

# The Effect of Clouds and Surface Albedo on the UV in the Antarctic

S.E. Nichol, G. Pfister, G.E. Bodeker, R.L. McKenzie, S.W. Wood

National Institute of Water and Atmospheric Research, New Zealand

G. Bernhard

Biospherical Instruments Inc, San Diego, California

## Abstract

Erythemal UV irradiances from two Antarctic sites and a mid-latitude site are compared in this study. The impacts of surface albedo and cloudiness on the UV irradiances are investigated separately by creating clear and cloudy subsets of the datasets, and also by using model simulations. The study shows that the UV attenuation by cloud is greater for a low surface albedo than for a high surface albedo. This effect is of particular importance at high latitudes where snow may be present during the summer months. The modelling has shown that there is greater cloud attenuation of UV with increasing cloud optical depth, and that there is also a tendency towards greater cloud attenuation with increasing SZA.

## Introduction

The factors which influence the UV irradiance are, in approximate order of decreasing importance: solar zenith angle (SZA), ozone, cloud cover, surface albedo, and atmospheric aerosol loading. In this study we look at the combined effects of cloud cover and surface albedo on erythemal UV to show how high surface albedos mitigate the UV reduction from clouds. This effect is of particular importance at high latitudes where snow may be present during the summer months. Comparisons are made between measured and clear-sky modelled erythemal UV from two Antarctic sites (McMurdo and South Pole), and a mid-latitude site with a low surface albedo (Lauder). The data from McMurdo are of particular interest since there is a very large change in surface albedo at that site; the albedo, which is about 0.7 during the winter and spring, drops to a value of about 0.2 in summer [Thompson and MacDonald, 1962].

## UV Instrumentation and Site Descriptions

Details of the UV instrumentation can be found in Booth et al. [1994] and McKenzie et al. [1992] for the Antarctic and Lauder sites respectively, and are also summarized in Nichol et al. [2002]. The erythemally weighted UV irradiances from all three sites are derived from routine spectral irradiance measurements.

The two Antarctic sites have quite different characteristics. The South Pole station (90.0°S, 0.0, altitude 2800 m) is at a very high altitude, and the surrounding area is covered by snow and ice throughout the year. The albedo at South Pole varies between about 0.82 and 0.88 [Dutton et al. 1989]. In contrast, the immediate area surrounding McMurdo station (77.8°S, 166.6° E, altitude 250 m) is covered in snow during the winter, however the snow gradually melts over the summer to reveal a surface of black basaltic rock. Albedo

measurements made at Scott Base have shown that the albedo, in the visible range, of the snow covered surface is within the range 0.7-0.8, and that when the snow melts the albedo drops to between 0.1 and 0.2 [Thompson and MacDonald 1962].

The surrounding area at Lauder (45.1°S, 169.7° E, altitude 370 m) is mainly covered with tussock grass, which has a very low albedo, varying from 0.01 at 300 nm to 0.02 at 400 nm [McKenzie et al. 1996]. Lauder is generally snow-free, although in winter there is occasionally snow cover that lasts for a day or two.

## UV Model

The Tropospheric Ultraviolet-Visible (TUV) radiative transfer model (version 4.1a) [Madronich 1993] was used to calculate a clear sky modelled value to correspond to each erythemal UV measurement from McMurdo, South Pole and Lauder. The clear sky modelled values were calculated using the same SZA that the UV measurement was made at. The pseudo-spherical discrete ordinate radiative transfer solver was used in the model.

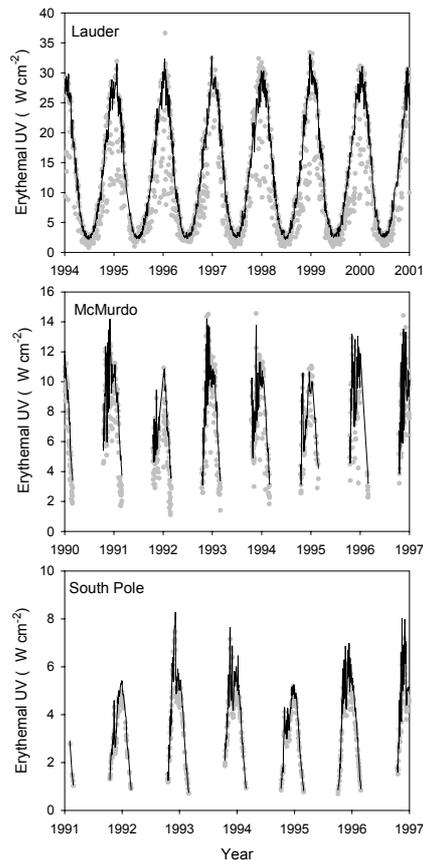
The dependence that exists between the surface albedo and the SZA was not taken into account in the TUV model. The model was run using albedos of 0.05, 0.75, and 0.85 respectively for Lauder, McMurdo and South Pole. The model was run for Lauder using USSA temperature and ozone profiles. The ozone profiles that were used for McMurdo and South Pole were generated using ozonesonde data obtained at McMurdo during the 1998 spring, and the temperature profiles for McMurdo and South Pole were generated using the McMurdo ozonesonde data and South Pole radiosonde data respectively. The ozone profiles used in the model were scaled to daily total ozone values from each site. Aerosol extinctions were not included in the model since all three sites are clean air sites.

## Results and Discussion

Figure 1 shows the noontime measured and the clear-sky modelled erythemal UV for the three sites; only the noontime data are shown in Figure 1 in order to illustrate the effect of UV attenuation by cloud. Figure 1 suggests that the UV attenuation by cloud is greater at Lauder than at the two Antarctic sites.

Mahesh et al. [2001] have found that two-thirds of the clouds detected at the South Pole have an optical depth less than 1, and so are optically thin; whereas clouds on the Antarctic coast (e.g. McMurdo) typically have a cloud optical depth greater than 20. Uddstrom et al.'s (2001) cloud classification algorithm showed that in the vicinity of Lauder that clouds thicker than transmissive cirrus are observed about 55% of the time.

*Figure 1: Noontime measured erythemal UV (gray dots)*



and clear-sky modelled noontime erythemal UV (black line) for Lauder, McMurdo, and South Pole.

The differences between the clear-sky modelled and measured erythemal UV data are explored by considering the ratios of the measured to the modelled values. The data were separated into clear and cloudy subsets to investigate the influence of clouds; the method used to separate the data is described in detail in Nichol et al. [2002]. It should be noted that the cloudy subset refers to overcast cloudy conditions. Contour plots of the probability distributions of these ratios (using a bin width of 0.1) are shown in Figure 2. As would be expected, the clear data from Lauder have ratios that are close to 1, and the cloudy data have ratios that tend to be between 0.3 and 0.8. The clear data from McMurdo also have ratios that are close to 1, but the McMurdo cloudy data tend to have ratios that are between 0.5 and 1. The measured and modelled clear data from South Pole are not in such good agreement as for the other two sites (i.e. the measured/modelled UV ratios tend to be close to 0.9 rather than 1), which is a result of the measurements being made at very high SZA and the increase in uncertainties of the model calculations at low sun. The cloudy data from South Pole tend to have ratios that are close to 0.8; these very high values show that the cloud influence at South Pole tends to not be as strong as at McMurdo, and will result from the low cloud optical depths at South Pole [Mahesh et al. 2001].

An interesting feature of Figure 2 is the tendency towards lower UV ratios in late summer (February) at McMurdo. This appears to be related to the changing albedo due to the melting of the surrounding snow. The McMurdo clear data have measured/modelled UV ratios that tend to slightly drop in value in late summer; this is

caused by the change in surface albedo (since the model run used a fixed albedo of 0.75 for the whole year). The cloudy data at McMurdo have measured/modelled UV ratios that have a much larger drop in value in late summer than the clear data. This suggests that at McMurdo the clouds become more important at reducing erythemal UV when the surface albedo decreases in summer.

The fact that the measured/modelled UV ratios for the cloudy data at McMurdo and South Pole tend to be closer to 1 than the cloudy data at Lauder are, suggests that clouds in the Antarctic are less important at reducing erythemal UV than at Lauder. We expect that this is a result of multiple scattering between the cloud base and the highly reflective snow surface in the Antarctic, which enhances the contribution from the scattered light component. This process is modelled in the next section.

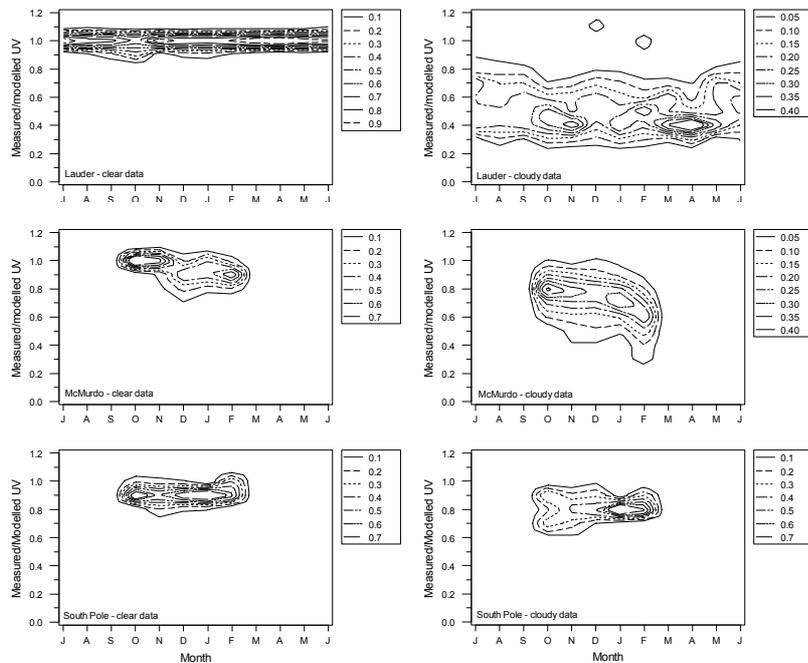
The relationship between cloudiness and surface albedo on the UV attenuation was investigated by using the TUV model to calculate erythemal UV radiation for cloudy conditions with surface albedos of 0.05 and 0.75. The cloud was a 1 km thick vertically homogeneous layer, with a cloud base at an altitude of 2 km; cloud optical depths ranging from 0.1 to 50 were used in the model. The cloud model used a single scattering albedo of 0.9999 and a cloud asymmetry factor of 0.85. Figure 3 shows, for the two albedos, the ratio of the modelled cloudy erythemal UV to the modelled clear-sky erythemal UV for three different SZAs ( $0^\circ$ ,  $35^\circ$ , and  $70^\circ$ ). The ratios for the three SZAs are shown in Figure 3 to illustrate that there is some variability with SZA, with a tendency towards greater cloud attenuation with increasing SZA. Figure 3 clearly shows that there is greater cloud attenuation of UV with increasing cloud optical depth, and it is also greater for the lower albedo than the higher albedo.

The modelled cloud/clear-sky ratios for the same cloud optical depth are always larger for the higher albedo than for the lower albedo (Figure 3). This is effectively what we see in Figure 2, where the measured/modelled UV ratios for the cloudy McMurdo data tend to drop in value in late summer when the snow melts. It also accounts for the difference between the measured/modelled UV ratios for the cloudy Lauder data and the cloudy data from the two Antarctic stations. Figure 3 shows that clouds play a more important role in attenuating erythemal UV as the surface albedo decreases.

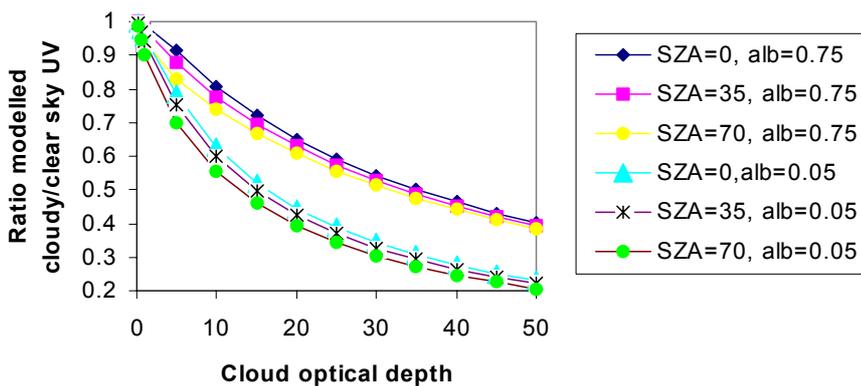
## Conclusions

This study has shown with an analysis of erythemal UV irradiances from three sites, and also with modelling, that the UV attenuation by cloud is greater for a low surface albedo than for a high surface albedo. This is a result of multiple scattering between the cloud base and the high albedo surface, which enhances the contribution from the scattered light component. This effect is of particular importance at high latitudes where snow may be present during the summer months.

The modelling has also shown that there is greater cloud attenuation of UV with increasing cloud optical depth. There is also a tendency towards greater cloud attenuation with increasing SZA.



**Figure 2:** Contour plots of the probability distribution of measured/clear sky modelled erythemal UV ratios for Lauder, McMurdo, and South Pole for the clear data subsets and the cloudy data subsets. The bin width of the ratios is 0.1. NB the months are in order July, August, September, ....., May, June.



**Figure 3:** Ratios of the modelled cloudy erythemal UV to the modelled clear-sky erythemal UV versus cloud optical depth for SZAs of  $0^\circ$ ,  $35^\circ$ , and  $70^\circ$  and albedos (alb) of 0.05 and 0.75.

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