like an artifact, the SET standard is not affected by this change because C is determined in situ each time the standard is cooled and operated.
17. Throughout this report, we use expanded uncertainty with coverage factor $k = 2$, which defines an interval that is expected to contain ≈95% of the reasonable values for the measured quantity.
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21. The authors gratefully acknowledge voltage calibration assistance from C. Hamilton, capacitance calibration assistance from A.-M. Jeffery, and discussions with E. Williams regarding Eq. 2.

19 May 1999; accepted 29 July 1999

Increased Summertime UV Radiation in New Zealand in Response to Ozone Loss

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Long-term decreases in summertime ozone over Lauder, New Zealand (45°S), are shown to have led to substantial increases in peak ultraviolet (UV) radiation intensities. In the summer of 1998–99, the peak sunburning UV radiation was about 12 percent more than in the first years of the decade. Larger increases were seen for DNA-damaging UV radiation and plant-damaging UV radiation, whereas UV-A (315 to 400 nanometers) radiation, which is insensitive to ozone, showed no increase, in agreement with model calculations. These results provide strong evidence of human-induced increases in UV radiation, in a region where baseline levels of UV radiation were already relatively high.

Ozone depletion, caused by the buildup of man-made chemicals in the atmosphere, is a concern because it leads to increased UV radiation at Earth's surface. Even relatively small increases in UV radiation can have serious impacts on human health, the biosphere, and materials. For example, a reduction in ozone of 1% leads to increases of up to 3% in some forms of nonmelanoma skin cancers (*1*). However, although the inverse relation between ozone and UV radiation is well established (*2*, *3*), the determination of trends from UV radiation measurements has been more problematic than for ozone. First, UV radiation measurements generally have a lower precision because they require an absolute calibration rather than the simpler relative calibration required for ozone determination. Second, UV radiation is more variable because it is strongly influenced by several factors other than ozone: notably solar zenith angle (sza), volcanic impacts, tropospheric aerosols, cloud cover, and surface albedo. These factors have compromised the ability of previous studies to unequivocally attribute increases in UV radiation to long-term declines in ozone (*2*, *3*). Here, we report a close correspondence between UV radiation changes calculated from ozone data and measured UV irradiances from Lauder, New Zealand.

Research into atmospheric ozone and its effects on UV radiation is undertaken by the National Institute of Water and Atmospheric Research (NIWA) at its laboratory in Lauder (45.04°S, 169.68°E, 370 m), Central Otago, New Zealand. This research has confirmed the expected downward trend in ozone associated with the buildup of ozone-depleting chemicals in the atmosphere. For annually averaged ozone, the largest decreases at this site occurred in the mid-1980s (*4*). Summertime ozone shows a more monotonic decrease with time (Fig. 1A). In recent years, it has been about 10 to 15% less than in the 1970s, before man-induced ozone depletion first became apparent. Superimposed on this downward trend are shorter term variabilities due to dynamical effects associated with changes in tropopause height, volcanic eruptions, the Quasi-Biennial Oscillation, the El Niño–Southern Oscillation, and the 11-year solar cycle. At this site, unlike other latitudes, the eruption of Mount Pinatubo (1991) had only a minor influence on ozone or peak global UV irradiance (*4*, *5*).

From the viewpoint of UV radiation and its effects on the biosphere, changes in ozone during the summer are particularly important, because at midlatitudes, the annual UV radiation dose is dominated by that received in the summer months. At Lauder, midday doses of erythemally weighted (*6*, *7*) (or "sunburning") UV radiation in winter are only 10% of those in the summer, and wintertime daily integrals are only 6% of summer values because of reduced daylight hours (*8*).

The UV radiation in the south has historically been more intense because of hemispheric differences in ozone and because the closest Earth-sun separation occurs during the Southern Hemisphere summer. Model calculations of erythemal UV radiation for clear-sky summer conditions are ~10 to 15% more for southern midlatitudes than for the north (*1*, *9*). Measurements that directly compare UV radiation in New Zealand with that in Europe have shown much larger differences (*10*, *11*). Even in the 1970s, before substantial ozone depletion had occurred, erythemal UV radiation at 45°S was probably substantially greater than during the 1990s at 45°N (*1*). In addition, in the Southern Hemisphere, ozone depletion has occurred all year round, whereas in the Northern Hemisphere, the depletions have been less severe in the summer (*3*). The resultant relatively intense UV radiation may be a factor contributing to the high rates of skin cancer in New Zealand (*12*), although other factors such as lifestyle and skin type are also important.

The changes in the UV radiation that would be expected from the changes in ozone observed at Lauder are shown in Fig. 1B, where the results are expressed in terms of the noontime UV Index, a standardized way of reporting UV radiation to the public (*13*). This UV Index was calculated with a sensitivity factor (RAF) of erythemal UV radiation to ozone change (*14*) and normalized to match measured values at the middle of the period for which measurements were available. The calculated UV Index increases with time in anticorrelation with the changes in ozone and in the summer of 1998–99 was the highest to date, about 15 to 20% higher than in the late 1970s.

Here we demonstrate a close correspondence between these calculated changes and those derived from spectral measurements of UV global irradiances obtained at Lauder since December 1989. The spectra were taken at 5° steps in sza and at 15-min intervals for a 90-min period centered at midday. The accuracy of biologically weighted integrals derived from these spectra for trend determination is limited mainly by the repeatability of the calibrations, which are estimated to be better than ±3% (*15*).

To minimize the effects of factors other than ozone, we considered a subset of the UV radiation data. First, we took the mean UV Index each day from the five spectra measured at 15-min intervals over a 1-hour period centered at local solar noon. By selecting

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midday values only, the effects of changes in sza are minimized while at the same time the period of greatest risk from UV radiation can be studied. At this site during summer, the effects of changing tropospheric aerosols and surface albedo can be neglected (*16*, *17*).

The next step was to select days for which cloud effects were small. One possible strategy would have been to select only clear-sky days. However, there is always some subjectivity in such selections, and they may not represent the maximum risk, because clear-sky conditions do not necessarily correspond to periods of maximum UV radiation. We chose instead to select days in which the midday UV radiation was a maximum value. To obtain this "summertime peak UV Index," we took the mean value over the five highest UV radiation days each month for the 3-month period corresponding to the New Zealand summer (December, January, and February). Thus, the summertime peak UV Index generally represents a mean of $5 \times 5 \times 3 = 75$ spectra.

During the first summer, observations were made only under near clear-sky conditions, whereas for later summers, observations were available for at least 15 days per month. Although clouds can reduce the UV radiation markedly, statistical studies have shown that at this site, cloud-induced changes are less than 10% for about half the scans.

The measurements (Fig. 1B) show a good correspondence with those calculated from the ozone climatology, although the upward trend is larger than expected. The highest UV radiation recorded so far occurred during the summer of 1998–99, when anomalously low ozone coincided with a period of clear weather near the summer solstice. The UV Index then exceeded 12.5 on several occasions.

To relate the observed changes in UV radiation to changes in ozone, we calculated corresponding column ozone amounts from the same spectra (*18*). These ozone values are generally close to or below the climatological means, except at the start of the observation period (Fig. 1A). It appears that ozone on the smaller number of days sampled in those years may have been greater than the mean. Consequently, the measurements of ozone based on the UV radiation spectra show a larger (downward) trend (0.86%/year) than those calculated from the summertime ozone climatology (0.45%/year).

We then investigated the changes for other biological weightings of the same spectra. The maximum values for plant-damaging UV radiation (*19*), DNA-damaging UV radiation (*20*), and UV-B radiation (290 to 315 nm) all occurred in the summer of 1998–99, and the measurements showed similar agreement with model calculations (*21*). By contrast, UV-A radiation (315 to 400 nm), which is not sensitive to ozone changes, was not notably high in the summer of 1998–99. During that summer, peak levels of sunburning UV radiation were 12 ± 4% larger than in the early years of the decade when UV radiation measurements began. Larger increases were seen for DNA-damaging UV radiation and for plant-damaging UV radiation.

The trends in UV radiation for each weighting were then related to the changes in ozone (Table 1). The trend in UV-A radiation, which is insensitive to ozone change, is not significantly different from zero, showing that cloud effects were unimportant. For the ozone-sensitive weightings, the observed changes increase as expected from their RAFs. They are somewhat larger than those calculated from the ozone climatology but agree with those calculated from the simultaneous ozone measurements within the limits of experimental uncertainty (±0.3%/year).

These conclusions do not depend on the definition of the summer period (*22*), nor are

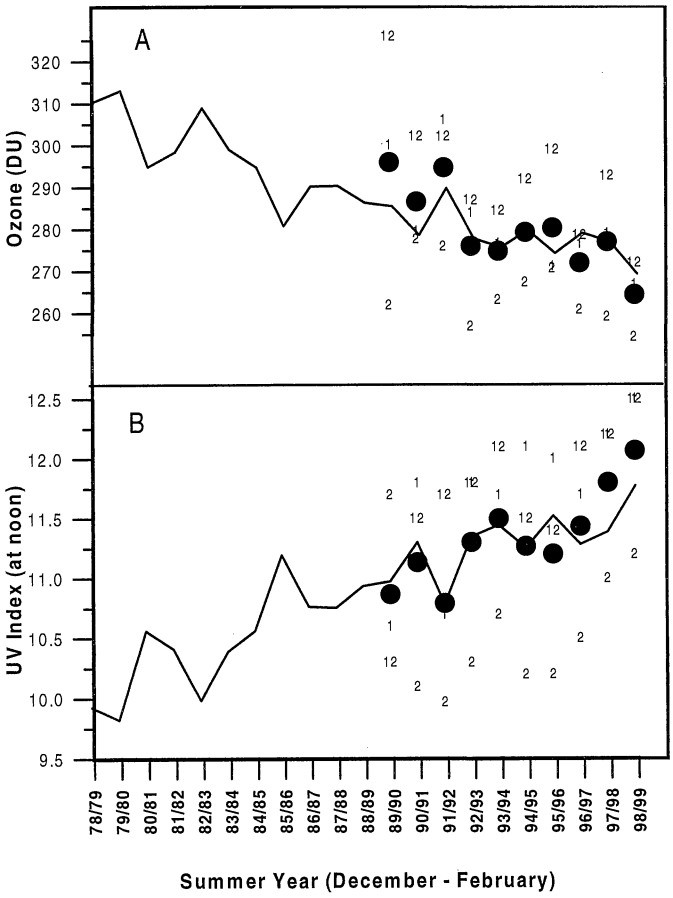

Fig. 1. Mean ozone (Dobson units, 1 DU = 2.69×10^{16} molecules cm^{-2}) (**A**) and estimated UV Index (**B**) at Lauder, New Zealand, for the summer of 1978–79 through the summer of 1998–99. Summer is defined as the period from December through February. The solid line in (A) shows the changes in summertime ozone that have occurred since the 1970s. The solid line in (B) shows the deduced changes in clear-sky UV radiation expected from these changes in ozone (*14*). The symbols (from 1989–90 on) show measured values of ozone and the summertime peak UV Index (*13*), as discussed in the text, both derived from the UV spectroradiometer. The plot also shows the values from each contributing month, labeled by the month number.

Table 1. Changes in peak summertime UV radiation deduced from a linear regression over the period 1990–91 to 1998–99 (the first summer was omitted because of data sparsity). The RAF is the sensitivity to changing ozone (*14*), and ΔO_3 is the ozone change (percent per year).

Weighting	RAF	References	Change measured (%/year)	Change calculated from RAF and ΔO_3	
				$\Delta O_3 = -0.45$%/year from climatology	$\Delta O_3 = -0.86$%/year from UV spectra
UV-A radiation (315 to 400 nm)	0.02	(*1*)	−0.02	+0.01	+0.02
UV-B radiation (290 to 315 nm)	1.0	(*1*)	+0.71	+0.45	+0.86
Sunburning UV radiation (UV Index)	1.2	(*1*, *13*)	+0.98	+0.54	+1.03
Plant-damaging UV radiation	1.6	(*14*, *19*)	+1.31	+0.72	+1.38
DNA-damaging UV radiation	2.2	(*1*, *20*)	+1.78	+0.99	+1.89

they substantially changed when the number of days included per month in the analysis is increased from 1 to 10. When this number of days is increased above 15, the ozone trends systematically revert to the expected climatological mean (0.5%/year). The trend in UV radiation decreases more rapidly because in the early years, when data were not taken during inclement weather conditions, the measurements were systematically biased toward higher values. These sampling differences would also bias any attempts to infer long-term changes in mean values from the current data set. For the purpose of assessing risks to humans, a consideration of peak midday values is perhaps more relevant, because the population is less likely to be exposed to UV radiation during inclement weather.

Because the downward trends in ozone had already been occurring for several years before the UV radiation measurements became available, one could infer that even larger increases in UV radiation may have accrued at this site since 1979. The future outlook is more uncertain. Although the stratospheric loading of ozone-depleting substances is now close to the maximum expected under the present control regime (*3*), there is concern about possible interactions between ozone depletion and global warming, which could delay the recovery of ozone by decades (*23*).

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28 May 1999; accepted 11 August 1999

Lower Mantle Lateral Heterogeneity Beneath the Caribbean Sea

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Seismic wave reflections from Earth's core recorded at seismic arrays in North America from events in the Caribbean Islands, Venezuela, and the Mid-Atlantic Ridge have observed slownesses more than 64 percent greater than predicted by the IASPEI91 standard Earth model. *P* waves turning in the lowermost mantle beneath the same region also have anomalous slowness. The slowness anomalies are not accompanied by significant travel time residuals and appear to be caused by lateral inhomogeneities in the velocity structure of the lower mantle.

On 1 January 1996, unusual signals (Fig. 1) from an earthquake in the Windward Islands [42.8-degree (*1*) epicentral distance] were recorded at the TXAR (Texas array) seismic array (*2, 3*) in the Big Bend area of west Texas (Fig. 2). Compressional waves reflected from Earth's core (*PcP*) had a much higher amplitude than the direct, first-arriving compressional waves (*P*). Large-amplitude *PcP* waves were also recorded at stations in California, Wyoming, and Canada (*2*). The earthquake was anomalous because the *PcP* slowness magnitude values measured at the TXAR and YKA (Yellowknife, northern Canada) seismic arrays were much larger than predicted by the IASPEI91 seismological tables (*4*). These tables are referred to here as the standard Earth model. Slowness magnitude, referred to subsequently as slowness, is measured as the reciprocal of the horizontal phase velocity and is directly related to the angle of incidence of the arriving ray. It is a measure of the travel time of an arrival across an array.

Here we estimate the slowness of *PcP* and teleseismic *P* wave arrivals using the small-aperture TXAR and YKA arrays. Previous studies at large arrays (aperture >100 km) (*5–7*) and at the YKA array (*8*) did not report large slowness residuals (*9*) for *P* phases, but mislocations were found for ray paths traveling in the deep mantle beneath the northern edge of South America, the Caribbean Sea, and the Gulf of Mexico. Although deep mantle heterogeneities were considered (*5, 8*) to explain the mislocations, these studies concluded (*6–8*) that source region, array site, or upper mantle structure near the arrays were more likely causes. The averaging effect in

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