SOLAR ULTRAVIOLET RADIATION WITHIN THE MIDDLE ATMOSPHERE

Paul C. Simon and Didier Gillotay
Institut d'Aéronomie Spatiale de Belgique
Avenue Circulaire 3, B-1180 BRUXELLES, BELGIUM

ABSTRACT

Ultraviolet solar radiation budget of the middle atmosphere depends upon extraterrestrial solar irradiance and its variations, its absorption by atmospheric constituents, its extinction by molecular and aerosol scattering, the scattering by the atmosphere and the reflection by the Earth's surface. This work briefly reviews and discusses the recent observations of solar ultraviolet irradiance above the Lyman α wavelength during the declining phase of solar cycle 21. Despite major improvements in the quoted uncertainties, important discrepancies (up to 40%) between those observations are still present below 200 nm, the agreement between the two Space Shuttle observations is very good, giving ultraviolet irradiance values with accuracies between 3.5 and 5.2%. Variabilities related to the 27-day rotation period and the 11-year cycle have also been revised on the basis of the most recent analysis of SBUV and SME observations.

1. INTRODUCTION

The solar electromagnetic radiation is the primary source of energy for the terrestrial environment. The largest fractions of energy associated with the solar spectrum is situated in the visible. The ultraviolet domain for wavelengths shorter than 320 nm represents only a small fraction (2 percent) of the total incident flux. This spectral range is of fundamental importance for chemical, dynamical and radiative processes in the middle atmosphere.

Solar Lyman α and ultraviolet radiation of wavelengths larger than 180 nm are absorbed in the mesosphere and in the stratosphere. The Lyman α solar chromospheric line initiates photodissociation processes in the B-region and the photodissociation, for instance, of water vapor in the mesosphere, controlling the ozone budget in the mesosphere through the production of hydroxyl radicals.

Ozone, which protects the biosphere from harmful solar ultraviolet radiation, is produced in the upper stratosphere by photodissociation of molecular oxygen by radiation of wavelengths shorter than 242 nm. It is itself photodissociated by solar radiation in the visible range and in the ultraviolet. Absorption of ultraviolet radiation of wavelengths larger than 200 nm by stratospheric ozone is responsible for the stratospheric heating. Below that wavelength, the absorption by molecular oxygen becomes predominant.

Because of the complexity of the atmospheric processes and the strong interplay and feedback between chemical composition and radiative budget, atmospheric and climate studies should include observations of visible and ultraviolet solar radiation and its variability, in close relation with the atmospheric constituents which control the penetration of solar radiation and the transfer of the outgoing thermal radiation. The ozone molecule is a key minor constituent for the stratosphere and the mesosphere. It provides the main heat source through the absorption of solar ultraviolet radiation and thus determines to a great extent the temperature profile in the stratosphere and the general circulation. Ozone therefore couples the stratosphere and the tropospheric climate through complex processes involving radiative, chemical and dynamic effects. The study of solar variability with respect to anthropogenic perturbations is of crucial importance to distinguish the impact of the various perturbations affecting the terrestrial environment in the future.

The purpose of this work is to provide a critical analysis of the recent observations of solar ultraviolet irradiance above Lyman α performed during the declining phase of solar cycle 21. A more detailed analysis of the solar variabilities is published elsewhere (Simon, 1988). The reader has to refer to previous works for solar ultraviolet solar irradiances observations performed during solar cycle 20 and the ascending phase of the solar cycle 21 (e.g. Simon, 1981; Simon and Brasseur, 1983, Lean, 1987).

2. THE LYMAN α EMISSION LINE

Since the Atmospheric Explorer E (AE-E) time series obtained during the rising phase of solar cycle 21 for which important controversy has been reported (e.g. Bossy, 1983), the only continuous observations of this solar emission line have been performed by the Solar Mesosphere Explorer (SME) launched in October 1981. The latter measurements ranging from 115 to 300 nm have been normalized on the observation obtained with a rocket flight made on May 17, 1982 (Mount and Rottman, 1983) and calibrated against the Synchrotron Users Radiation Facility (SURF) at NBS. The SME results give a maximum value of the order of $4 \times 10^{11}$ photons. s$^{-1}$.cm$^{-2}$ at the beginning of 1982 and minimum values around $2.5 \times 10^{10}$ photons. s$^{-1}$.cm$^{-2}$ in 1986 (Rottman, 1988).

Besides the SME observations, several snapshot measurements including rockets and one space shuttle flight have been performed up to 1985. They are summarized in Table 1. The Solar
Ultraviolet Spectral Irradiance Monitor (SUSIM) observation (VanHoosier and Brueckner, 1987) performed during the Spacelab 2 mission in August 1985, during the minimum of solar activity between solar cycle 21 and 22, gives a value of $3.8 \times 10^4$ photons $s^{-1} cm^2$ in contradiction with the SME minimum values obtained at the same time. This important discrepancy cannot be explained in terms of differences in radiometric scales because both experiment calibrations are traceable to the SURF.

Nevertheless the consistency of the SME time series favors its minimum value and a solar cycle variation less than a factor of 2 at wavelengths. The measurements obtained during the solar cycle 21 are of differences in radiometric scales because both experiment calibrations are traceable to the Lyman Q.

This spectral range has been extensively studied because it is much less affected by sensitivity drifts observed for the SME spectrometer. If the agreement between the two satellites during the overlapping period of time is very good for the major rotation modulation on August 1982, the average during the declining phase of the solar cycle shows some appreciable differences beyond 240 nm where SME data are less noisy than those of SME and below 190 nm where SME data give 27-day variations higher than SME data, especially at the Si II lines lying in the 180-182 nm interval. Figures 4 and 5 present a FFT analysis of the 27-day variations on both time series between 160 and 300 nm.

5. SOLAR ULTRAVIOLET VARIATIONS

The ultraviolet range of the solar electromagnetic spectrum is characterized by its temporal variations which directly affect the atmosphere. Two time scales are generally considered in relation with atmospheric studies: the 11-year activity cycle and the 27-day rotation period of the Sun. Despite of considerable effort during the last solar cycle, the amplitude of solar variation associated with its 11-year activity cycle is still uncertain. The Solar Backscatter Ultraviolet (SBUV) spectrometer data were analysed by Heath and Schlesinger (1986); they deduced a long-term variability from an empirical relation based on temporal variations of ratios between core and wing irradiances of the Mg II lines at 280 nm. Their variations are not fully confirmed by the SME results obtained since 1982 which lead to lower values in the overlapping wavelength range (175-300 nm). On the other hand, a solar cycle variation of a factor of 2 at Lyman α and around 150 nm was proposed on the basis of the comparison deduced from the rocket observations made during the maximum of solar activity, namely in June 1979 and July 1980 (Mount et al., 1980; Mount and Rottman, 1983) and those performed at solar minimum (Rottman, 1981). These values are now totally contradicted by recent analysis of SME data, leading to variations of the order of 15 percent around 150 nm and of 5 percent between 190 and 210 nm.

The 27-day solar rotation modulation has been well documented with the SBUV satellite and the SME, data base. This short-term variation has been more extensively studied because it is much less affected by sensitivity drifts observed for the SBUV spectrometer. If the agreement between the two satellites during the overlapping period of time is very good for the major rotation modulation on August 1982, the average during the declining phase of the solar cycle shows some appreciable differences beyond 240 nm where SME data are less noisy than those of SME and below 190 nm where SME data give 27-day variations higher than SME data, especially at the Si II lines lying in the 180-182 nm interval. Figures 4 and 5 present a FFT analysis of the 27-day variations on both time series between 160 and 300 nm.

6. CONCLUSIONS

In spite of major improvements in calibration procedures, important discrepancies persist between recent solar ultraviolet irradiance measurements
mainly below 200 nm. This fact could be due to experimental difficulties encountered in that spectral range. Some basic irradiance figures like the minimum values of Lyman a need to be confirmed by new measurements during the current cycle.

If the 27-day modulation is well documented with the SME and the SBUV observations performed during the solar cycle 21, the long-term variations associated with the solar activity cycle need further studies. The preliminary SME values of 15% around 150-160 nm and of 5% at 205 nm urge new observations having a precision of 1% over a half cycle in order to provide accurate figures in relation with the ozone perturbations in the stratosphere and their climate impact. The strong variations in the 27-day modulations during the last solar cycle also emphasized the need of continuous monitoring of short-term variabilities for which their amplitudes could be as high as the solar cycle variation.

REFERENCES


Figure 1. Comparison of solar ultraviolet irradiance integrated over 1 nm between 150 and 200 nm. The solid curve represents the average between 4 rocket observations (Mount and Rottman, 1983; 1985; Mentall and Williams, 1988) performed between May 1982 and December 1984. The dashed curve represents the SUSIM data reported by Vanhoosier and Brueckner (1987) from the Spacelab 2 mission in August 1985.

Figure 2. Comparison of the solar ultraviolet irradiances between 190 and 240 nm. The solid curve (SL 1) represents the data published by Labs et al. (1987) and the dashed curve (SL 2) the data reported by VanHoosier and Brueckner (1987) integrated over 1 nm intervals.
### Table 1: Snapshot observations of the solar H I Lyman-α emission line

<table>
<thead>
<tr>
<th>Date</th>
<th>Irradiance</th>
<th>Ratio flux (104 cm^-2 at 1 AU)</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec. 13, 1972 a</td>
<td>3.00</td>
<td>111</td>
<td>± 25%</td>
</tr>
<tr>
<td>Aug. 30, 1973 a</td>
<td>2.02</td>
<td>101</td>
<td>± 20%</td>
</tr>
<tr>
<td>Nov. 01, 1973 a</td>
<td>1.14</td>
<td>90</td>
<td>± 30%</td>
</tr>
<tr>
<td>Apr. 25, 1974 a</td>
<td>2.51</td>
<td>74</td>
<td>± 30%</td>
</tr>
<tr>
<td>Jul. 28, 1975 a</td>
<td>2.20</td>
<td>76</td>
<td>± 25%</td>
</tr>
<tr>
<td>Feb. 16, 1976 a</td>
<td>1.70</td>
<td>70</td>
<td>± 25%</td>
</tr>
<tr>
<td>Mar. 09, 1977 a</td>
<td>4.28</td>
<td>80</td>
<td>± 10%</td>
</tr>
<tr>
<td>Jun. 09, 1979 a</td>
<td>4.98</td>
<td>210</td>
<td>± 12%</td>
</tr>
<tr>
<td>Jul. 15, 1980 a</td>
<td>5.50</td>
<td>210</td>
<td>± 6%</td>
</tr>
<tr>
<td>May 17, 1982 a</td>
<td>3.24</td>
<td>142</td>
<td>± 5%</td>
</tr>
<tr>
<td>Jan. 12, 1983 a</td>
<td>3.01</td>
<td>155</td>
<td>± 10%</td>
</tr>
<tr>
<td>Jul. 25, 1983 a</td>
<td>2.69</td>
<td>127</td>
<td>± 6%</td>
</tr>
<tr>
<td>Aug. 03, 1983 a</td>
<td>3.70</td>
<td>78</td>
<td>± 1%</td>
</tr>
</tbody>
</table>

References:

- Berruyer and Higgin (1977)
- Begg and Higgin (1981)
- Mount and Bettman (1985)
- Weidinger and Brecher (1987), SUREM, Spacelab 2

### Table 2: Integrated solar irradiance values between 150 and 180 nm. All measurements have been obtained from rocket flights except the last in August 1985 made during the Spacelab 2 mission.

<table>
<thead>
<tr>
<th>Date</th>
<th>Ratio flux at 1 AU (10.7 cm)</th>
<th>Irradiance 150-160 nm 10^10 W/m^2 cm^2</th>
<th>Accuracy</th>
<th>Reference</th>
<th>Wavelength range of instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov. 16, 1976</td>
<td>129</td>
<td>1.30</td>
<td>± 8</td>
<td>Mount et al. (1980)</td>
<td>150-185</td>
</tr>
<tr>
<td>Jun. 05, 1979</td>
<td>230</td>
<td>2.17</td>
<td>± 12</td>
<td>Mount et al. (1980)</td>
<td>120-255</td>
</tr>
<tr>
<td>May 22, 1980</td>
<td>277</td>
<td>1.40</td>
<td>± 13</td>
<td>Mount et al. (1980)</td>
<td>150-185</td>
</tr>
<tr>
<td>Jul. 15, 1980</td>
<td>218</td>
<td>2.27</td>
<td>± 13</td>
<td>Mount and Bettman (1985)</td>
<td>120-310</td>
</tr>
<tr>
<td>May 17, 1982</td>
<td>142</td>
<td>1.14</td>
<td>± 8</td>
<td>Mount and Bettman (1985)</td>
<td>115-317</td>
</tr>
<tr>
<td>Jul. 25, 1983</td>
<td>137</td>
<td>1.09</td>
<td>± 8</td>
<td>Mount and Bettman (1985)</td>
<td>115-317</td>
</tr>
<tr>
<td>Dec. 10, 1984</td>
<td>76</td>
<td>1.06</td>
<td>± 3</td>
<td>Mount and Williams (1988)</td>
<td>150-342</td>
</tr>
<tr>
<td>Aug. 03, 1985</td>
<td>79</td>
<td>1.45</td>
<td>± 3.5</td>
<td>Van Hoosier and Breyer (1987)</td>
<td>120-400</td>
</tr>
</tbody>
</table>

### Figure 3
Comparison of 10 nm spectral averages of solar irradiances measurements between 200 and 350 nm with the Spacelab 1 results (SL 1).

**SOLAR UV IRRADIANCE COMPARISON**

- Mount & Bettman / SL1 (1983-86)
- Mount & Williams / SL1
- Von Hoosier & Brecher / SL1
- Mount et al. / SL1
- Hertel & Larson / SL1

**Wavelength (nm)**

### Figure 4
Comparison of 27-day variation deduced from SME and SBUV observations as a function of wavelength, for a major variation on August 11, 1982.

**SME & SBUV 27-d Variation (Aug.11, 1982)**

- SME
- SBUV

### Figure 5
Comparison of 27-day variation averaged over 1982, 1983 and 1984, deduced from SME and SBUV observations, as a function of wavelength.


- SME
- SBUV