expected at 45°S. However, for the purposes of this study, such a relationship between ozone and erythemal UV proves to be too simple due to its SZA dependence. Even though all locations are at the same latitude (and therefore experience the same noon SZA) results from the statistical model indicate that there is significant zonal variation in the time of the annual minimum in total column ozone along the line of 45°S. This can vary from 10 March at 155°W to 1 April near 15°E. The annual minimum in New Zealand generally occurs near 16 March.

These phase relationships in the signals for each of the 288 zonal TOMS cells have made it necessary to use a simple single layer model to map the total column ozone to erythemal UV (McKenzie, 1991). Tables of total column ozone at 1 week temporal resolution and 5° longitude spatial resolution were generated for the years 1979, 1992 and 2000 and used as inputs to the irradiance model. Erythemally weighted UV was calculated for each week and for each of the 72 longitude points. Annual maximum noon values and annual mean noon values were determined along the 45°S parallel. Although the statistical ozone model is based on monthly average total column ozone, data at one week temporal resolution may be generated using fractional month numbers within the model.

It is important to stress that the forward extrapolation to the year 2000 is hazardous since the statistical model cannot track unforeseen changes such as the introduction of new stratospheric chemistry, volcanic aerosols, and other unforeseen changes in climate.

RESULTS OF UV CALCULATION

The longitudinal and secular changes in erythemal UV are summarized in Figure 3 and Figure 4. Figure 3 shows the annual maximum midday erythemal UV at 45°S where measured data for 1979 and 1992 are shown using solid lines and model data for 1979, 1992 and 2000 are shown using dashed lines. Since the annual maximum in midday erythemal UV always occurs in December or January at these latitudes, interannual variations in ozone during these months can result in large differences in surface irradiance. 1992 was known to be a year of anomalously low ozone (Gleason et al., 1993) with the result that differences between model results and measured data were high. The measured data plots for 1979 and 1992 show consistent zonal variability which often exceeds the 13 year temporal differences. The long-term trends in annual maximum midday erythemal UV observed in Figure 3 are summarized in Table 1 where results based on measured and modelled total column ozone are listed for 45°S as well as for New Zealand. Note that there are large zonal differences in the predicted trends for both the measured data and model results.

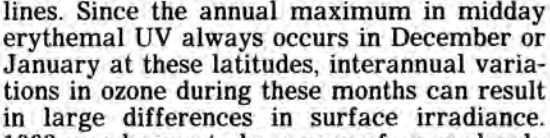

Figure 3: Longitudinal variation in erythemal UV midday annual maximum at 45°S.

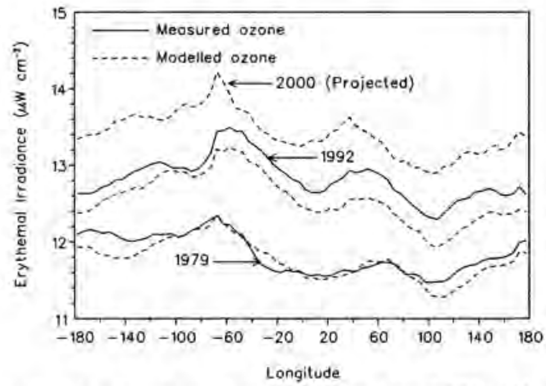

Figure 4: Longitudinal variation in erythemal UV midday annual mean at 45°S.

Figure 4 shows the annual mean midday erythemal irradiance at 45°S were both model and measured data are shown. Model values for 1979 and 1992 (dashed lines) agree well with measured values. With the 5° averaging (4 TOMS cells) the sharp discontinuities at the mountain ranges are less pronounced than in Figure 2, but still detectable. At 45°S there is a marked seasonal variation in noontime UV resulting in mean values that are approximately half that of the maximum. This is important when placing the measurement in the context of much larger changes with latitude. The trends in the annual mean midday erythemal UV observed in Figure 4 are

Period	45°S latitude						New Zealand	
	Measured data			Model data			Measured data	Model data
	Mean	Max	Min	Mean	Max	Min		
1979-1992	9.3	13.9	4.3	7.6	10.6	3.1	10.5	5.5
1979-2000	NA	NA	NA	12.8	17.8	8.7	NA	11.5

Table 1: Trends (in %) in annual maximum midday erythemal irradiance along the line of 45°S and for New Zealand in particular. Trends for surface irradiances based on both measured and modelled total column ozone are listed. Along the 45°S parallel, the mean, maximum and minimum values are listed.

summarized in Table 2 where again results based on measured and modelled total column ozone are listed for 45°S and for New Zealand. The predicted increase in annual mean mid-day erythemal irradiance at New Zealand is greater over the 8 year period (1992 to 2000) than over the 13 year period (1979 to 1992). Thus, according to the model, the secular changes between 1979 and 2000 will greatly exceed any longitudinal differences at this latitude. Note that in unpolluted conditions the peak monthly fluxes are already 13% greater at mid-southern latitudes than at comparable northern latitudes (McKenzie, 1991).

CONCLUSIONS

This study has shown that from the period 1979 to 1992, erythemal UV increases due to ozone depletion have been significant at 45°S. Calculated mean noontime clear sky UV levels have increased by approximately 5%, while maximum levels have increased by approximately 10%. According to the statistical model describing ozone trends, even larger increases in UV are predicted to occur over New Zealand by the year 2000. The investigation has not only shown New Zealand to be a country 'at risk', but that it also provides one of the best locations in the Southern Hemisphere for the measurement of surface UV irradiance. For these reasons it is imperative that the active campaign of ground-based UV measurements be maintained.

ACKNOWLEDGEMENTS

For access to the TOMS total column ozone data we wish to thank Dr. R.D. McPeters and Dr. A.J. Krueger (NASA/GSFC) members of the TOMS Nimbus Experiment and Ozone Processing teams; and the National Space Science Data Center through the World Center-A for Rockets and Satellites.

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	45°S latitude						New Zealand	
Period	Measured data			Model data			Measured data	Model data
	Mean	Max	Min	Mean	Max	Min		
1979-1992	8.3	12.7	3.9	6.8	9.3	3.8	6.3	5.0
1979-2000	NA	NA	NA	14.0	17.5	11.7	NA	13.3

Table 2: Trends (in %) in annual mean midday erythemal irradiance along the line of 45°S and for New Zealand in particular. Trends for surface irradiances based on both measured and modelled total column ozone are listed. Along the 45°S parallel, the mean, maximum and minimum values are listed.