A Note on the Effect of Stratospheric Ozone Fluctuations on Mean Transmitted Ultraviolet

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ABSTRACT

Fluctuations in the atmospheric ozone column may significantly increase mean transmitted ultraviolet radiation at biologically sensitive wavelengths, and increase mean photodissociation rates in the lower stratosphere.

O'Brien (1971) and Donaldson and Hilst (1972) have studied the important retarding effects which inhomogeneities in reacting chemical species may have upon reaction rates. In this note we wish to point out a similar type of effect, namely that fluctuations in stratospheric ozone may lead to an increase in average transmitted ultraviolet radiation. This increase may be significant in calculating photodissociation rates or obtaining the effect of changes in the ozone column on the erythemal response of exposed skin.

Consider first the oxygen photodissociation rate j_2 at a height z in the atmosphere:

$$j_2=\int Q_\lambda \sigma_{O_2,\lambda} \exp[-(\sigma_{O_2,\lambda}N_2+\sigma_{O_3,\lambda}N_3)/\cos\phi]d\lambda. \quad (1)$$

Here λ is the wavelength; Q_λ is the number of photons in the ultraviolet incident at the top of the atmosphere per unit area, per unit time, and per wavelength interval; $\sigma_{O_2,\lambda}$ and $\sigma_{O_3,\lambda}$ are the cross sections for absorption of radiation at wavelength λ by molecular oxygen and ozone, respectively;

$$N_2=\int_z^\infty (O_2)dz \quad \text{and} \quad N_3=\int_z^\infty (O_3)dz$$

are the columns of molecular oxygen and ozone; and ϕ is the solar zenith angle. We do not consider absorbers of ultraviolet other than O_2 and O_3.

If N_3 varies with time, j_2 will also vary; the average value of j_2 will be increased because changes in the exponential in (1) will strongly weight increases in j_2. If the fluctuations in N_3 are normally distributed with mean $\langle N_3\rangle$ (where the angle brackets indicate an average over fluctuations) and variance s_3^2, it is easily calculated that

$$\langle j_2(N_3)\rangle = j_2(\langle N_3\rangle)\left(1+\frac{1}{2j_2(\langle N_3\rangle)}\frac{\partial^2 j_2}{\partial N_3^2}s_3^2\right), \quad (2)$$

where higher order derivatives of j_2 have been neglected.

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Actually a more relevant quantity for many calculations is $\langle J_2 (N_3)\rangle$, where J_2 is the average of j_2 over solar zenith angle. In Table 1 we present sample results [based on the solar fluxes and oxygen and ozone cross sections of Ackerman (1971)] for $\frac{1}{2}J_2^{-1}\partial^2 J_2/\partial N_3^2$, and the corresponding quantity for the ozone photodissociation rate j_3.

The fractional increase in the mean photodissociation rates J_2 and J_3 may be found by multiplying the last two columns in Table 1 by $s_3^2/\langle N_3\rangle^2$, which is the variance of the ozone column measured in units of the mean column. This variance will be most sizeable in the lower stratosphere where transport effects predominate, and may range up to values of 0.1 or more, though smaller values are more typical (Dobson *et al.*, 1927; Craig, 1965; Dütsch, 1969, 1974).

In most ozone models, this effect of fluctuations on photodissociation rates is not taken into account. The latest general circulation models do incorporate them, but are forced to make severe approximations in averaging over the solar angle on taking into account UV absorption by oxygen (Cunnold *et al.*, 1975).

Consider now the biological efficiency of solar ultraviolet radiation for erythema or sunburn, averaged over a day:

$$S=\frac{1}{2\pi}\int_{\cos\phi>0}\int Q_\lambda s_\lambda \exp[-\sigma_{O_3,\lambda}N_3/\cos\phi]d\lambda dt, \qquad (3)$$

where s_λ measures the relative sensitivity of the skin for erythema (Urbach, 1969). Another quantity of concern (see, for example, Bassett *et al.*, 1974), the effect of a change in the mean ozone level on S, is given by $S'=\partial S/\partial N_3$. The effect of fluctuations on S and S' is given by expressions directly analogous to (2). In Table 2 we list values for the quantities $\frac{1}{2}S^{-1}\partial^2 S/\partial N_3^2$ and $\frac{1}{2}S'^{-1}\partial^2 S'/\partial N_3^2$ at selected ozone columns, latitudes, and times of the year.

In summary, we find that fluctuations in the ozone column increase the mean flux of transmitted ultraviolet, and this may lead to increased photodissociation rates, and to a significant increase in the effect of changes in the mean ozone column on transmitted radiation at biologically sensitive wavelengths.

TABLE 1. Sample computations of effects of ozone fluctuations on J_2 and J_3.

Height (km)	N_2 (10^{27} m^{-2})	$\langle N_3\rangle$ (10^{22} m^{-2})	$\frac{1}{2}J_2^{-1}\partial^2 J_2/\partial N_3^2$	$\frac{1}{2}J_3^{-1}\partial^2 J_3/\partial N_3^2$
Equator, equinox				
30	0.53	1.0	0.86	0.48
25	1.13	2.0	1.40	0.36
45°, winter solstice				
30	0.53	0.5	1.25	0.43
30	0.53	1.0	1.78	0.32
30	0.53	2.0	3.73	0.21
25	1.13	1.0	2.24	0.31
25	1.13	2.0	4.07	0.21
25	1.13	3.0	7.23	0.16

TABLE 2. Sample computations of effects of ozone fluctuations on S and S'.

	$\langle N_3\rangle$ (10^{-22} m^2)	$\frac{1}{2}S^{-1}\partial^2 S/\partial N_3^2$	$\frac{1}{2}S'^{-1}\partial^2 S'/\partial N_3^2$
Equinox, 30°N	8.0	2.4	4.2
Summer solstice, 30°N	7.5	2.1	3.9
Equinox, 45°N	9.3	3.0	4.9
Summer solstice, 45°N	8.5	2.4	4.2

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