Where on Earth has the highest UV?

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Abstract. Ultraviolet intensities in the New Zealand summer are extreme on the international UV Index scale, but it reflects the risk of erythema, and UVI's origin in Canada, rather than the global range. We used 7 years of TOMS v 8 estimates of surface UV to review global peak intensities, and to identify where the highest UV occurs. Throughout the Altiplano region of Peru, Bolivia, Chile and Argentina, UVI values exceed 20. The highest UVI of 25 was in the grid cell centred on Cuzco, in southern Peru (13.5° S, 3360 m a.s.l.). Peak values on the edge of the Antarctic Plateau also exceed the highest UVI in New Zealand, and are comparable to those at sea level in the tropics. The time of year for peak UV varies smoothly from spring in the Antarctic, under the annual ozone hole, through SH summer at mid-latitudes, March-April in the tropics, to NH summer in the northern extra-tropics.

Extreme UV intensity

With the world's highest rates of skin cancer, New Zealanders should be aware of the health risks posed by overexposure to UV radiation. A long-established UV advisory service regularly reports the risk, which is heightened by (mostly) fair skins, outdoor lifestyle, and a climate that encourages sun-seeking. Relatively high UV intensities also play a part. The erythemal (sun-burning) strength of UV radiation is usually given in terms of the UV Index (UVI), a scale first used in Canada and defined to range from 1 to 10 there. In the NZ summer, UVI values regularly exceed 13, even in the south of the country where UV is less intense. A recent study showed that peak UVI values in NZ are about 40% more than at similar latitudes in North America (McKenzie *et al.*, 2006).

Compared with equatorial regions, our UV is not particularly strong – contrary to anecdotal evidence from travellers. The main factors controlling UV, in desdending order of importance, are:

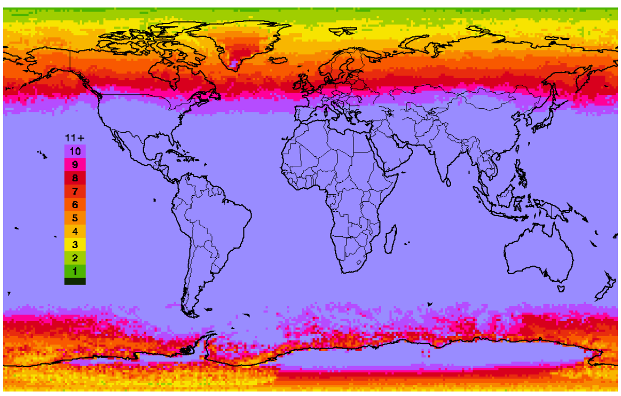
- Solar elevation causes the diurnal, seasonal and latitudinal range.
- Clouds reflect and scatter radiation. Heavy overcast conditions can reduce UV intensity by more than 90%, while clouds near the Sun can cause short-term UVI increases of ~20%. On average, clouds reduce clear sky UV by about 30%.
- Ozone absorbs UV. UVI decreases by about 1% for every 1% increase in ozone, which varies from a minimum of about 100 Dobson Units[1] inside the Antarctic ozone hole to a (seasonal) maximum of about 500 DU at mid latitudes. The global average ozone column is about 300 DU, and away from the ozone hole it tends to be lowest (~ 200 DU) in the tropics.
- Aerosols extinction can reduce UVI by 20-30%.
- Altitude reduces the air column for scattering and absorption; even in the most pristine air, UV increases by about 5% per kilometre.
- Snow reflects UV for backscatter from air. It can add 20-40% to UVI, but less at high altitude.
- The elliptical orbit of the Earth about the Sun is also significant; at closest approach in early January, the UV intensity at the top of the atmosphere is about 7% more than in July.

So where on Earth's surface would we expect the highest UV? Peak UV should occur within the tropics (high sun, low ozone), at a high altitude site, in the Southern Hemisphere. Near the Tropic of Capricorn, overhead Sun occurs during the period when the Earth-Sun separation is a minimum.

Satellite observations

To answer the question, we used a climatology of gridded UV data measured by NASA's Total Ozone Monitoring Spectrometer (TOMS) on board the Earth Probe (E-P) satellite over the 7 year period between 1997 and 2003. Previous studies (McKenzie *et al.*, 2003) had shown that while there are problems with this data set under polluted conditions, the results are reliable for the clean lower atmosphere expected for peak daily UVI values. The spatial resolution of the data product is 1° latitude x 1.25° longitude (approximately 100 km x 100 km) so the results represent an average over that footprint area. The data include corrections for cloud cover, ozone absorption, terrain altitude, snow cover, and absorbing aerosols. They do not include the possibility of the cloud enhancements mentioned above, which are expected to be small for data averaged over such large areas. The data give daily peaks of erythemal UV in mW m^{-2}, which are divided by 25 to give UVI.

Figure 1 shows that the internationally-standardised colours for UV Index are not adequate for this purpose. As well as representing the risk of erythema and correlated skin damage, the UVI scale was chosen to show the range of intensities in Canada. All higher values, as experienced on clear summer days by over 90% of the world's population, lie above this range.



[1] 1 DU = 2.69 x 10^{16} molec. cm^{-2}, 100 DU = 1 mm gas at STP.

Figure 1. Map of peak UVI. The standard colour code for UVI does not allow identification of peak values. All sites between about 50° S and 40° N experience extreme UVI (>10) at some stage of the year.

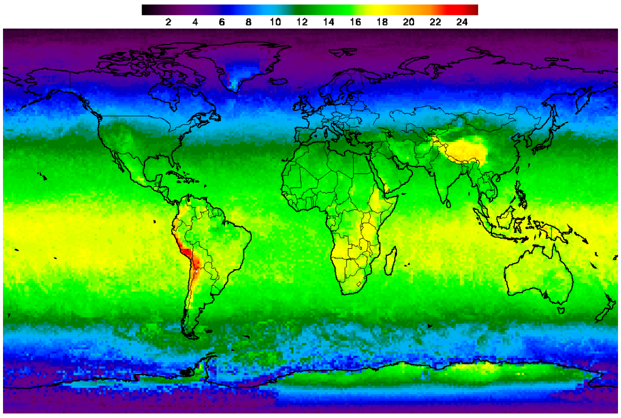


Figure 2. Map of peak UVI, using a modified colour scale to highlight the absolute peaks.

Figure 2 uses a modified colour scale and shows that the highest values of UVI occur in the Peruvian Andes and throughout the Altiplano region. The maximum UVI of 25 is for the grid cell at 13.5° S, 172° W, centred on Cuzco in Peru. The city is at 3360 m a.s.l., with surrounding terrain extending to over 6000 m a.s.l. As the capital of the Inca empire, Cuzco seems to be well sited for sun worship.

There was single outlying data point with higher UV (UVI = 29) just south of the tropic of Capricorn in Argentina (23.5° S, 67° W), but we suspect that this is a bad data point. Time series of the full data sets from the Altiplano region, for Cuzco and this outlier site are plotted in Figure 3. They show the expected seasonal variations, which are attributable to changes solar elevation, ozone, and Earth-Sun separation. Additionally, at Cuzco especially, there is a stepwise increase in UV each year that occurs in the autumn and is probably associated with the increases in surface reflectivity expected from snow cover. In the TOMS UV retrieval, surfaces are also flagged as containing snow or ice using a climatological database.

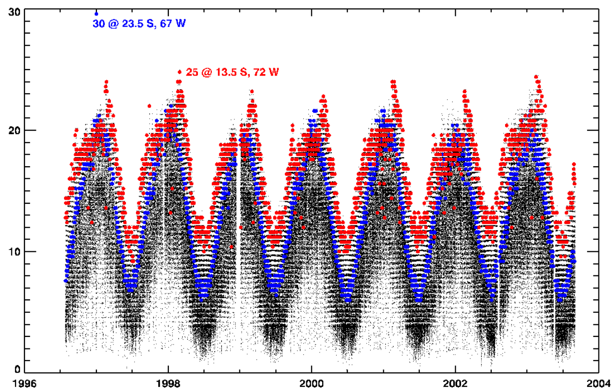


Figure 3. Time series plots of daily UVI maxima for the Altiplano region of South America. Red points are for the Cuzco cell, identified here as having the maximum UVI. Blue points are for the outlier peak discussed in the text.

These peak UVI values are about a factor of two greater than in New Zealand, and about 1.5 times those at low altitudes in the tropics.

It is interesting to compare the predicted daily noontime peak values of UVI with measured values. In New Zealand, the peak UVI is about 14 (and at corresponding North latitudes it is about 10). Peak values similar to those in NZ are measured in Boulder, Colorado (40° N, 1700 m), and at Mauna Loa Observatory in Hawaii (19° N, altitude 3400 m), the peak value is ~20. These peak values should be contrasted with the peaks that occur near sea level at the equator (UVI ~ 16), which are similar to the snow-enhanced peak values observed in Antarctica during the ozone hole period. All values are small compared with the UVI ~300 present outside the Earth's atmosphere. Prospective astronauts take note.

Date of peak UV

Finally, in Figure 4 we show the day of year on which the peak UVI values occurred. Notice that the peak UVI in Antarctica occurs in early December when the effects of the Antarctic ozone hole are still present, and from Figure 2 this peak value is significantly more that at mid-latitudes such as New Zealand. Furthermore, during the period, there are 24 hours of daylight in Antarctica, so the total daily dose can be further enhanced compared with other locations.

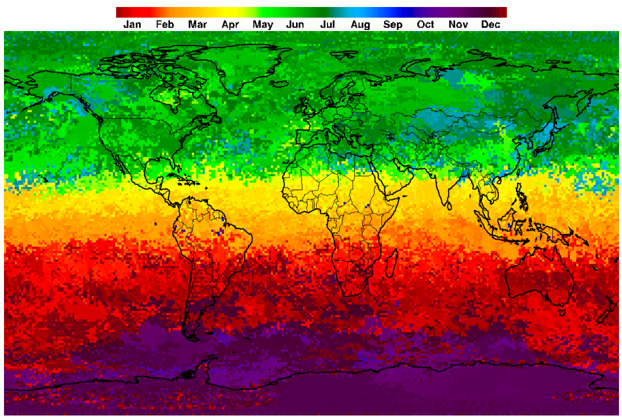


Figure 4. Map showing the day of year on which the peak UVI occurred. Usually this corresponds to periods when the Sun is highest in the sky. Outside the tropics this is near 21 June in the Northern Hemisphere, and near 21 December in the Southern Hemisphere. However, in Antarctica, the peak UVI occurs in earlier because of the much lower ozone values in spring.

References

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