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Enhanced UV penetration due to ozone cross-section changes induced by CO_2 doubling

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Abstract. Models predict that CO_2 doubling in the atmosphere cools the stratosphere by as much as 10°C. We argue that this effect alone, through the temperature dependence of the ozone spectrum, can result in an increase of a few percent in UV-B (280-320 nm) penetration at the Earth's surface. The increase in Erythema-weighted UV radiation is about 1%. Future spectral observations of UV at the surface could distinguish this effect from any result of changes in ozone abundance.

Introduction

The increase of carbon dioxide in the atmosphere has two distinct consequences [Hansen *et al.*, 1984]. On the one hand, temperature increases, by a few degrees C, at the surface and in the troposphere. On the other hand, the stratosphere cools by as much as 10°C. As we shall show, the latter may have a significant impact on the penetration of solar UV radiation to the surface of the Earth.

Since 90% of atmospheric ozone resides in the stratosphere, and its absorption cross sections in the UVB (280 - 320 nm) region are strongly temperature dependent, the cooling effect induced by a CO_2 increase will cause a decrease in the absorption cross sections of ozone in the stratosphere, and hence an increase of solar UV radiation at the surface. In this note, we quantify how cooling due to CO_2 doubling should affect the UV radiation at the surface of the earth, and the biologically effective UV-dose.

In our work the feedbacks on the ozone layer due to temperature change are not considered.

Model

To investigate quantitatively the radiative properties of atmospheric ozone in the UV region, we employ a radiative transfer model consisting of 80 vertical layers from 0 km to 80 km with vertical resolution of 1 km. This model accurately computes multiple scattering using a method described by Michelangeli *et al.* (1992) and it includes the effects of absorption, Rayleigh and aerosol scattering without polarization.

In this model, the temperature-dependent ozone absorption cross section data in the UV region are taken from Malicet *et al.* (1995) with resolution of 0.01 nm at 5 temperatures (218 K, 228 K, 243 K, 273 K, 295 K). Our calculations are performed at the resolution of 0.2 nm. The vertical profile of ozone concentration (Fig. 1b) is taken from a standard model for the tropics [Yang *et al.*, 1991]. The total column ozone is 267.23 DU.

The aerosol vertical profile and the size distribution are taken from Demerjian *et al.* (1980). The maximum radius of this distribution and the complex refractive index of the particles are 0.07μm and 1.5-0.1*i*, respectively. The surface albedo is set to 0.1 [Eck *et al.*, 1987; Jiang and Yung, 1997].

The temperature profile for a recent CO_2 condition is also taken from a standard model for the tropics [Yang *et al.*, 1991], and that for the doubled CO_2 case is from Pitari *et al.* (1992), who predicted temperature changes due to CO_2 doubling by using a three dimensional spectral model of the atmosphere. We adopt a representative tropical profile of temperature change from this model (see Fig. 1). The model predicts a temperature increase of 2.0°C at the surface and 2.5°C in the upper troposphere. In the stratosphere the trend is negative. There is maximum cooling of 10°C around 50 km and 5°C around 30 km, where most of the ozone resides. The results are comparable to those obtained by other groups [Schlesinger and Mitchell, 1985].

Results and Discussion

Figure 2 gives the spectral change in UV transmissions due to CO_2 doubling for solar zenith angles (SZA) 0°, 30° and 60°. As shown in this figure, most of the change is in the UVB region with up to 8% of increase around 280 nm when SZA = 0°, and 10% increase when SZA = 60°. In all the perturbed calculations, the ozone column density remains the same. The changes shown in Figure 2 are solely due to the effect of temperature change on the cross-sections.

It has been shown that larger than normal levels of UV radiation inhibit photosynthesis in marine microflora [Smith and Baker, 1980] and damage DNA in all organisms [Friedberg, 1985]. The biological effect of UV radiation may be conveniently expressed in terms of the effective UV-dose rate defined as the convolution of an action spectrum of the

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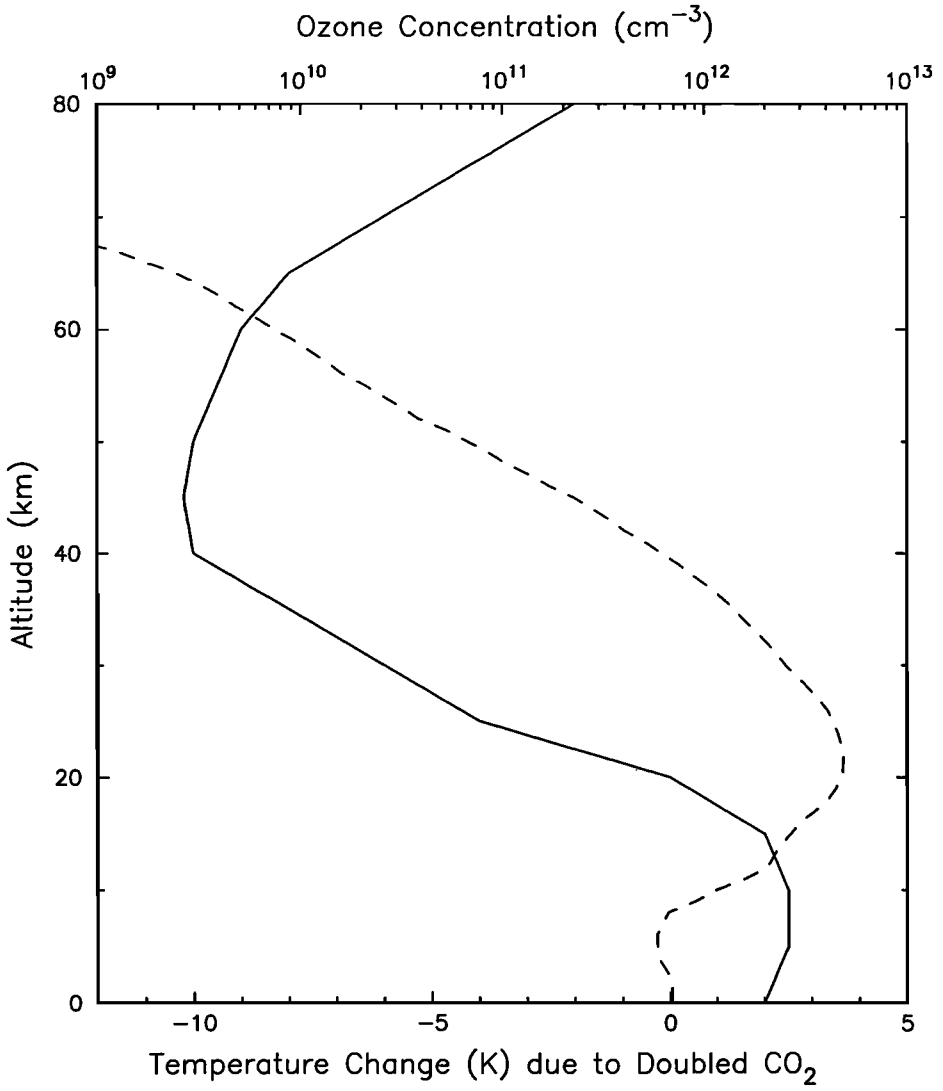

Figure 1. Altitude profiles of temperature change (solid line) and ozone concentrations (dashed line) adopted in the model.

particular biological response with the solar irradiance spectrum in the biosphere [Tsay and Stamnes, 1992; Stamnes, 1993]. Action spectra are empirical wavelength dependent functions that measure the adverse impact of UV radiation on life processes.

Table 1. The Percentage Change of Integrated UV-Dose at the Earth Surface Due to CO_2 Doubling and 1% Column Ozone Reduction

	Solar Zenith Angle (degree)	CO_2 Doubling	1% Column Ozone Reduction
DNA	0	1.04	0.68
	30	1.08	2.31
	60	1.20	2.39
Plant	0	0.72	0.47
	30	0.78	1.71
	60	1.10	2.33
Erythema	0	0.66	0.41
	30	0.67	1.31
	60	0.77	1.35

The UV-dose rate change (280-400 nm) for DNA, Plant and Erythema action spectrum is summarized in Table 1. The changes increase as SZA increases, mainly because of the increased optical path of ozone absorption. The change is larger than 1.0% at SZA 60°, which may have a measurable effect on the biosphere. For comparison, Table 1 also includes the UV-dose rate changes we calculate for 1% reduction in the ozone column density. The UV dosage change induced by CO_2 cooling is equivalent to that caused by 1% reduction in the ozone column. Since efforts to decrease the use of chlorofluorocarbons seem to be ahead of any agreement to reduce the burning of carbon [Houghton *et al.*, 1996], the relative importance of the effect we are describing might be expected to increase in the future.

The comparisons we have shown against 1% ozone decreases serve mainly to illustrate that the effect we are describing need not be negligible. High precision measurements of the spectral characteristics of UV fluxes in the Huggins bands at the Earth's surface in the future could reveal the contribution due to each mechanism.

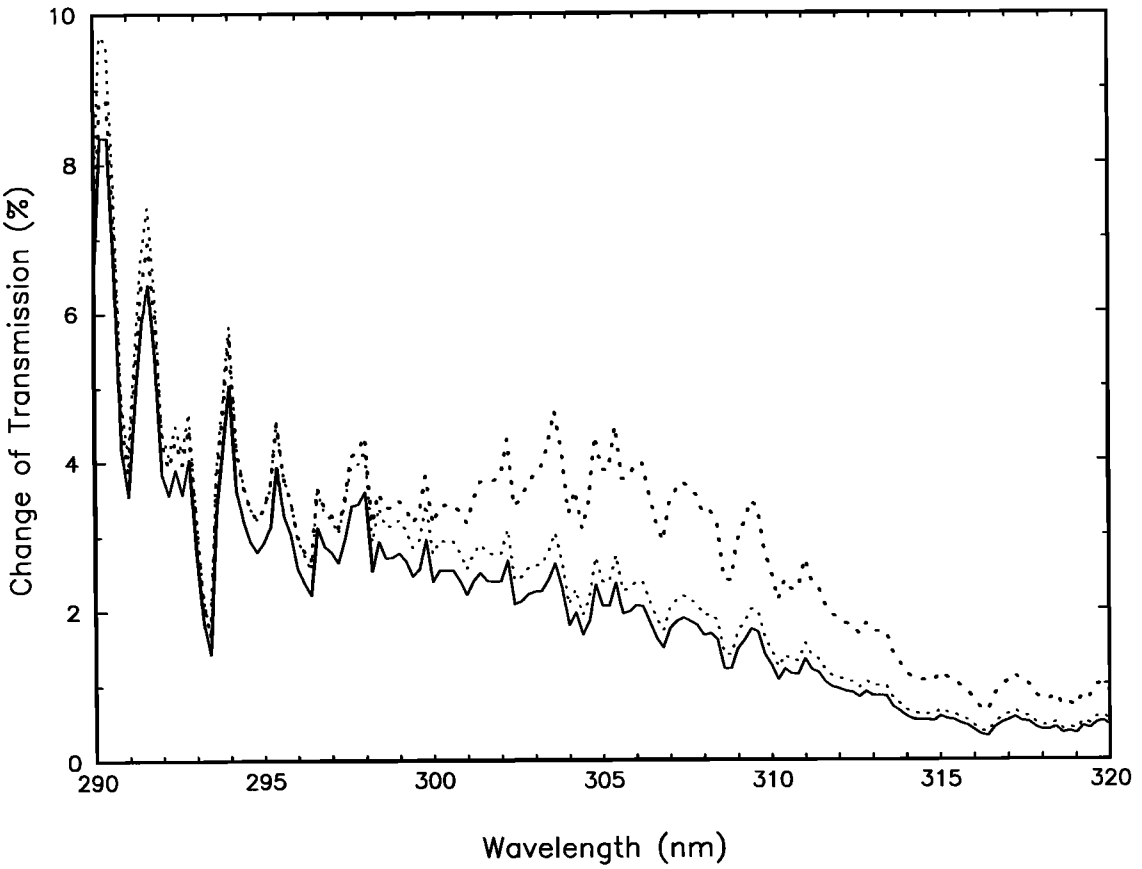

Figure 2. Change of transmission at SZA 0° (solid line), 30° (dotted line) and 60° (dashed line) due to ozone cross-section changes induced by CO_2 doubling.

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