Solar Ultraviolet Flux below 50 Kilometers

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The available values of the solar flux from 1700 Å to 4000 Å are presented. The penetration of this radiation in the stratosphere is discussed and the role of scattering on direct and global radiation in the troposphere is emphasized.

On présente les valeurs disponibles du flux solaire de 1700 Å à 4000 Å. On discute de la pénétration de cette radiation dans la stratosphère et on met en relief le rôle de la diffraction sur la radiation directe et globale au niveau de la troposphère.

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Introduction

The solar ultraviolet radiation penetrating into the atmosphere below 50 km has various actions. It dissociates molecular oxygen in the 2000 Å atmospheric window leading to the formation of ozone; it photodissociates minor constituents and has biological actions at ground level. The flux in the absence of absorption is a boundary condition of all the photochemical processes. Its stability as a function of time and solar conditions must also be known. Its penetration is controlled by various factors whose complexity increases with the atmospheric density. In the upper stratosphere the absorption is due to molecular processes related to the electronic spectra of oxygen and ozone. In the lower stratosphere and in the troposphere, Rayleigh scattering and interaction with aerosols also contribute to the filtering of the solar ultraviolet flux.

These various aspects will be summarized here. The choice between different sets of values will be discussed with emphasis on the practical aspects leading to the definition of input data for photochemical evaluations.

The Unabsorbed Flux

The ultraviolet solar radiation of wavelengths larger than 1800 Å is pertinent to the present subject. In the 2000 Å atmospheric window the solar u.v. can be observed without too much attenuation from stratospheric balloon altitude (1). Balloon measurements (1) have shown a different intensity distribution versus wavelength than previously deduced values (2) shortward of 2100 Å. The flux increases by a factor of 7 from 2000 to 2100 Å. In addition, recent rocket flights (3) have yielded fluxes at 1700 Å in agreement with the lowest values obtained between 1400 Å and 1900 Å (4). There should be an intensity change between 1950 Å and 1900 Å. Such a feature appears on high resolution rocket spectrograms obtained in 1957 (5). This feature is also supported by our balloon measurements below 1950 Å where, in spite of the low intensity and the already large absorption by oxygen, the data have been reduced taking into account the absorption in the Schumann–Runge bands (6). This latter spectral region is important for the photodissociation of nitric oxide in the δ bands (7), as shown in Figs. 1 and 2, where the δ bands of NO, the Schumann–Runge bands of O_2, and the solar flux are simultaneously shown. Most of the dissociation of O_2 of importance for the formation of O_3 takes place about 2000 Å (10) in the atmospheric optical window. Recent rocket data obtained by Broadfoot (8) are in agreement at wavelengths larger than 2100 Å with the data of Detwiler *et al.* (2)[1] even if these could have been based on underestimated carbon arc irradiance at short wavelengths (9).

It has been suggested by Brewer and Wilson (11) that the values published by Detwiler *et al.* (2) should be multiplied from 1800 Å to 2400 Å by 0.36. The mutual agreement shown in Table 1

[1]The data obtained by Broadfoot (8) is in agreement with the Detwiler *et al.* data (2), as published by Brinkman, Barth, and Green (Jet Propulsion Laboratory Tech. Rep. 32–951, 1966), not with the original report of the data (Table 1, ref. 2). There are substantial differences in the solar fluxes in the range $\lambda >$ 1700–2100 Å as reported by Detwiler *et al.* (2) and Brinkman *et al.* for which no adequate reason has been given.

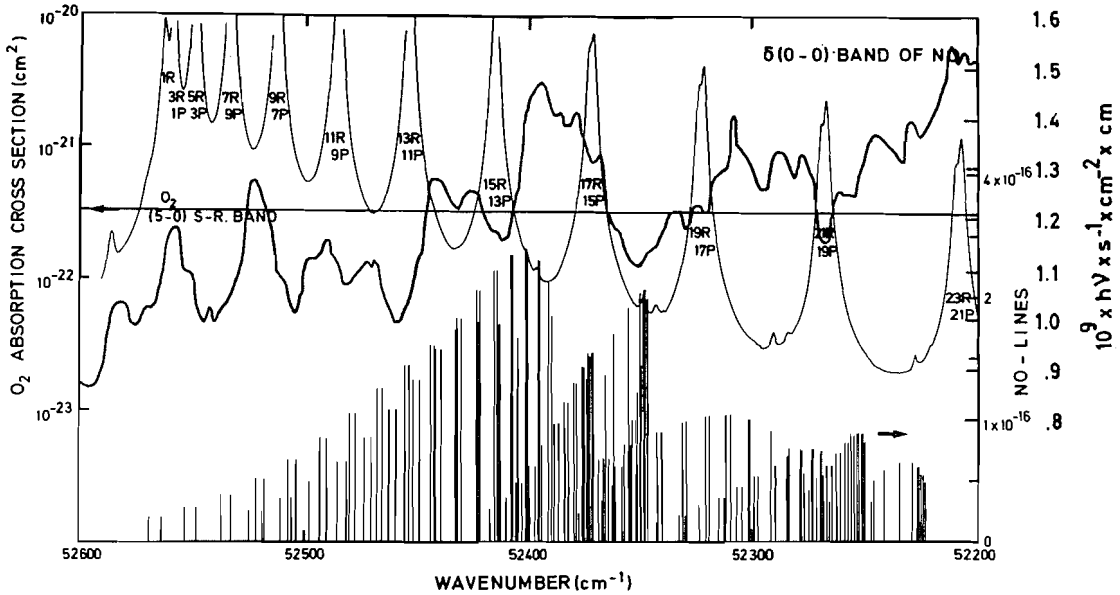

FIG. 1. Distribution of intensity of the NO lines in the δ(O–O) band and absorption cross section of O_2 *vs.* wavenumber after Cieslik and Nicolet (7). The solar flux taken from McAllister (5) and adapted for a solar black body temperature of 4660 °K is also shown. The choice of the average value of the flux represented by the horizontal line would in this case lead to an overestimate of the photodissociation of NO of which the dissociation limit is at 52 400 cm^{-1}.

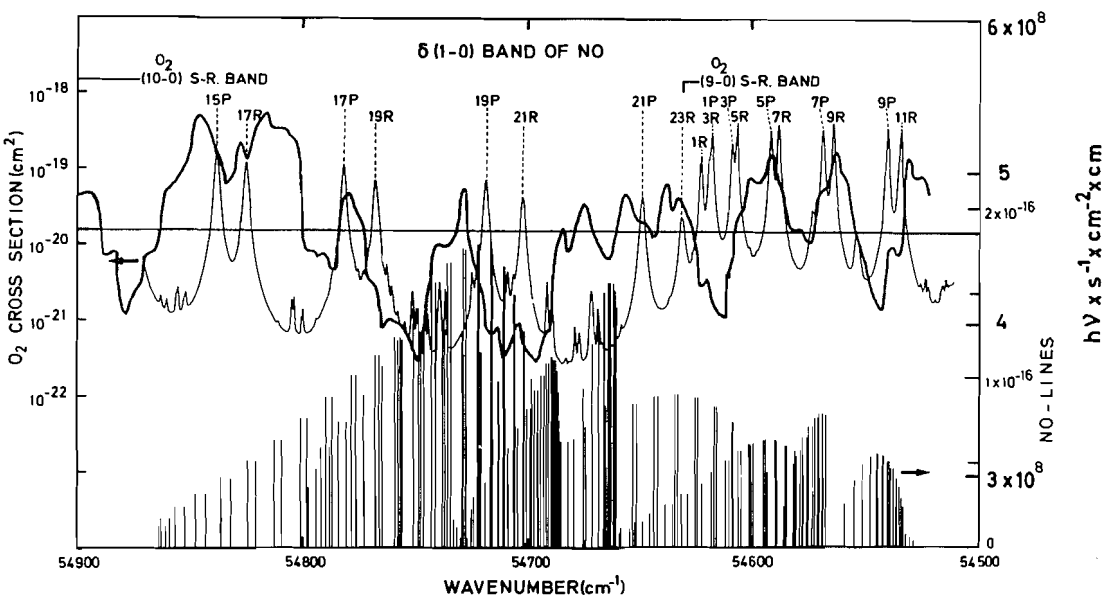

FIG. 2. Distribution of intensity of the NO lines in the δ(1–O) band and absorption cross section of O_2 *vs.* wavenumber after Cieslik and Nicolet (7). The solar flux taken from McAllister (5) and adapted for a solar black body temperature of 4580 °K is also shown. The choice of the average value represented by the horizontal line does not appear to introduce a large error in the photodissociation of NO even if an exact evaluation requires the use of the fine structure of the solar flux.

TABLE 1. Comparison between the most recent values of solar flux of interest to stratospheric ozone formation in the range of wavelength where they overlap

Wavelength interval (Å)	Flux (8) × 10^{-12} (hv cm^{-2} s^{-1})	Flux (12) × 10^{-12} (hv cm^{-2} s^{-1})	Ratio between values from ref. 8 and ref. 12
2105–2128	10.4	9.42	1.10
2128–2150	11.2	10.6	1.05
2150–2174	11.9	13.4	0.89
2174–2198	15.0	13.2	1.14
2198–2222	15.0	17.3	0.87
2222–2247	20.6	18.0	1.14
2247–2273	16.8	18.2	0.92

between more recent values (8, 12) where they overlap implies that the proposed reduction can hardly be accepted. Brewer and Wilson, using the equivalent of a broad band filter, have made the assumption that the change of sensitivity with wavelength of their detector had no influence on their measurements. They have used an intensity distribution of the solar radiation without taking into account the 2085 Å discontinuity and their ozone concentration above 30 km appears to be low. All these factors would have a tendency to bring their computed and observed integrated fluxes into better agreement.

At wavelengths larger than 2700 Å the ozone absorption decreases so much that the solar radiation reaches lower and lower altitudes in the stratosphere where the dissociation of ozone leads to significant (13) steady concentrations of excited oxygen atoms. These contribute to the transformation of molecules having their source at ground level, such as CH_4 and N_2O, into other species that have, in turn, their source in the stratosphere itself. Between 2700 Å and 3500 Å determinations of the solar flux with relatively high spectral resolution have been performed (8, 14); the quality of these determinations has been discussed by Broadfoot (8). These values are in close agreement with the low resolution data published by Tousey (15) in 1963 which are 10% higher on the average than those of Arvesen *et al.* (14).

The solar u.v. flux has been measured over long periods of time from 1150 Å to 3500 Å by means of broad band detectors from Nimbus 3 and 4 satellites. The data have been reported by Heath (16). It has been concluded that the variability of the flux appears particularly for the radiation originating from the solar chromosphere, while it reaches the limits of detectability in the case of the photospheric flux. Some effect, of the order of a few percent, can be expected in the transition region below 2100 Å relevant to the stratospheric photochemistry. It should affect the dissociation rate of O_2 and of NO, for example. The magnitude of the possible resulting change in ozone *vs.* time would be very small and most probably undetectable in the actual measurements.

The Atmospheric Attenuation

The attenuation of the solar u.v. in the 2000 Å atmospheric optical window can be represented by the molecular absorptions due to O_2 and O_3 (12, 17). This has an impact on the photodissociation of these latter constituents themselves and also on minor constituents. The rapidly changing absorption cross section of O_2 with wavelength and temperature in the Schumann–Runge bands is such that the photodissociation by the solar u.v. shortward of 2000 Å is specific to each set of aeronomic conditions, such as solar zenith angle, temperature vertical profile, ozone vertical distribution, and absorption spectrum of the species whose photodissociation is considered. Typical conditions have been evaluated (18, 19, 7, 20) for H_2O, NO, and HNO_3.

On the long wavelength side of the Hartley bands of ozone the attenuation of solar radiation in the stratosphere depends on ozone itself. The role of aerosols and air has to be added in the troposphere. As already pointed out by Larsen (21) the ozone effect can be separated from the other two since it mostly takes place well above the tropopause. Considerable work has been performed on scattering of solar radiation in the atmosphere with emphasis on polarization effects. Most of the considerations have been

given to the visible region of the spectrum and less work has been devoted to the ultraviolet with special concern about the influence of scattering on the operation of the Dobson spectrophotometer and on the topside ozone sounding from satellites. The solution of aeronomic problems of the troposphere requires the knowledge of the total number, by volume, of photons available for photochemical reactions. A theoretical evaluation requires taking into account the transparency of the atmosphere to evaluate the direct solar radiation and integration of the radiation scattered by the atmosphere over all directions. To evaluate the importance of this at ground level a simple model can be constructed where half of the radiation scattered is assumed to reach the surface. For this purpose an average attenuation due to aerosols can be taken from Elterman (22) and a scattering cross section for air can be used (23, 24). The various contributions are shown in Fig. 3, where the resulting transmission for the radiation coming directly from the sun and for the global radiation (sky added) are represented. The model is for a particular altitude, a zenith angle of 40°, and a total ozone amount of 0.250 cm, since experimental data are available for comparison. They have been obtained by Bener at the observatory of Davos.

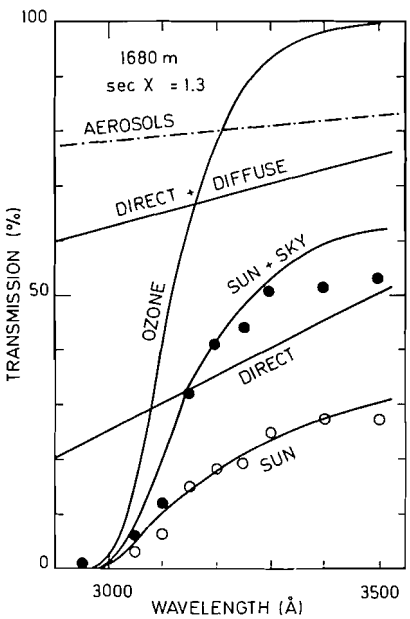

FIG. 3. Atmospheric optical transmission at an altitude of 1680 m, for a solar zenith angle of 40° and a total vertical ozone reduced thickness of 0.25 cm. The ozone contribution is represented by the line marked "ozone." The dot and dash line marked "aerosols" represents their contribution for an average amount (22), The transmission computed from the total air column and the scattering cross section (24) is represented by the line marked "direct," while an apparent transmission evaluated by assuming that one-half the scattered light reaches the ground is represented by the line marked "direct + diffuse." The curve "sun" indicates the resulting transmission for the direct solar radiation and can be compared to the values deduced from Bener's work (25) (●). The curve "sun + sky" shows the resulting transmission if the scattering component "direct + diffuse" is used and can be compared to the values deduced from Bener's work (25) (○).

The measured spectral distributions of global and sky u.v. fluxes received per unit area can be compared with the solar flux in absence of absorption (12) to compute the transmission of direct radiation and the apparent transmission of global radiation. The results are represented by the points in Fig. 3. They indicate that a very crude model gives a satisfactory representation of reality. In the 3000 Å region the flux received per unit surface from the sun is of the same order as the flux received from the sky so that computations neglecting the latter underestimate the photochemical action by a factor of about 2. In addition, the ozone layer high in the stratosphere is illuminated from below by the integrated scattered radiation coming from the troposphere.

Conclusions

Little attention has been paid to the influence of scattered radiation on the actinic effects of solar u.v. Even if a full treatment of the subject implying complex radiation transfer mechanisms is not required these phenomena should be kept in mind. The accuracy reached now in the determination of the absolute solar flux cannot be improved if the dimension of the efforts to measure it is not increased by a large factor. However, higher spectral resolution and higher accuracy of the measurements can still improve the actual situation.

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