# Do Clouds Mitigate the Biological Effects of Ozone Depletion in the Antarctic?

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## Introduction

Recent studies have shown that biological production in the maritime Antarctic is affected by the ratio of irradiance in the UVB band to that in the UVA or PAR radiation bands (Smith and Cullen 1995). This result is consistent with the idea that the overall productivity is determined by how well the damaging effect of UVB photons can be erased by DNA repair mechanisms which are powered by UVB or PAR photons. While cloud opacity will certainly reduce the UVB, UVA and PAR irradiance, the effect it has on the WB/UVA irradiance ratio is less certain. The goal of this research is to determine how clouds and surface albedo affect this important environmental parameter.

## Data

This study is based on observations made by the NSF/UV spectroradiometer (Booth et al. 1995) deployed at Palmer Station, Antarctica (64° 46'S, 64° 04' W). The spectroradiometer is a temperature stabilized double scanning monochromator coupled to a photo-multiplier tube detector and is optimized for operation in the UV. The UV monitor data are collected hourly and are packaged in a number of standard data products by Biospherical Instruments Inc. (BSI), San Diego.

The system provides three types of datasets with spectral resolutions of 0.2, 0.5 and 2.5 nm and wavelength pass-bands of 280-315, 280-380 and 280-620 nm, respectively. BSI preprocesses the data into-UVB(290-320 nm), UVA(320-400 nm), and dose weighted data convolved over several published biological action spectra.

In addition, microwave observations from the Special Sensor Microwave/Imager (SSM/I) sensor aboard the DMSP satellite are used to estimate the ice areal coverage for the south west coast of Anvers Island. As we shall show, this information on the surface conditions in the vicinity of the station is crucial to understanding how clouds modulate the UVB/UVA ratio.

## Method

To distinguish the cloud effect from the strong modulating effects of the total ozone, we developed a retrieval technique which simultaneously retrieves column ozone and cloud opacity. The retrieval technique is based on the idea that atmospheric transmission for pass-bands in the UVA and UVB differ in their response to overcast and ozone: The UVA irradiance responds to changes in cloud thickness but is relatively insensitive to the ozone column amount, while a UVB band is sensitive to both ozone and clouds. The differing response of these wavelength bands to clouds and ozone provides the leverage required to make the retrievals.

We used our radiative transfer code, SBDART (Ricchiazzi et al. 1995), to relate irradiance to cloud optical depth and total ozone amounts. SBDART is a detailed atmospheric radiative transfer code based on LOWTRAN7 atmospheric transmission models (Kneizys et al. 1983), Mie scattering calculations and the DIScrete Ordinate Radiative Transfer (DISORT) multiple scattering RT module (Stamnes et al. 1988). The model calculations were carried out over a wide range of solar zenith angle, surface snow fraction, cloud optical depth, and ozone amount.

## Results

To limit the scope of this study, we used Setlow's biological action spectra (Setlow 1974) to characterize the degree of DNA damage expected from a given UVB spectra. Figure 1 shows this DNA action spectra compared to the atmospheric transmission expected for a range of total ozone column amount. Henceforth we will refer to the UVB irradiance convolved over Setlow's action spectra as the "DNA" band.

Figure 2 shows the measured irradiance at 345 nm versus solar zenith angle. Measurements in this band are used with model results from SBDART to get a first guess at the cloud optical depth. The final values of cloud optical depth and ozone amount are a result of a simultaneous retrieval consistent with measurements in the UVB and UVA.

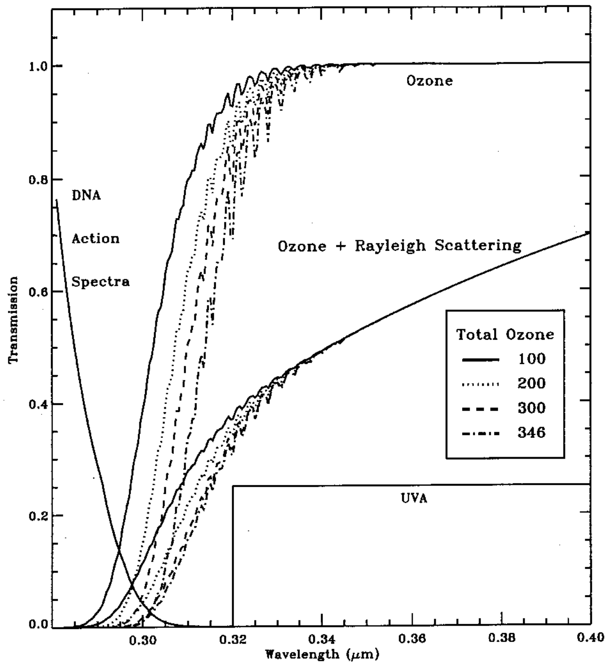


**Figure 1**. Atmospheric transmission due to ozone and Rayleigh scattering. Wavelengths most damaging to biologic systems are indicated by a typical DNA action spectra. In this study the convolution of this function with surface UV will be taken as a measure of UVB radiation.

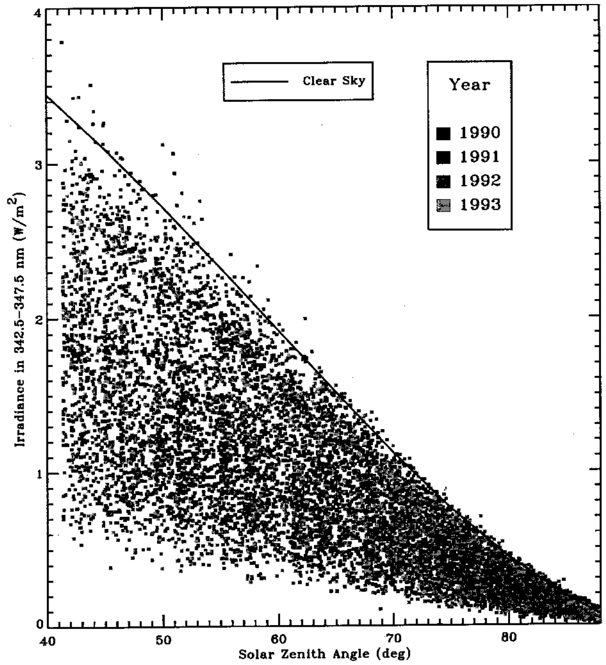


**Figure 2**. Measured irradiance in a narrow part of the UVA band versus solar zenith angle for years 1990 through 1993. The theoretical clear sky irradiance as computed from SBDART is also shown. The ratio of measured irradiance to the clear sky values is used to compute the cloud amount.

Figure 3 shows the cloud transmission in the UVA for various snow fractions and solar zenith angles. When the snow fraction is large the total transmission can be maintained at a relatively high level—even at large optical depth—due to multiple reflection between surface and cloud base.

The total ozone from the Total Ozone Mapping Experiment Spectrometer (TOMS) (solid line) and our surface retrieval (dotted line) is shown in Figure 4 for the austral spring of 1991. The slightly smaller ozone amounts from TOMS could be explained by the coarse spatial resolution used in the satellite retrievals. The disagreement could also be caused by 3-D cloud morphology, which was not included in our cloud transmission model or to an underestimate of the surface albedo due to the coarse spatial resolution of SSM/I.

To evaluate the strength of the cloud effect, consider the ratio of DNA/UVA divided by the same quantity in clear sky conditions. Dividing through by the clear sky ratio suppresses sensitivity to changes in stratospheric ozone. Figure 5 shows the normalized DNA/UVA ratio and the cloud transmission for the austral spring of 1991. The surface fraction of snow/ice estimated from SSM/I is indicated along the x-axis and varies from 95% around day 270 to less than 10% after day 330. The correlation between the normalized ratio and cloud transmission is seen to be strong only for the time interval for which the surface fraction of snow/ice is above 95%.

Figure 6 shows the normalized DNA/UVA ratio versus cloud transmission selected according to surface condition. The sensitivity of the normalized DNA/UVA ratio to the cloud transmission drops significantly for snow/ice fractions less than 95%.

We used SBDART to investigate how the normalized DNA/UVA ratio depends on cloud optical depth for a range of hypothetical surface and atmospheric conditions. The results are shown in Figure 7. The cloud effect virtually disappears when the snow fraction or the amount of tropospheric ozone is set to zero (in all cases the amount of stratospheric ozone is held fixed at 310 DU). The normalized DNA/UVA ratio decreases with increasing cloud optical depth most strongly for high clouds over a 100% snow surface. The strength of the effect does not depend on the spectral variation of the snow albedo. When the snow albedo is fixed at 0.97—a

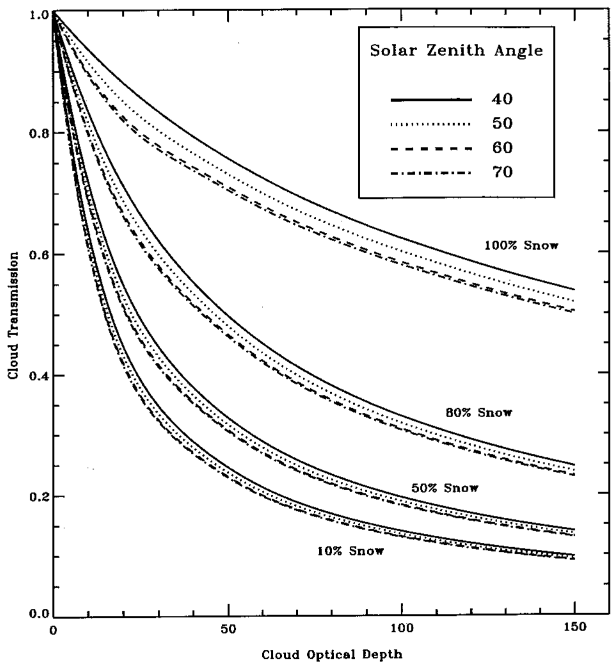


**Figure 3**. Cloud transmission (the ratio of UVA transmission to the clear sky transmission) for various snow fractions and solar zenith angles.

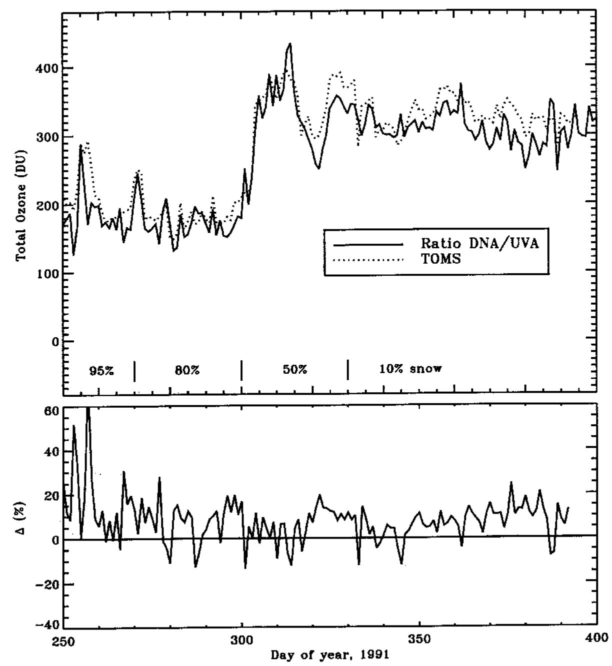


**Figure 4**. Total ozone for the austral spring of 1991. The surface retrieval uses measurements in the "DNA" and UVA bands to simultaneously solve for cloud optical depth and ozone. Some of the difference between the surface and satellite retrievals (lower panel) may be due to 3-D cloud morphology or disparate spatial resolution.

value midway between the pure snow albedos at 300 nm and 350 nm—the reduction is very close to that obtained using the observed spectral albedo of snow.

Evidently clouds over a highly reflective surface amplify the absorption of tropospheric ozone. Figure 8 shows a simplified model of how this can come about. Because snow reflectivity is so large for these UV wavelengths, the photons which do manage to penetrate the cloud layer will undergo multiple reflections between cloud and surface. By summing the infinite series of multiple reflection terms, the net transmission to the surface can be obtained as,

$$T = \frac{T_{clr}\ (1 - A_c)}{1 - A_s\ A_c\ T_{bc}^2} \tag{1}$$

where $A_c$ is cloud albedo, $A_s$ is the surface albedo, $T_{bc}$ is the transmission below cloud layer, $T_{clr}$ is the transmission above cloud layer, and $T_{rlr}$ is the clear sky transmission ($T_{clr} = T_{bc}\ T_{ac}$).

The ratio of transmission in the DNA and UVA band is then given by,

$$\left[\frac{T_{DNA}}{T_{UVA}}\right]\left[\frac{T_{UVA}}{T_{DNA}}\right]_{clear} = \frac{1 - A_s\ A_c}{1 - A_s\ A_c\ T_{bc}^2(DNA)} \tag{2}$$

where we have made the assumption that $T_{bC}$(UVA) is close to one. This formula indicates why the cloud effect is only important over a highly reflective surface. Only when the product of the surface albedo and the cloud albedo is close to one does the value of $T_{bc}$(DNA) become important.

The reduction of the normalized DNA/UVA ratio under clouds also has implications for surface retrievals of total ozone. For surface retrievals at Palmer Station, the current practice (Lubin and Frederick 1990) is to assume the areal coverage of snow/ice is less than 50% and to use the ratio of narrow lines at 300 and 313.5 nm to obtain the ozone amount. However, when snow covered sea ice surrounds the station the effective surface albedo can be well above 90% (Ricchiazzi et al. 1995). In this case, clouds can greatly amplify absorption by tropospheric ozone, causing

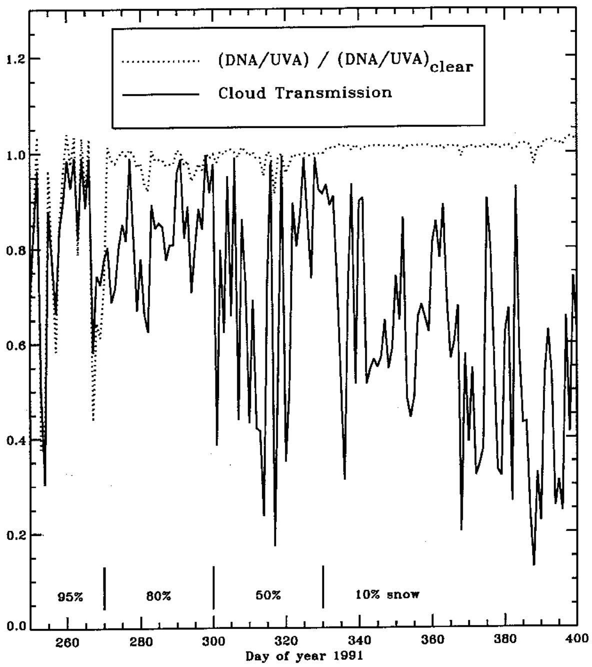


**Figure 5**. Comparison of cloud transmission to the normalized ratio of DNA to UVA irradiance throughout a time period for which the surface conditions changed from 95% ice and snow to less than 10%. The normalized quantity, (DNA/UVA)/ $(\mathrm{DNA/UVA})_{\mathrm{clear}}$, is not sensitive to changes in stratospheric ozone.

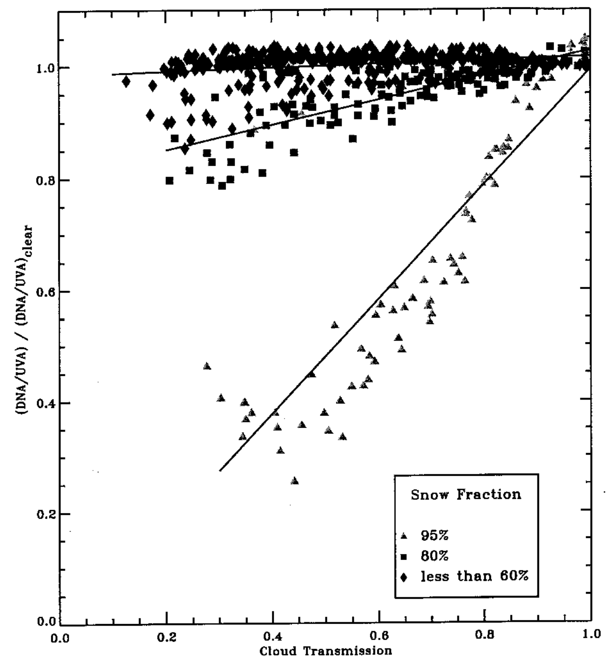


**Figure 6**. Correlation of the normalized DNA/UVA ratio to cloud transmission.

the surface retrievals to overestimate the ozone amount. Figure 9 shows the amount of overestimate for actual ozone amounts of 150, 250 and 350 DU, and for 100% snow surface fraction. The overestimate becomes more serious for higher clouds because of the additional ozone below the cloud.

The analysis presented here indicates that the current procedures used for surface ozone retrieval are only appropriate under clear skies or when the snow fraction is below about 70%. Since cloud cover is a ubiquitous feature of the maritime Antarctic, this limitation implies that current procedures cannot be used during the early parts of the austral spring when the snow/ice cover is widespread. It is during this time that biological production is most vulnerable to damage caused by stratospheric ozone depletion. It is crucial to develop techniques for this period to predict how UVB/UVA responds to the combined effects of clouds, surface condition and tropospheric ozone.

## Summary of Conclusions

- Clouds suppress the DNA/UVA ratio, but the effect is only significant over highly reflective surfaces.
- The strength of the suppression is sensitive to the amount of tropospheric ozone between surface and cloud base.
- Surface based ozone retrievals which ignore the cloud/surface effect may significantly overestimate total ozone.

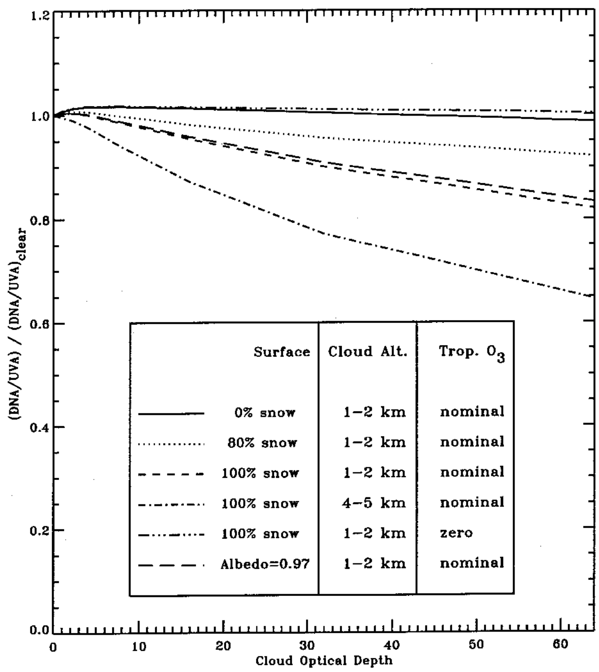


**Figure 7**. Variation of normalized DNA/UVA ratio with cloud optical depth, for various surface conditions, cloud heights, and tropospheric ozone amounts.

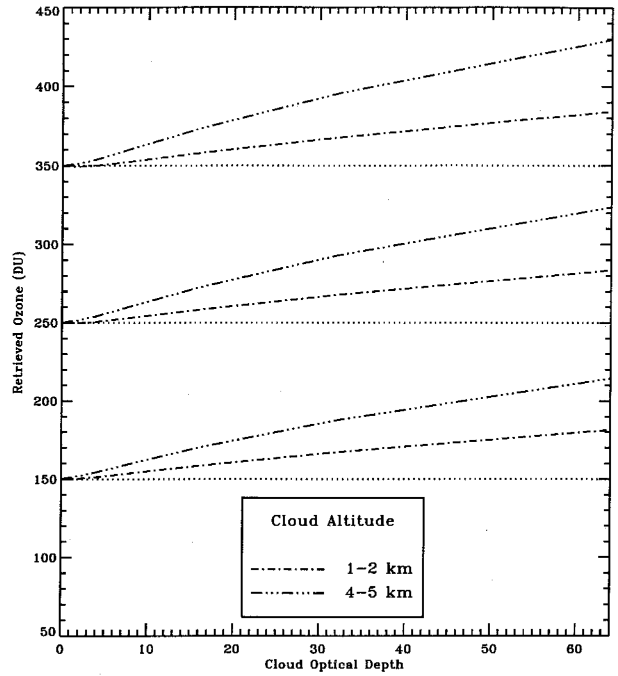


**Figure 8**. Error associated with ozone surface retrievals which ignore cloud/surface interactions. Higher clouds produce greater discrepancy because of the additional ozone between the cloud base and surface.

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