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ORIGINAL PAPER

Fifty years of changes in UV Index and implications for skin cancer in Australia

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Abstract Surface ultraviolet (UV) radiation plays an important role in human health. Increased exposure to UV radiation increases the risk of skin cancer. In Australia, public campaigns to prevent skin cancer include the promotion of daily UV forecasts. If all other atmospheric factors are equal, stratospheric ozone decreases result in UV increases. Given that Australia still has the highest skin cancer rates in the world, it is important to monitor Australia's stratospheric ozone and UV radiation levels over time because of the effects cumulative exposure can have on humans. In this paper, two long-term ozone datasets derived from surface and satellite measurements, a radiation code and atmospheric meteorological fields are used to calculate clear-sky UV radiation over a 50-year period (1959–2009) for Australia. The deviations from 1970–1980 levels show that clear-sky UV is on the rise. After the 1990s, an overall annual increase from 2 to 6% above the 1970–1980 levels was observed at all latitudes. Examining the summer and winter deviations from 1970–1980 showed that the winter signal dominated the annual changes, with winter increases almost twice those in summer. With ozone levels not expected to recover to pre-depletion levels until the middle of this century, UV levels are expected to continue to rise. Combined with Australians favoring an outdoor life-style, when temperatures are warmer, under high levels of UV, the associated risk of skin cancer will increase.

Keywords Ultraviolet radiation · UV Index · Skin cancer · Ozone · UV climatology

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Introduction

The impact of surface ultraviolet radiation (UV) on human health and terrestrial ecosystems is an ongoing concern for the Australian community. It is known that reductions in stratospheric ozone result in surface UV increases, and increased exposure to UV increases the risk of skin cancer (Armstrong 2004). In Australia, it is estimated that nearly 450,000 people get skin cancer every year [Australian Institute of Health and Welfare (AIHW) 2008]. Therefore it is important to monitor UV levels over short and long time scales in Australia, in particular because of the effects cumulative exposure can have on humans.

The amount of surface UV radiation strongly depends on stratospheric total ozone amounts, geographical location, date and time of day. Ozone absorbs most of the UV radiation at wavelengths below 290 nm; however, most of the radiation in the 300-400 nm part of the spectrum that is most important for human health and ecosystems reaches the Earth's surface. Variations in surface radiation related to ozone depletion have been reported for several locations worldwide during the last few years [World Meteorological Organization (WMO) 2006].

In Australia, daily UV Index forecasts are provided to the public as part of the Bureau of Meteorology's weather report (Lemus-Deschamps et al. 1999). The monthly average UV

Index for several locations over the period 1997–2001 has been previously reported by Lemus-Deschamps et al. (2004). The UV Index describes the level of solar UV radiation at the Earth's surface, weighted to the part of the spectrum that is important for human health. It comprises numerical values with descriptive exposure categories: values below 3 are considered low, 3–5 moderate, 6–7 high, 8–10 very high, and 11 and above are extreme [World Health Organization (WHO) 2002]. The maximum UV Index in Australian summer ranges from around 10 (very high) in the far south to around 14 (extreme) in the central-north. In southern regions of Europe and the United States, typical summer UV Index maxima are around 10 (very high), and at higher latitudes like Scandinavia or Alaska, peak values reach around 5 (moderate).

In this paper, for the first time, we present the seasonal changes in ozone and UV Index in Australia over a period of 50 years, 1959–2009, and discuss the possible impact on skin cancer incidence in Australia.

Materials and methods

To calculate the UV surface radiation that is most relevant to human health, monthly total ozone amounts from the European Centre for Medium-Range Weather Forecast (ECMWF) global atmospheric reanalysis (ERA40), from the National Aeronautics and Space Administration (NASA) Total Ozone Mapping Spectrometer (TOMS) and Ozone Monitoring Instrument (OMI) and atmospheric fields from the Bureau of Meteorology atmospheric model (Bourke et al. 1995) were first used as input to a UV radiation scheme (a two-streams delta-Eddington). The response of human skin to UV radiation was then taken into account by multiplying the monthly clear-sky UV irradiances by the erythemal action spectrum from the Commission Internationale d'Eclairage (CIE 1987) over the wavelength interval 290-400 nm. The monthly surface UV radiation was calculated for clear skies and expressed in terms of standard UV Index units (WMO 2002). The model was run for a resolution of 200 km and 50 levels in the vertical. Other inputs to the model were geographical location, date, time of day and extraterrestrial solar irradiance. Rayleigh scattering and ozone absorption cross-sections were also included. Altitude was taken into account implicitly by the pressure coordinates used in the model. Reduction of UV radiation due to aerosol absorption and scattering was accounted for. This is particularly relevant in urban areas where absorption due to pollution can have a major effect on UV radiation compared to rural areas. Variable UV surface albedo from TOMS was also included (described in Lemus-Deschamps et al. 2004).

The ozone gridded monthly averages from TOMS/OMI (NASA/TOMS Website) and ERA40 (Uppala et al. 2005) were interpolated to the model resolution of 200 km. Both datasets were used independently, and we did not attempt to adjust and merge them; hence, systematic errors from both satellites are present. The TOMS record used was version 8 from 1979 to 2009, and ERA40 data were from 1959 to 2002. This was done to cover the full time period for which data were available. ERA40 data apply a three-dimensional variational analysis of surface and satellite measurements (Uppala et al. 2005). The gap in the TOMS record from December 1994 to June 1995 was not interpolated. Both ozone datasets were used to calculate the global monthly average clear-sky UV Index, for local solar noon, using the UV model described above.

Ozone and UV Index seasonal averages were calculated for each year over the period 1959–2009. Australia (longitudes 110–160˚W) was divided into three regions, defined according to the approximate latitudes of the borders separating the eastern seaboard states: Queensland (North, 10–29˚S,), New South Wales (Central, 29–37˚S), and Victoria/Tasmania (South, 37–45˚S). The seasonal weighted averages were calculated for the each of the three regions for each year of the records, as were seasonal averages of ozone and UV Index over the period 1970–1980. The 1970–1980 period was chosen as the baseline to reduce the influence of the ozone reduction trend reported since the early 1980s. The normalized weighted deviations were then calculated by subtracting the seasonal-regional average over the period 1970–1980 from the seasonal-regional average for each year, and normalizing by the former. The percentage annual, summer (December–February) and winter (June–August) ozone and clear-sky UV Index deviations for Australia as a whole were calculated following the same method. For brevity, (Australian) summer values are referred to in the results and discussion using the year in which January and February fall, although the calculations include data from December of the previous year.

Finally, to compare the geographical distribution of contour lines corresponding to UV Index categories "High", "Very High" and "Extreme" in the last 10 years with the period before the reduction of ozone during the early 1980s, summer and winter clear-sky average local noon UV Index maps were drawn for Australia for the 1970–1980 and 2000–2009 periods.

Results

The inverse relationship between ozone and UV Index is illustrated in Fig. 1a–c. The annual mean over the period between 1959 and 2009 is presented for North, Central and South Australia regions. For all three regions, an ozone decrease (solid line) and a clear-sky UV increase (dashed line) is observed during the last 30 years. Fig. 1a–c show ozone and UV Index values from both datasets for the

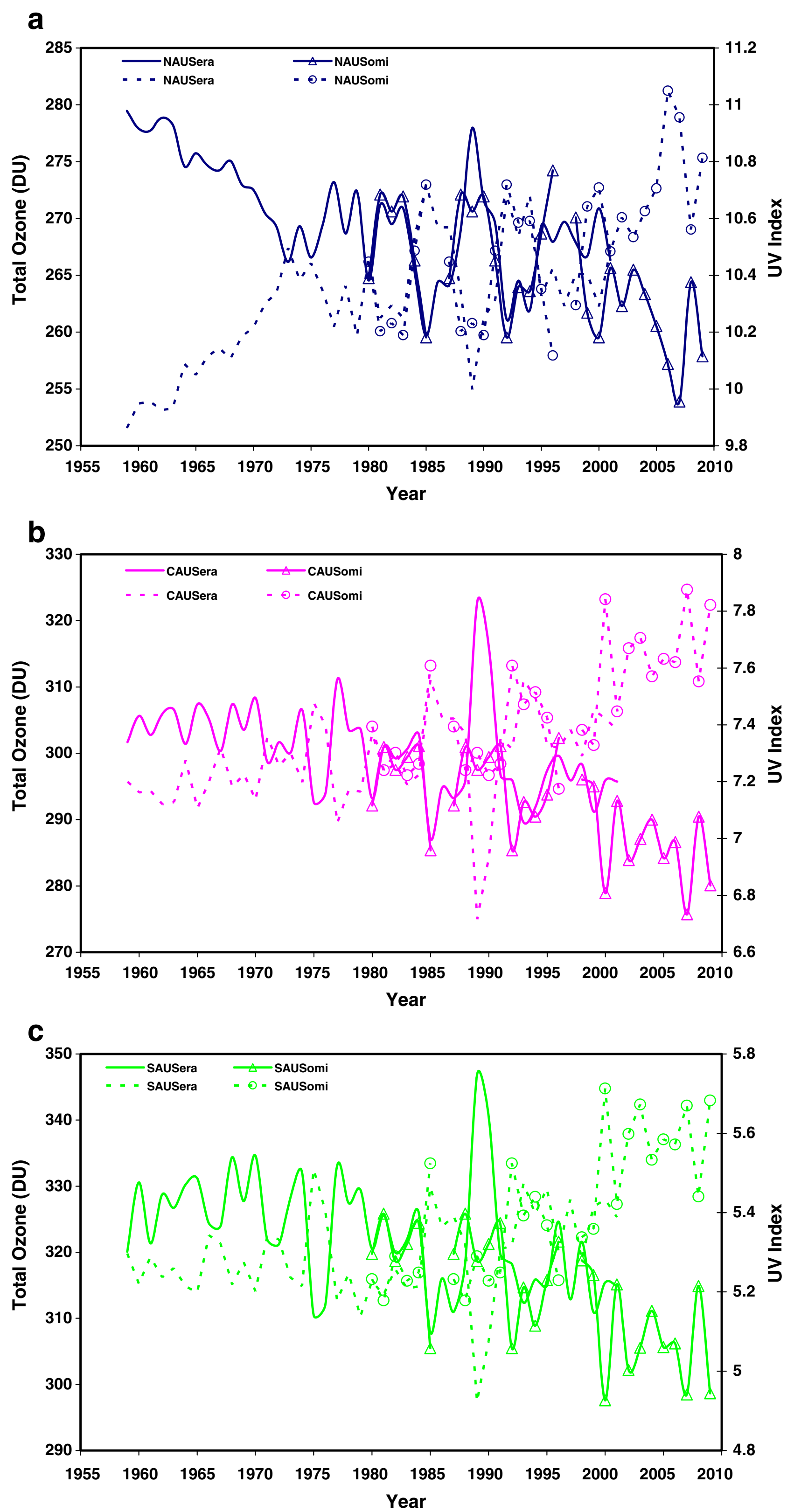

Fig. 1 **a** Annual total ozone from ERA40 (*solid line*) and TOMS/OMI (*solid line and triangles*) and calculated clear-sky UV Index using ERA40 (dotted line) and TOMS/OMI (*dotted line with circles*) for northern (10–29˚S) Australia. Note overlapping TOMS/OMI data from 1979–2009. **b** Annual total ozone from ERA40 (*solid line*) and TOMS/OMI (*solid line and triangles*) and calculated clear-sky UV Index using ERA40 (*dotted line*) and TOMS/OMI (*dotted line with circles*) for central (29–37˚S) Australia. Note overlapping TOMS/OMI data from 1979–2009. **c** Annual total ozone from ERA40 (*solid line*) and TOMS/OMI (*solid line and triangles*) and calculated clear-sky UV Index using ERA40 (*dotted line*) and TOMS/OMI (*dotted line with circles*) for southern (37–46˚S) Australia. Note overlapping TOMS/OMI data from 1979–2009

overlapping period (1979–2002). Inspecting the ozone plots from the two datasets showed that the ozone from TOMS/OMI (denoted by solid line and triangle line markers) closely follows the ERA40 (denoted by solid line) ozone for most of the overlapping period (1979–2002). However, for 1989–1990, differences of around 25DU are observed for the central and southern regions (Fig. 1b, c). The maximum observed in 1989–1990 was more pronounced in the TOMS data than in ERA40, producing a strong UV Index decrease when using ERA40 as input to the radiation code (denoted by dashed line).

For the three regions, an overall increase in clear-sky UV Index due to ozone decreases was observed. From 1960 to the early 1970s, an ongoing increase in UV Index was observed for the Northern region (dashed line, Fig. 1a). This may be due to biases in the low latitude ozone data sets used by ERA40 in the reanalysis for the pre-satellite-data period. Once the TOMS satellite data became available in 1979, the UV Index calculated with TOMS data (dashed line and circles in Fig. 1a–c) are similar to the UV Index calculated with ERA40 (dashed line in Fig. 1a–c). There are large differences in ozone levels and therefore in the UV Index between Northern and Southern Australia. As such, it was necessary to use slightly different scales for the Y-axes of Fig. 1a–c, in order to effectively show the inverse correlation between ozone and UV Index for each region.

During the 1970s and early 1980s, the UV Index levels for the three Australian regions (North, Central and South) were fairly stable. Increasing thereafter, a strong minimum was observed for the three regions during 1989. The total annual ozone deviation from the period 1970–1980 presented in Fig. 2a shows, for all three regions, an ongoing ozone decrease that will produce the corresponding inverse increase in annual UV Index (Fig. 2b).

The Australian summer (December–February) and winter (June–August) deviations from 1970–1980 for ozone and UV

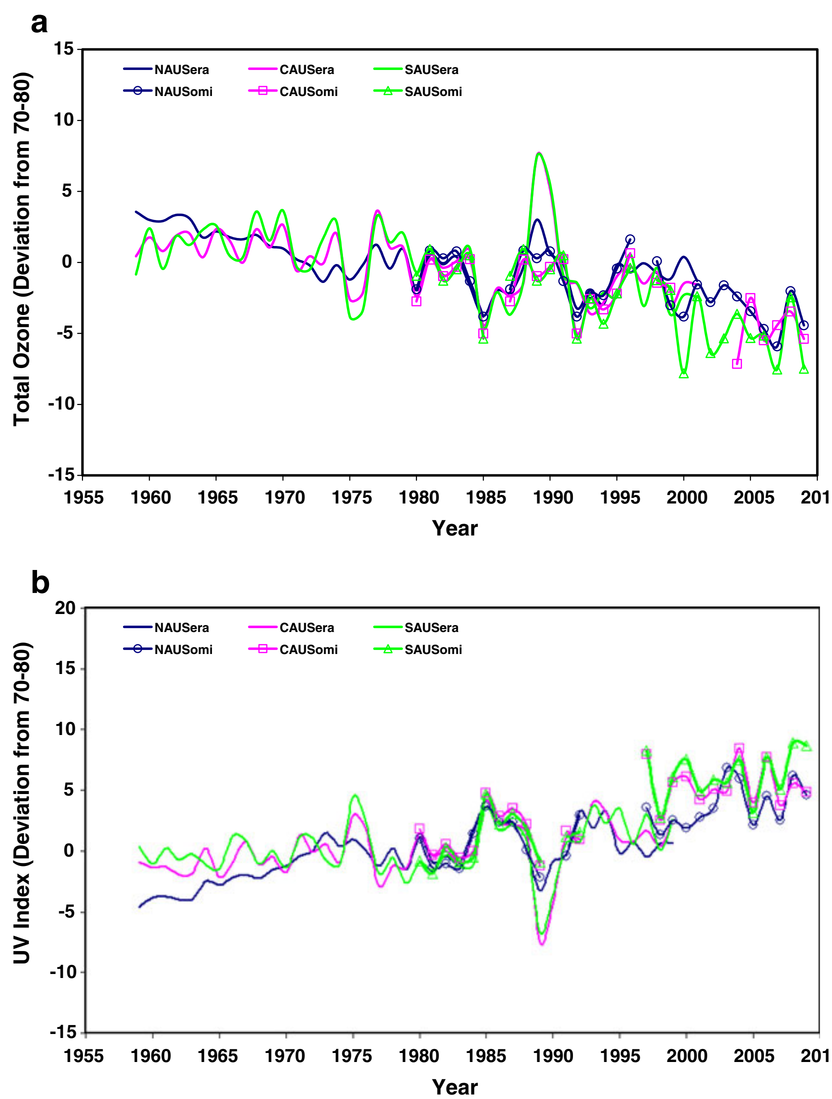

Fig. 2 **a** Annual total ozone (%) deviation from 1970–1980, calculated for northern (10–29°S) *NAUS*, central (29–37°S) *CAUS*, and southern (37–46°S) *SAUS*, Australia. **b** Annual clear-sky UV Index deviation from 1970–1980, calculated for northern (10–29°S) *NAUS*, central (29–37°S) *CAUS*, and southern (37–46°S) *SAUS*, Australia

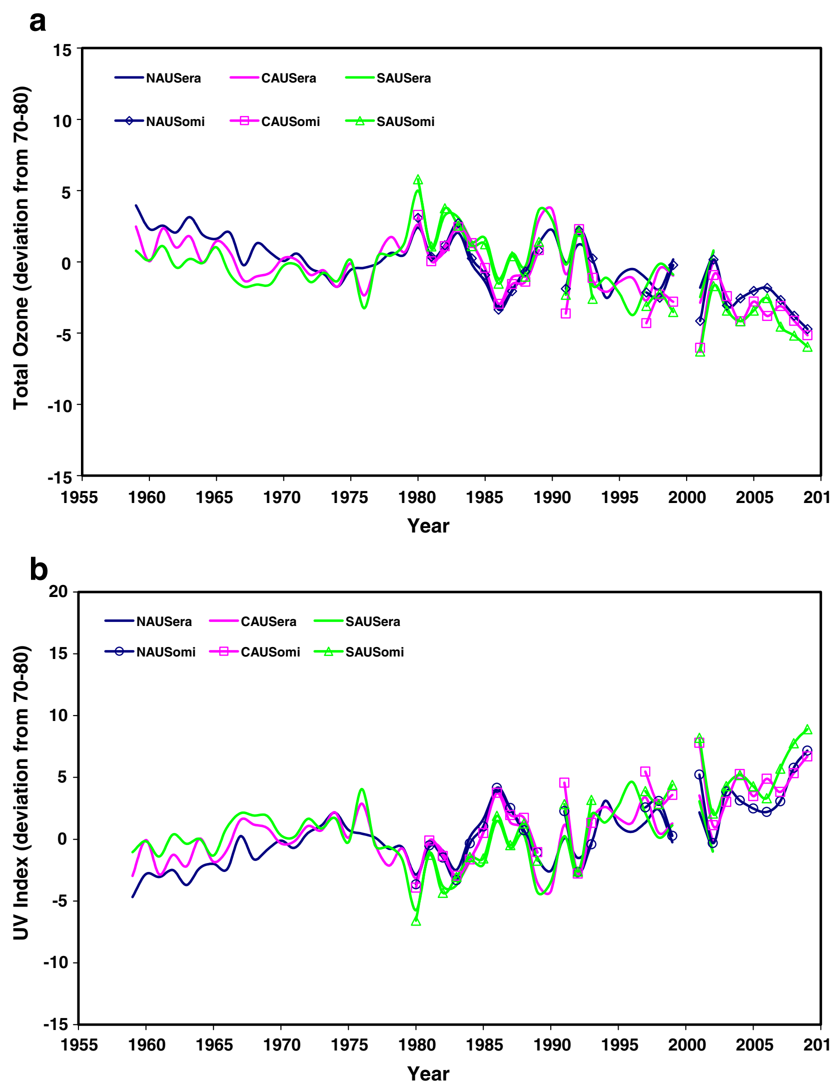

Fig. 3 **a** Australian summer (December–February) total ozone deviation from 1970–1980, averaged over 10–29°S for ERA40 (*NAUSera, solid line*) and TOMS/OMI (*NAUSomi, solid line and cicles*), averaged over 29-37°S for ERA40 (*CAUSera, solid line*) and TOMS/OMI (*NAUS-omi, solid line and squares*), and averaged over 37–46°S for ERA40 (*SAUSera, solid line*) and TOMS/OMI (*SAUSomi, solid line and triangles*). **b** Australian summer (December–February) clear-sky UV Index deviation from 1970–1980, averaged over 10–29°S using ERA40 (*NAUSera, solid line*) and TOMS/OMI (*NAUS-omi, solid line and circles*), averaged over 29–37°S using ERA40 (*CAUSera, solid line*) and TOMS/OMI (*NAUSomi, solid line and squares*), and averaged over 37–46°S using ERA40 (*SAUSera, solid line*) and TOMS/OMI (*SAUSomi, solid line and triangles*)

Index are presented in Figs. 3 and 4. The UV Index was fairly stable in Central and Southern Australia during the 1960s and 1970s. The observed fluctuations are mainly related to ozone inter-annual variability. The summer variability is weaker than in winter, indicating that the winter variability is the main contributor to the ozone inter-annual variability (Fig. 2a). For summer and winter, Figs. 3 and 4 show differences of up to 4% between ERA40 and TOMS for 1991, 1995, 1996 and 2002.

The clear-sky UV Index deviations compared with the period 1970–1980, presented in Figs. 3 and 4, show an overall decrease in ozone (with negative values) and an increase in UV Index levels from 1980 for the three Australian regions (North, Central and South). A minimum of up to 10% was observed for the three regions during 1989. During the 1990s and 2000s, the UV Index for the three regions was more than 2% percent higher than during the 1960–1970s.

During summer, UV Index levels (Fig. 3b) (due to ozone decreases; Fig. 3a) steadily increased from the 1980s throughout the 1990s and 2000s for the three Australian regions. From 1976 to 1986, a relatively steady UV Index decrease is observed. The 1980 minimum of about 6% is followed by relative maxima, up to 4%, in 1986 and the early 1990s, increasing continuously thereafter. The low levels of ozone observed during early 1990s in the annual plot (Fig. 2) are not seen in the summer series.

During winter, the UV Index (Fig. 4b) (due to ozone decreases; Fig. 4a) steadily increased for all three regions. These increases are stronger than those observed for summer. A relative strong maximum is observed in 1976, stronger for the Southern region (up to 8%). From 1976 to 1980, the UV Index deviations for winter continued to increase, with a relative strong minimum in 1977 (about 5%), returning to relatively high levels thereafter. Another strong minimum (of about 9%) is observed for Central and

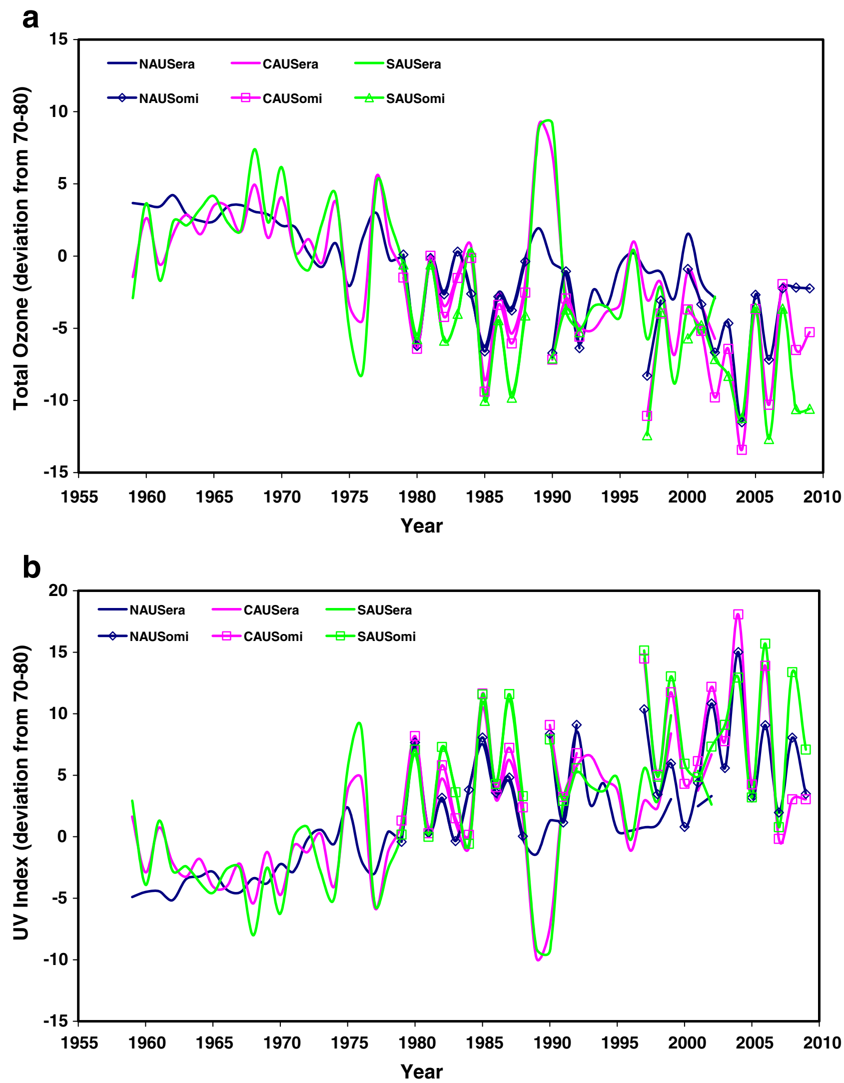

Fig. 4 **a** Australian winter (June-July-August) total ozone deviation from 1970–1980, averaged over 10–29˚S for ERA40 (*NAUSera, solid line*) and TOMS/OMI (*NAUSomi, solid line and cicles*), averaged over 29-37˚S for ERA40 (*CAUSera, solid line*) and TOMS/OMI (*NAUSomi, solid line and squares*), and averaged over 37–46˚S for ERA40 (*SAUSera, solid line*) and TOMS/OMI (*SAUSomi, solid line and triangles*). **b** Australian winter (June–August) clear-sky UV Index deviation from 1970–1980, averaged over 10–29˚S using ERA40 (*NAUSera, solid line*) and TOMS/OMI (*NAUSomi, solid line and circles*), averaged over 29–37˚S using ERA40 (*CAUSera, solid line*) and TOMS/OMI (*NAUSomi, solid line and squares*), and averaged over 37–46˚S using ERA40 (*SAUSera, solid line*) and TOMS/OMI (*SAUSomi, solid line and triangles*)

Southern regions, associated with relatively high ozone levels during 1989–1990. The strong high ozone level in 1989–1990 (up to 10%) in the ERA40 (Fig. 4a, blank line markers) is not present in the TOMS data (Fig. 4a, solid line markers). Low levels of ozone are observed during the early 1990s, indicating that the low ozone levels in winter are the main contributor to the signal in the annual ozone levels shown in Figure 2. The UV Index levels increased again throughout the 1990s and 2000s.

From the summer and winter deviations, presented in Figs. 3 and 4, it is seen that the annual ozone decrease (increase in clear-sky UV Index) is dominated by the winter season. From 1976 to 1980 the strong annual UV Index decline observed, being more pronounced in the Southern region, is associated with relatively high summer ozone levels during the pre ozone-depletion period. The strong annual ozone decline in 1985 is due principally to the winter low ozone values. During the early 1990s, low ozone levels were observed during winter, impacting the annual distributions. In summary, an overall increase in clear-sky UV Index levels (ozone decrease) is observed since the 1980s for the Northern, Central and Southern regions (Figs. 2, 3 and 4).

Figure 5a, b shows geographical variations of the UV Index in the pre-ozone-depletion period (1970–1980) compared with that of the decade 2000–2009. The results show that, for 2000–2009, the summer average UV Index levels of 11 (extreme) or more, are displaced around 2° (400 km) south when compared with 1970–1980 (top panel, Fig. 5) distributions. Likewise, the average winter UV Index level 6 at about 21˚S and level 3 at about 32.5˚S were displaced around 1.5° (300 km) to the south in 2000–2009 (bottom panel, Fig. 5).

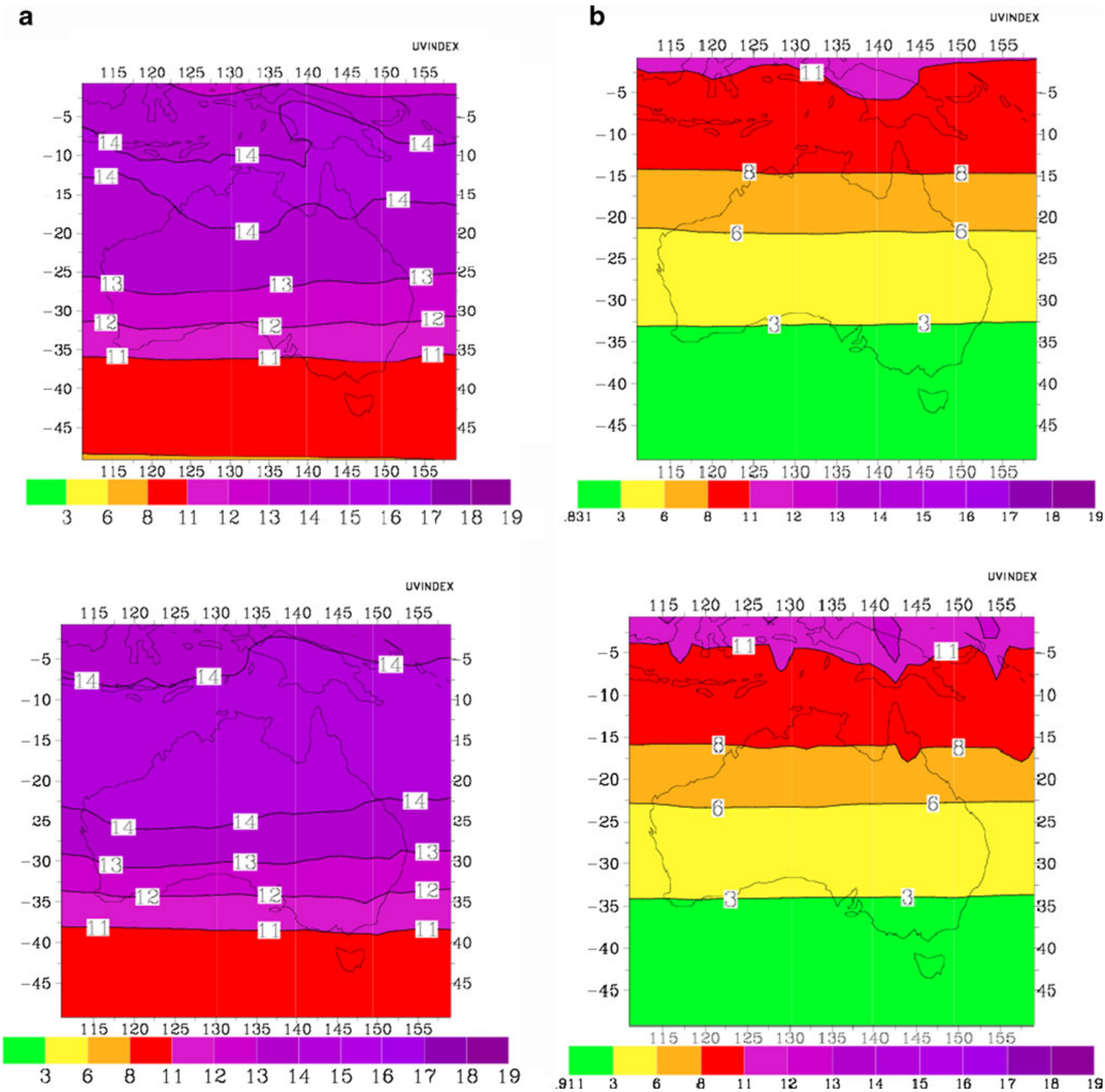

Fig. 5 **a** Australia's summer (December–February) average clear-sky UV Index for 1970–1980 (*top*) and 2000–2009 (*bottom*). **b** Australia's winter (June–August) average clear-sky UV Index for 1970–1980 (*top*) and 2000–2009 (*bottom*)

Discussion

The results show that the clear-sky UV Index over Australia has increased in all three regions since the 1970s. These regions correspond approximately to the latitudes of the Eastern seaboard states of Queensland, New South Wales, and Victoria, for which melanoma (Fig. 6) and non-melanoma skin cancer incidence increases have been reported over a similar period [National Cancer Control Initiative (NCCI) 2003]. The UV Index observed in all three regions from 1985 decreasing sharply in 1989 was associated with winter ozone concentrations from 1985 that increased sharply in 1989. The strong difference in 1989–1990 between ERA40 and TOMS ozone datasets requires further investigation since the signal is only noticeable during winter time.

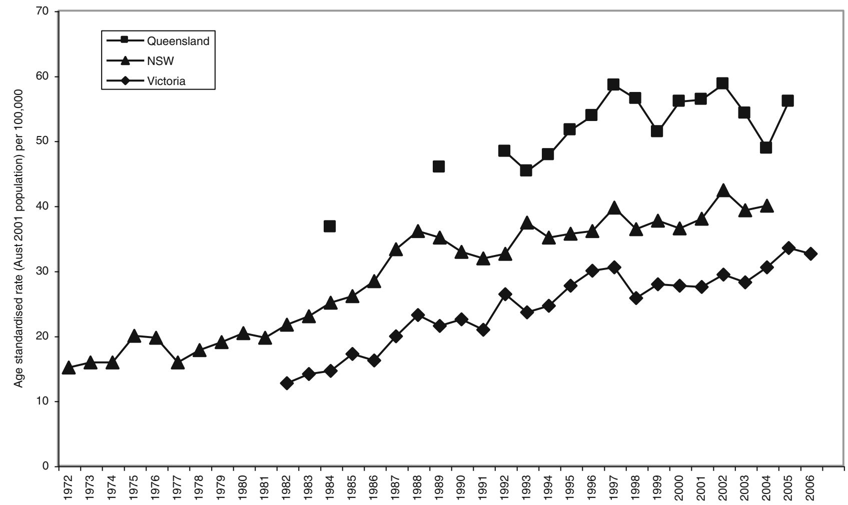

Fig. 6 Trends in melanoma skin cancer for males in Queensland [Queensland Cancer Registry (TCCQ) 2008] (137–157˚E, 12–25˚S), New South Wales [Australian Institute of Health and Welfare Australasian Association of Cancer Registries (AIHW/AACR) 2007] (140–167˚E, 12–35˚S), and Victoria [Victorian Cancer Registry (VCR) 2009] (140–167˚E, 32–40˚S)

The maxima in the annual and winter UV Index (due to low ozone values) in the early 1990s are likely related to the impact of the Mount Pinatubo eruption in June 1991 on ozone concentrations. During this period, large amounts of stratospheric aerosol due to the eruption resulted in low ozone levels observed during winter. This effect was also reflected in the annual distributions. Low ozone concentrations caused by the Mount Pinatubo eruption have been reported elsewhere (Gleason et al. 1993).

From the early 1990s to around 2006, ozone and UV Index were fairly stable. However, a maximum for 2001 and a summer increase (ozone decrease) for the last three years of the record were observed. For winter, the maximum value was observed in 2004. The large UV Index winter values during the early 2000s and the summer values for the last three years of the record seem to modulate the annual response.

The ERA40 records during the 1960s to early 1970s are subject to surface measurement uncertainty. The results presented here are for clear skies, they do not account for changes in UV radiation due to cloudy conditions, which requires further calculations outside the scope of this work.

The results show a shift of about 1.5–2 degrees (300–400 km) south of each category of the UV Index and that the UV Index levels have been increasing since the early 1980s in both summer and winter. The increase in UV Index during this period for winter has been about twice that of summer. For the southern parts of Australia, summer increases are concerning because this is when temperatures are warmer, which encourages an increase in outdoor activities, sun exposure and sunburn (Dobbinson et al. 2008). These higher UV Index levels therefore come at a time of year when people are more likely to be exposed to the sun, increasing their risk of over-exposure to UV radiation, and hence skin cancer. In contrast, the greater increases observed in winter UV levels are of particular concern for central and northern Australia. During winter in these regions, temperatures are more pleasant than in summer, resulting in increased exposure to the sun (Vishvakarman et al. 2001). A perception that UV levels are low during winter could also contribute to increased exposure during this season, as in fact these regions are subject to high to extreme UV Index levels all year around (Lemus-Deschamps et al. 2004).

Australian skin cancer rates are already high, so any increases in UV Index are concerning for skin cancer prevention advocates. While incidence rates for melanoma, the most dangerous form of skin cancer, are higher in more northerly latitudes where surface UV levels are higher, rates have been increasing in all states located at different latitudes over the past 30 years (see Fig. 6), as have those for non-melanoma skin cancer (basal and squamous cell carcinoma) (NCCI 2003).

While there is a long and variable lag time between exposure to UV and the incidence of skin cancer, it is possible that some of the recorded increases in incidence [Queensland Cancer Registry (TCCQ) 2008; Australian Institute of Health and Welfare Australasian Association of Cancer Registries (AIHW/AACR) 2007; Victorian Cancer Registry (VCR) 2009; National Cancer Control Initiative (NCCI) 2003] at all latitudes may be due to increases in surface UV. More recent increases in UV could be expected to result in higher rates of skin cancer in the future. With ozone levels not expected to return to pre-1980s levels before mid-century (Andrady et al. 2011), UV levels are expected to continue to rise. Combined with predictions that temperatures will continue increasing for the rest of the century [Intergovernmental Panel on Climate Change (IPCC) 2007a, b], and with the established tendency for people to spend more time outdoors at warmer temperatures (Dobbinson et al. 2008), under clear skies, the associated risk of skin cancer will increase. In this context, it is important that UV levels continue to be monitored, in order to inform skin cancer prevention strategies and prepare for further increases in incidence.

References

Andrady AL, Aucamp PJ, Austin A, Bais AF, Ballaré CL, Björn LO, Bornman JF, Caldwell MM, Cullen AP, de Gruijl FR, Erickson DJ, Flint SD, Häder D-P, Hamid HS, Ilyas M, Longstreth J, Lucas RM, Madronich S, McKenzie RL, Norval M, Paul ND, Robinson R, Shao M, Solomon KR, Sulzberger B, Takizawa Y, Tang X, Torikai A, van der Leun JC, Williamson CE, Wilson SR, Worrest RC, Zepp RG (2011) Environmental effects of ozone depletion and its interactions with climate change: 2010 assessment. Executive summary. Photochem Photobiol Sci 10:178–181

Armstrong BK (2004) How sun exposure causes skin cancer: an epidemiological perspective. In: Hill D, Elwood JM, English DR (eds) Prevention of skin cancer, cancer prevention - cancer causes, vol 3. Kluwer, The Netherlands, pp 89–116

Australian Institute of Health and Welfare (AIHW) (2008) Non-melanoma skin cancer: general practice consultations, hospitalisation and mortality, Cancer series no. 43. Cat no. 39. Australian Institute of Health and Welfare, Canberra, Australia

Australian Institute of Health and Welfare Australasian Association of Cancer Registries (AIHW/AACR) (2007) Australian cancer incidence and mortality workbooks (ACIM). Australian Institute of Health and Welfare. Retrieved from www.aihw.gov.au/cancer/data/acim_books/index.cfm on February 8, 2010.

Bourke W, Hart T, Steinle P, Seaman R, Embery G, Naugton M, Rikus L (1995) Evolution of the Bureau of Meteorology global assimilation and prediction system. Part 1: Analysis and Initialisation. Aust Meteorol Mag 44:19–40

Commision Internationale d'Eclairage (CIE) (1987) A reference action spectrum for ultraviolet induced erythema in human skin. CIE J 6:17–22

Dobbinson SJ, Wakefield M, Hill D, Girgis A, Aitken JF, Beckmann K, Reeder AI, Herd N, Fairthorne A, Bowles KA (2008) Prevalence and determinants of Australian adolescents' and adults' weekend sun protection and sunburn, summer 2003–2004. J Am Acad Dermatol 59(4):602–614

Gleason JF, Bhartia PK, Herman JR, McPeters R, Newman P, Stolarski RS, Flynn L, Labow G, Larko D, Seftor C, Wellemeyer C, Komhyr WD, Miller AJ, Planet W (1993) Record low global ozone in 1992. Science 260:523–526

Intergovernmental Panel on Climate Change (IPCC) (2007a) Fourth Assessment Report: Climate Change (2007): Synthesis Report: Projected climate change and its impacts. http://www.ipcc.ch/publications_and_data/ar4/syr/en/spms3.html

Intergovernmental Panel on Climate Change (IPCC) (2007b) Technical Summary. In: Solomon S (ed) Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, United Kingdom and New York

Lemus-Deschamps LL, Rikus L, Gies P (1999) The operational Australian ultraviolet index forecast 1997. Meteorol Appl 6:241–251

Lemus-Deschamps LL, Rikus L, Grainger S, Gies P, Sisson J, Li Z (2004) UV Index and UV dose distributions for Australia (1997–2001). Aust Meteorol Mag 53:239–250

National Cancer Control Initiative (NCCI) 2003. The 2002 national non-melanoma skin cancer survey, A report by the NCCI Non-melanoma Skin Cancer Working Group. Edited by MP Staples. NCCI Melbourne. www.ncci.org.au

Queensland Cancer Registry (TCCQ) (2008). *Cancer in Queensland incidence and mortality 1982 to 2005 statistical tables.* The State of Queensland, Queensland Health: Brisbane, January 2008. Available from http://www.health.qld.gov.au/hic/qcr2005/1982_2005.pdf.

Uppala SM, Kållberg PW, Simmons AJ, Andrae U, da Costa BV, Fiorino M, Gibson JK, Haseler J, Hernandez A, Kelly GA, Li X, Onogi K, Saarinen S, Sokka N, Allan RP, Andersson E, Arpe K, Balmaseda MA, Beljaars ACM, van de Berg L, Bidlot J, Bormann N, Caires S, Chevallier F, Dethof A, Dragosavac M, Fisher M, Fuentes M, Hagemann S, Hólm E, Hoskins BJ, Isaksen L, Janssen PAEM, Jenne R, McNally AP, Mahfouf J-F, Morcrette J-J, Rayner NA, Saunders RW, Simon P, Sterl A, Trenberth KE, Untch A, Vasiljevic D, Viterbo P, Woollen J (2005) The ERA-40 re-analysis. Q J R Meteorol Soc 131:2961–3012

Victorian Cancer Registry (VCR) (2009). Cancer trends, Victoria. Cancer Council Victoria: Melbourne. Available from http://vcrdata.cancervic.org.au:8082/ccv/#.

Vishvakarman D, Wong JC, Boreham BW (2001) Annual occupational exposure to ultraviolet radiation in central Queensland. Health Phys 81(5):536–544

World Health Organization (WHO) (2002). *Global Solar UV Index: A practical guide: A joint recommendation of the World Health Organization, World Meteorological Organization (WMO), United Nations Environment Programme, and the International Commission on non-ionizing radiation protection.* WHO: Geneva, Switzerland, Available from http://www.who.int/uv/publications/en/UVIGuide.pdf

World Meteorological Organization (WMO) (2006): Global Ozone Research and Monitoring Project-Report No 50: Scientific Assessment of Ozone Depletion: 2006