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Richard McKenzie

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UV Radiation in the Melanoma Capital of the World: What Makes New Zealand so Different?

Richard McKenzie[1, a)]

[1]*NIWA, Lauder, Central Otago, New Zealand*

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[a)]Corresponding author: richard.mckenzie@niwa.co.nz

Abstract. To better understand New Zealand's high rates of skin cancer, the UV climate of New Zealand is discussed in relation to other locations, and the factors contributing to geographical differences in UV are explored. Historical and projected future changes in UV are discussed in the context of what would have happened without implementation of the Montreal Protocol to protect the ozone layer. The effects of interactions due to future climate change are also discussed. Finally, the effects of our unique UV climate on human health are discussed briefly; along with changing public advice.

INTRODUCTION

New Zealand has the world's highest rates of melanoma skin cancer. Age-standardized incidence rates and mortality rates for melanoma are slightly more than Australia's, and are twice as high as in the UK (see http://globocan.iarc.fr). A major contributing factor is our relatively high level of UV radiation in summer, which is due in part to our relatively low levels of atmospheric ozone. The discovery of the Antarctic ozone hole in 1985 therefore spurred research into understanding the causes and effects of ozone depletion. Much of that research has been undertaken at NIWA's clean-air measurement laboratory at Lauder Central Otago (45°S, 170°E, 370 m altitude, see https://www.niwa.co.nz/our-services/online-services/uv-ozone), which is the best-instrumented site for atmospheric research in the southern hemisphere. It is also one of very few atmospheric monitoring sites in the southern hemisphere, and is the key southern mid-latitude site in the international Network for the Detection of Atmospheric Composition Change (NDACC), and the Baseline Surface Radiation Network (BSRN). Here we focus on aspects of that research related to UV radiation: its propagation through the atmosphere, its measurement at the surface, and its relationship with Antarctic ozone depletion. We make use of data from a network of broad-band measurements of erythemally-weighted UV at several sites in the New Zealand region, along with a large database of UV spectral irradiances that meet the stringent demands of the Network for the Detection of Atmospheric Composition Change (NDACC, formerly NDSC) [1], at several global sites, as shown in Figure 1.

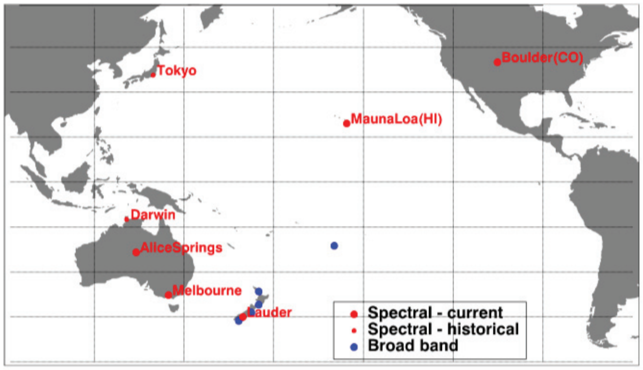

FIGURE 1. "NIWA" UV measurement sites.

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VARIABILITY IN UVI

UV irradiances are expressed in terms of the UV Index (UVI = 40 x UV_{Ery}, where UV_{Ery} is in Wm^{-2}). The amount of UV that is transmitted to Earth's surface depends strongly on the solar elevation angle. Consequently, in addition to the large diurnal swings (from zero at night), there are large seasonal swings outside the tropics. At mid latitude sites, the winter UVI values are typically only 10% of the summer values, and they reduce to zero in winter at latitudes poleward of 67°. Figure 2 shows the variability at sites in New Zealand [2], and in comparison with sites in Australia and the UK [3].

		Lat (S)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Darwin	AUS	12	12	13	13	11	9	8	9	10	12	13	12	12
Brisbane	AUS	27	12	11	10	7	5	4	4	5	7	9	11	11
Perth	AUS	31	12	11	9	6	4	3	3	4	6	8	10	11
Sydney	AUS	33	11	10	8	5	3	2	3	4	5	7	9	10
Adelaide	AUS	35	11	10	8	5	3	2	2	3	5	7	9	11
Canberra	AUS	35	11	8	7	5	3	2	2	3	5	7	9	11
Auckland	**NZ**	**37**	10	8	7	4	2	1	2	2	3	6	8	9
Melbourne	AUS	38	10	9	7	4	2	2	2	3	4	6	8	10
Wellington	**NZ**	**41**	9	8	6	3	1	1	1	2	2	5	7	8
Hobart	AUS	43	8	7	4	3	1	1	1	2	3	4	6	7
Christchurch	**NZ**	**44**	8	7	5	2	1	1	1	1	2	4	7	8
Invercargill	**NZ**	**46**	7	6	4	2	1	0	0	1	2	3	5	6
		(N)	Lagged by six months for NH											
London (Chilton)	UK	52	5	4	3	1	0	0	0	1	1	3	4	5
Leeds	UK	54	5	4	3	1	0	0	0	1	1	2	4	4
Glasgow	UK	56	4	3	2	1	0	0	0	0	1	2	3	4

FIGURE 2. Seasonal range of mean noon UVI for New Zealand compared with locations in Australia and UK.

Color coding is as currently recommended by the WHO [4], although changes to that have been recommended [5]. In New Zealand and Australia, protection is advised whenever the UVI exceeds 3, although that threshold too has been questioned [6]. There is a strong latitudinal gradient UVI. Consequently, the mean UVI in New Zealand is significantly less than in Australia, but is about twice as much as in the UK, which spans a range of much higher latitudes. The forebears of most New Zealanders (and possibly Australians) are from the British Isles, so have skin type better adapted to those latitudes.

TABLE 1. Statistics from multi-year observations of spectral irradiance measurements, sorted by latitude. SZA_{min} is the minimum solar zenith angle sampled. Because spectra are taken at 10 or 15 minute intervals over the midday period, the absolute lowest SZA possible at each site is not necessarily sampled. OZ_{min} is the lowest ozone value sampled. Other abbreviations are explained in the text.

Location	Year Start	No of Years	SZA_{min} (Deg)	Oz_{min} (DU)	Mean CMF	UVI Stats			SED Dose Stats	
						Max	% days UVI>3	% days UVI>10	Max	% days SED>3
USA										
Boulder CO (40°N)	2001	15	16.6	221	0.73	13	48	11	67	99
MLO, HI (20°N)	1997	18	0.3	215	0.88	20	99	79	95	100
Australia										
Darwin (12°S)	2003	3	0.1	229	0.77	18	99	61	78	100
Alice Springs (24°S)	2006	10	0.5	219	0.82	19	79	48	85	100
Melbourne (38°S)	2009	7	14.3	236	0.67	14	42	19	77	99
New Zealand										
Lauder (45°S)	1994	11	21.6	220	0.74	14	37	15	77	95
Lauder (45°S)	2006	11	21.6	225	0.74	14	40	16	76	95

PEAK UVI

For its latitude, New Zealand has relatively high peak UVI. In an earlier study, we showed that peak UVI at Lauder New Zealand is 40% greater than at equivalent latitudes in North America [7]. However, peak values are only half the global peaks, which occur in the Altiplano region of South America [8]. Further, more than half the globe (virtually all locations within 30° of the equator, and other high altitude areas) receives peak UVI values greater than experienced in New Zealand.

In Table 1, we summarize statistics of extreme daily UVI values, from spectral irradiance measurements at sites in New Zealand, Australia, and USA, made with NIWA-designed spectrometers that meet the exacting standards of the NDACC. The effects of clouds are represented as cloud modification factors (CMFs), which are ratios of measured irradiance to calculated values for clear skies and low surface albedo. The UV statistics are presented in terms of the peak UVI values (dose rates), and the daily doses in SED (Standard Erythemal Dose, where 1 SED =100 Jm^{-2} of UV_{Ery}). Protection against sun damage is recommended whenever the UVI exceeds 3, and the UVI is considered "extreme" when it exceeds 10 [4]. The percentage of days where these thresholds are exceeded at each site are shown. The daily UV peak dose in SED is shown, as well as the percentage of days when the dose exceeds 3 SED. The minimum erythemal dose (MED) depends on skin type. For fair-skinned individuals, skin damage (erythema) can occur for doses less than that threshold (i.e., 1 MED < 3 SED), which is exceeded on at least 95% of days at all sites shown. So care is needed almost every day of the year for fair-skinned outside workers. Sometimes there is sufficient UV to induce more than 30 MED in a single day. On those days, it is particularly important to take precautionary measures, even if spending a just a few minutes in the sun.

The two USA sites are at relatively high altitudes: Mauna Loa Observatory, Hawaii (MLO, 3.4 km) and Boulder Colorado (1.7 km). The rest are less than 0.5 km above sea level. Despite Boulder's lower latitude and higher altitude compared with Lauder, its peak UVI doses are not significantly higher than at Lauder. This is mainly due to pollution, but differences in stratospheric ozone, and the closer Sun-Earth separation in the SH summer also contribute, as has been discussed previously [7]. The relatively low CMF at Boulder is in part due to the effects of pollution, which attenuates the clear sky UV. In contrast, neither Lauder nor MLO are significantly affected by tropospheric pollution.

MLO has the highest UVI and dose, and also the largest CMF. Its large CMF is due in part to the effect of clouds below the observatory, which increase the effective albedo [9].

The peak UVI values of the northern Australian sites are significantly higher than at Lauder New Zealand. Despite the difference in latitude between Melbourne and Lauder, the peak UVI values are slightly larger at the New Zealand site. However, for the main population centers, UV doses are generally higher in Australia than New Zealand (see Figure 1). As expected, the percentage of days with UVI > 3 or SED > 3 becomes progressively smaller at the higher latitude sites, due to the lower solar elevations in winter.

SO WHAT MAKES NEW ZEALAND DIFFERENT?

Based on the UV data presented above, one would expect melanoma rates in Australia and New Zealand to exceed those at corresponding northern latitudes, and the UK in particular. And such differences are observed. But why are they are higher in New Zealand than Australia, where UV irradiances are greater? There are several possible causes:

1. Genetics: With a greater proportion of its population of UK descent (especially Celtic), the skin types of New Zealanders are not as well adapted as Australians, of whom a larger fraction are of southern European descent.
2. Lifestyle: The outdoor lifestyle is highly valued in New Zealand, and with its cooler summer temperatures compared with Australia, it is more comfortable to spend longer periods in the sunlight in New Zealand.
3. Healthcare: Australia has been a world leader in public health campaigns to protect against skin cancer.

Other genetic differences associated with country of origin may also be important. For example, epidemiologic studies strongly suggest that UV acts to superimpose additional melanoma risk on genetically vulnerable populations, such as those carrying cyclin-dependent kinase inhibitor 2A (CDKN2A) mutations [10]. It has been shown the presence of that heritable marker is associated with a significant increase in the lifetime probability of developing melanoma. It may be that the population of New Zealand has a higher prevalence of that marker. In recent decades, the population distribution of New Zealand has changed dramatically, with a higher proportion of Asian descent. This may result in reduced age-standardized rates in future (though as the population ages, the non-standardized rate will likely increase).

It is interesting that the ratios between NZ and Australia are similar for both mortality and incidence. For most forms of cancer, mortality rates are higher in New Zealand than Australia (see http://globocan.iarc.fr). It is not known whether this is due to environmental factors (e.g., less winter UV, leading to lower vitamin D status, lower temperature), or sociological factors (e.g., genetics, affluence), or whether it can also be attributed to a superior health service in Australia.

The relative importance of these is unknown, and other factors may also be important. More research is needed.

SO WHAT SHOULD WE DO?

Because of the wide variabilities in UV, and the complications of too much in summer (leading to sunburn – a marker for melanoma), and too little in winter (leading to vitamin D insufficiency – a marker for bone disease and many other possible conditions), it is difficult to formulate advice to the public to optimize their UV exposure. The temporal and geographical variabilities are just too large. However, if the UVI is known, then individuals can plan their day to avoid sunburn, while still receiving enough UV to maintain vitamin D status, as illustrated in Figure 3 (note the logarithmic scale for the y-axis) [11]. The figure shows that for fair-skinned individuals, damage to skin can occur in less than 15 minutes when UVI=12, and within approximately 60 minutes when UVI=3. At mid-latitude sites (e.g., most of New Zealand), there are extended periods during the winter months when the mean noon UVI remain less than 3 (see Figure 2 - though peak values can be up to ~50% greater than means), and there is insufficient UV to maintain adequate levels of vitamin D. In addition to skin type, the daily exposure time needed for vitamin D sufficiency depends on the area of skin exposed (and other factors, including age, BMI, vitamin D status) [11]. For fair-skinned people, it has been estimated that when UVI=12, sufficient vitamin D can be maintained with daily exposure of less than 10 minutes to only the face and hands. The necessary exposure times are commensurately shorter when larger skin area are exposed, but are longer for darker skinned people [11]. The intersection of the red and blue curves implies that it is not possible to receive enough vitamin D without erythema when the UVI is less than 2.

The sort of time-resolved UVI information that is necessary to make use of the results shown in Figure 3 has recently become available through smartphone apps. Two examples, uv2Day (New Zealand and Australia only) and GlobalUV, provide forecasts of UVI for any location and time, along with corresponding behavioral advice to avoid erythema (see Figure 4). The apps make use of global forecasts of ozone, aerosols, and cloud - based on satellite-derived measurements [12].

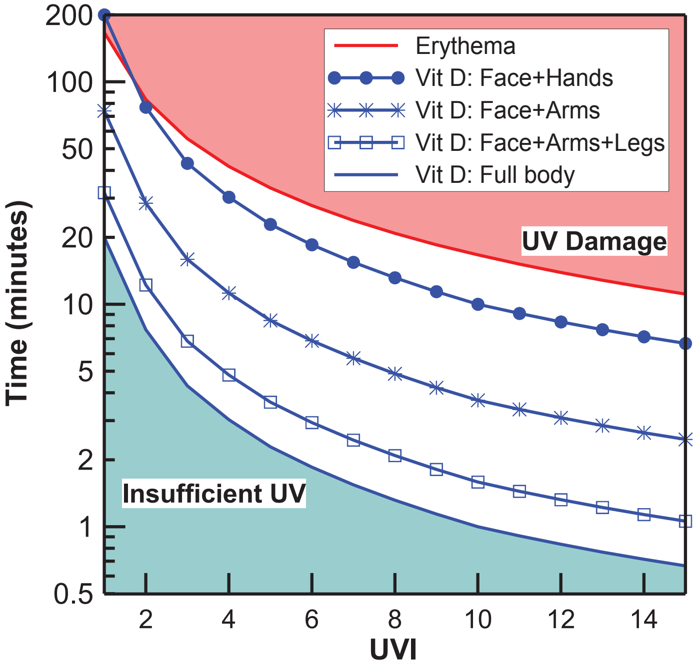

FIGURE 3. Approximate exposure time for fair skin plotted as a function of UVI. Times required for optimal UV are represented by the white region. The area shaded red gives too much UV, leading to erythema (skin reddening). The region marked in blue gives not enough UV to maintain an intake of 1000 IU for full body exposure. Multiply times by ~2 for brown skin, and ~5 for black skin. Reproduced from [11].

Clear sky UVI max = 6.7 at 12:43
Cloudy sky UVI max = 6.4
Ozone = 278 DU
Max sun elev = 49°
AOD365nm = 0.1
Albedo = 0.05
Altitude = 370 m (Site list)

UV Index at 13:32 is 6.5.
Damage to skin type I can occur
within 23 minutes.

FIGURE 4. The "GlobalUV" smartphone App, developed by JGR Burke in consultation with the author [12].

LONG TERM CHANGES IN UV

In Table 1 above, data from Lauder are split into two parts, to demonstrate that any changes in UVI between the last two decades have been small. The effects of clouds, shown by the mean cloud modification factors (CMF) is also unchanged between these two periods. Even the frequency distribution of irradiances is similar over these two periods, as seen in Figure 5.

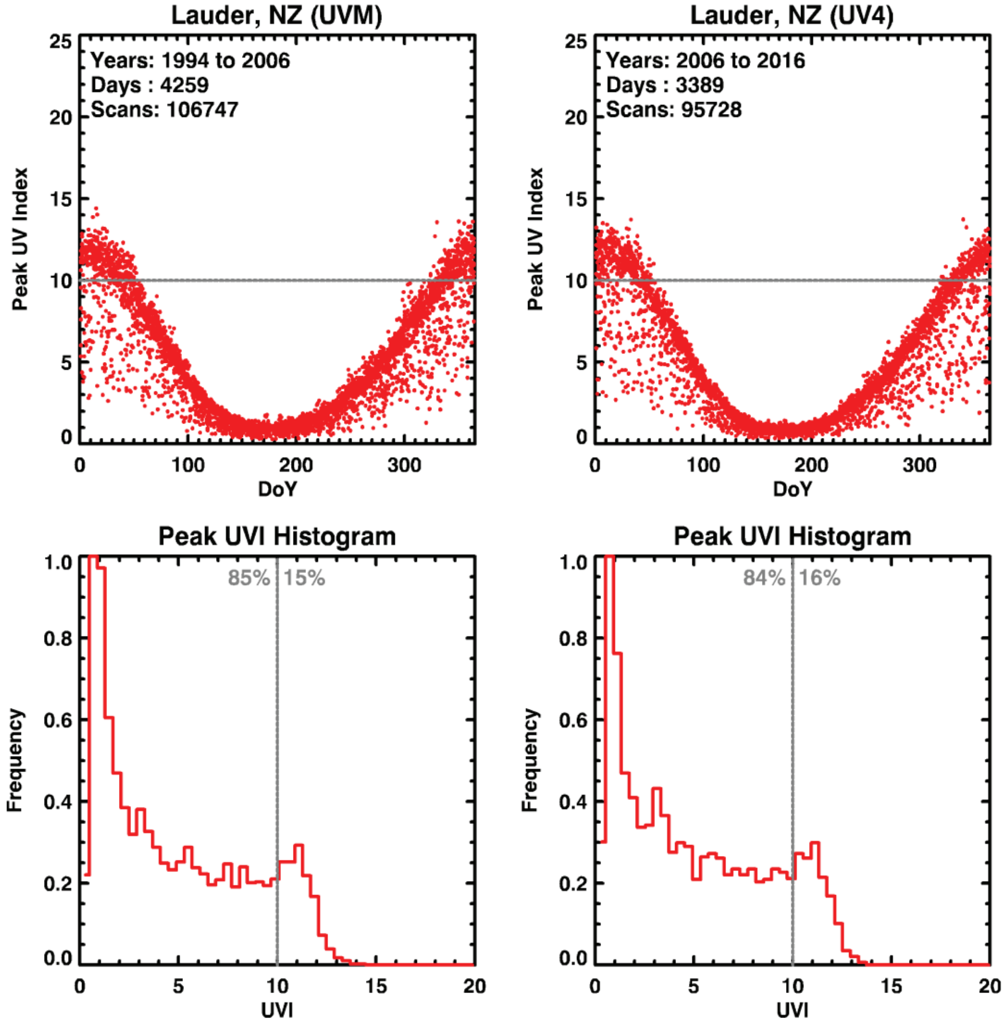

FIGURE 5. Peak daily UVI (upper panels), and their frequency distribution (lower panels) for 1994 to 2006 (left panels), and for 2006 to 2016 (right panels).

Because of the success of the Montreal Protocol on protection of the ozone layer, any increases in UV due to ozone depletion have been small outside the Antarctic region, and year-to-year differences due to changing weather patterns completely mask long-term trends. To detect any changes in UV that are attributable to changes in ozone, it is necessary to screen out the effects of cloud absorption (e.g., by selecting only peak values) [13]. The longest time series of UV available in New Zealand dates back to the early 1980s, and shows no significant long-term trends (Figure 6). Seasonal differences are huge, with summer values being larger than winter values by more than a factor of 10, while year to year differences, due mainly to changes in cloud patterns, are ~ ±10%. Note that the seasonal and inter-annual patterns for daily dose differs markedly from than those for peak UVI values. On some occasions, the mean daily dose in a month exceeds 50 SEDs, even at this southernmost site in New Zealand.

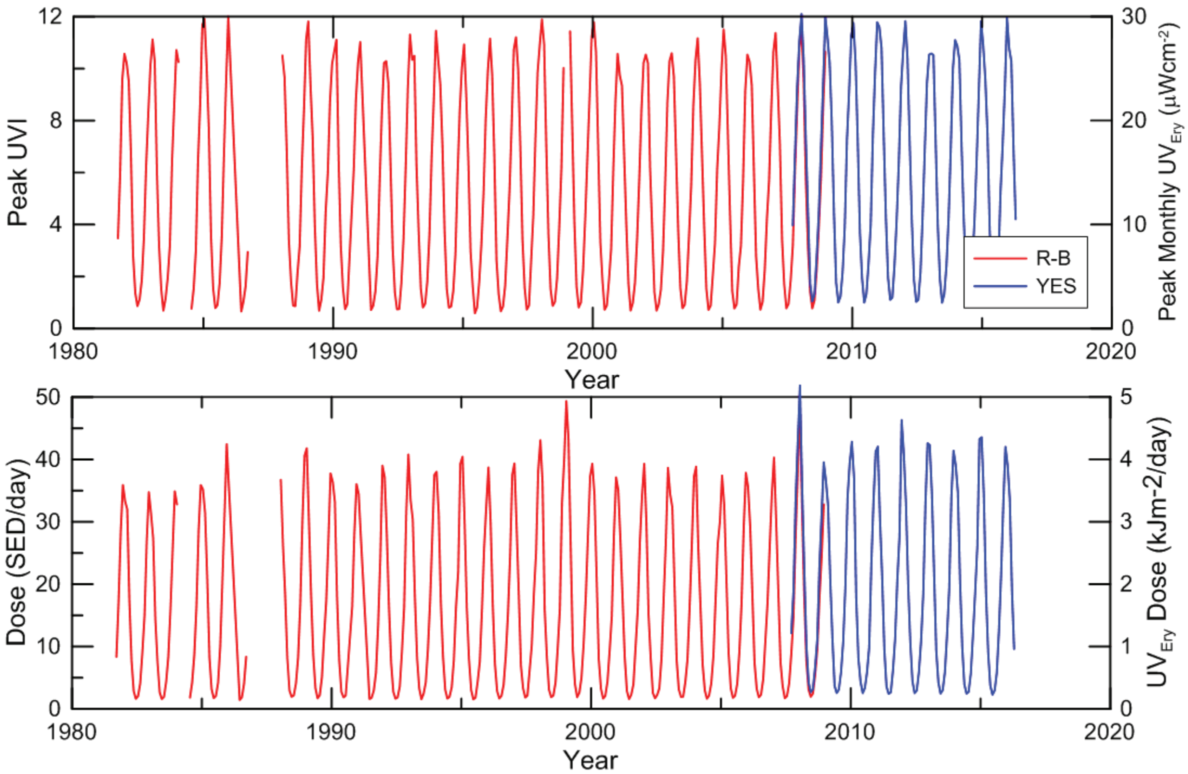

FIGURE 6. Time series of UV measured at Invercargill, New Zealand. *Upper panel*: Peak monthly UVI. *Lower panel*: Mean daily does in SED. In 2007 the original Robertson-Berger meter (with 30-min integrations) was replaced with a Yankee instrument (with 10-min integrations).

In the future, interactions between "ozone depletion" and "climate change" will be important. As the concentrations of ozone-depleting substances (e.g., CFCs, chlorine gas) reduce, the concentrations of greenhouse gases (e.g., CO2) will continue to increase. The consequently warmer troposphere and cooler stratosphere in turn affect the rates of ozone depletion: slowing it down for gas-phase chemistry which prevails though most of the stratosphere, but increasing the probability of Polar Stratospheric Clouds (PSCs), on the surfaces of which more rapid ozone depletion can occur. The increased levels of NO_x and HO_x since ozone depletion began also affect ozone chemistry. The most recent WMO and UNEP Assessments indicate that we are on a path to ozone recovery, and that outside Polar Regions, future changes in UV will be probably influenced more by changes in clouds and aerosols than by changes in ozone. Changes in surface albedo will also be important at high latitudes [14].

A disaster has been averted through the success of the Montreal Protocol. Without it, UVI values would have become a factor of three higher by 2065 [15]. We would already have experienced Antarctic ozone hole conditions in the Arctic region, which is much closer to populated regions [16]. The problem is not completely solved: for example, the ozone hole in 2015 was one of the deepest and most persistent on record (see http://ozonewatch.gsfc.nasa.gov/).

CONCLUSIONS

New Zealand's high melanoma rates have little to do with the Antarctic ozone hole, or ozone depletion. Melanoma typically takes decades to develop after exposure to UV, and rates were already high at the turn of the century (see http://sunsmart.org.nz/skin-cancer/skin-cancer-facts-and-statistics). In this region, any UV changes due to ozone depletion have been smaller than the normal year-to-year variability in UV.

UV in New Zealand is relatively high compared with corresponding northern latitudes, due to its lower summer ozone amounts, closer Earth-Sun separation in summer, and unpolluted air. But peak values are only half the global maximum. New Zealand's high rates of melanoma are due to having the wrong skin types for its latitude, and outdoor lifestyle. Its relatively high rates, compared with Australia, must be due to other factors (e.g., lower temperatures encouraging a sun-seeking lifestyle, or genetic differences).

The undeniable risk of skin cancer due to excessive UV exposures in the summer months must be balanced against health risks associated with receiving insufficient UV to maintain adequate vitamin D levels in the winter months. Smartphone apps (e.g., GlobalUV) have been developed to inform users of the current risk and how it will change over the day. This enables users to plan their UV exposure to optimize health outcomes.

The Montreal Protocol has been hugely successful. Its success is a testament to the collective efforts of all involved (including scientists, politicians, policymakers, and industry). More strenuous efforts should be made to advertise that success, and to let the public know what would have happened without it. The Montreal Protocol has the potential to be a blueprint to fixing the current issue of climate change. In both cases, the problem was caused by industrial advances associated with our modern lifestyle. Industry has already been instrumental in the success of the Montreal Protocol, where manufacturers have profited from the supply of ozone-friendly replacement technologies. Similarly, consumer-driven uptake of renewable energy from the sun and wind to replace fossil fuels, and electric vehicles to replace the current hydrocarbon-powered fleet will be part of the solution to climate change. As informed scientists, we need to take leadership in efforts to move the world away from its dependence on fossil fuels.

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