BALLOON MEASUREMENTS OF SOLAR FLUXES BETWEEN 1960 Å AND 2300 Å

P. SIMON
Institut d'Aéronomie Spatiale de Belgique
Brussels, Belgium

ABSTRACT: New observational data in the 1960 - 2300 Å wavelength range have been obtained by means of a balloon-borne spectrometer. Ultraviolet spectra for different zenith angles were recorded with an equivalent slit width of 6 Å. Extrapolation to zero air mass leads to extraterrestrial solar fluxes lower than the values measured previously. The present results give an apparent blackbody temperature of the sun on the order of 4700°K at 2000 Å.

INTRODUCTION

From the point of view of aeronomy, knowledge of the spectral distribution of the ultraviolet solar fluxes reaching the atmosphere is fundamental to determining the photodissociation rates of atmospheric constituents. For instance, in the stratosphere, solar radiation in the wavelength range from 1800 to 2400 Å photodissociates O_2 to form O_3. Minor constituents such as N_2O, HNO_3, and H_2O_2 are also photodissociated in that wavelength range (see, for example, Nicolet (1972, 1973)); the most recent measurements of solar flux for these constituents are those reported by Ackerman et al. (1971) and by Broadfoot (1972). The data obtained at wavelengths shorter than 1880 Å by Parkinson and Reeves (1969), and confirmed at 1700 Å by recent rocket observations (Ackerman and Simon, 1973; Rottman, 1973) and by satellite experiments (Heath, 1973), show the need for new determinations in the 2000-Å atmospheric window.

This paper reports new measurements of absolute ultraviolet solar fluxes between 1960 and 2300 Å, obtained by means of a balloon-borne spectrometer integrated into a sun-pointing gondola.

INSTRUMENTATION

The instrument is a modified version of the spectrometer used aboard rockets by Ackerman and Simon (1973). A coarse-ground quartz window, used as a diffuser, was placed in front of the entrance slit to integrate the radiation over the whole solar disk. Spectral scanning was achieved by rotation of a 26 × 26 mm plane grating (Bausch and Lomb 35-53-04-020) ruled at 1200 grooves per mm and blazed at 2000 Å. The diffracted light was received by a solar-blind photomultiplier (EMR 542 P-09-18) with a RbTe photocathode. The slit width of the spectrometer was equivalent to a triangular slit function with a full width at half maximum of 6 Å. The analog output signal was telemetered to the ground after measurement and amplification by a solid-state electrometer. The flight instrument was aligned with fine sun sensors which pointed the balloon gondola at the sun to better than 30 arcseconds. The instrument alignment accuracy was on the order of 5 arcminutes. (A more detailed description is given in Simon (1974).)

The absolute calibration of the spectrometer is referenced to the 1956 International Pyrheliometric Scale. Using a Reeder thermopile as a transfer standard, the irradiance of a low-pressure mercury lamp was measured at 2537 Å. The spectrometer was directly and absolutely calibrated against this lamp before and after each flight. The relative sensitivity curve of the spectrometer was determined by comparison with a sodium-salicylate-coated photomultiplier, using a monochromatic beam emerging from a McPherson 30-cm-focal-length monochromator (model 218).

An electroless discharge lamp filled with $SiCl_4$ (emitting silicon atomic lines in the 1800-2600 Å wavelength range) and a deuterium lamp were used as light sources. The final accuracy of the flight-instrument calibration is estimated to be ± 10%.

The resulting absolute sensitivity curve of the instrument is shown in Figure 1.

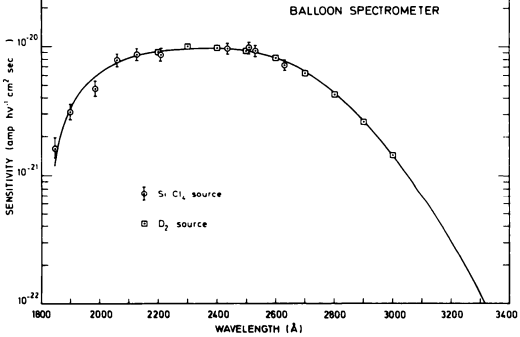

Figure 1. Absolute sensitivity curve of the flight instrument versus wavelength.

OBSERVATIONS AND RESULTS

The two flights were carried out on September 23, 1972 and May 16, 1973, at Aire sur l'Adour in France. On the first flight, the balloon (Raven, 3 X 10^5 m^3) reached an altitude of 41.5 km. The main purpose of this flight was the measurement of the stratospheric absorption of the solar radiation (Simon, 1974), so this experiment was performed at large solar zenith angles. The observation period extended from 1630 to 1840 GMT. Ultraviolet spectra between 1900 and 2300 Å were obtained for zenith angles increasing from 78° to 88°.

On the second flight, the balloon (Winzen, 3 X 10^5 m^3) reached an altitude of 39 km. In this case, the main purpose of the flight was to determine the ultraviolet solar fluxes, so measurements were made at relatively smaller solar zenith angles. Spectra were recorded from 1600 to 1722 GMT. The corresponding zenith angles were 54° and 70°. Figure 2 shows one of the recorded spectra.

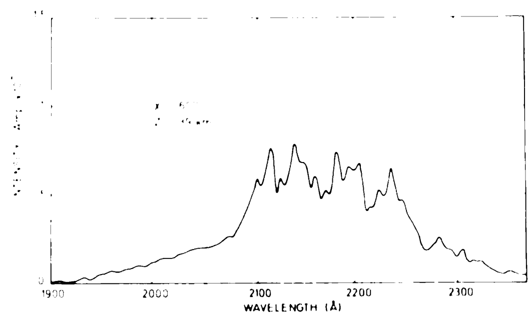

Figure 2. Stratospheric solar spectrum recorded during the second flight from 1900 Å to 2400 Å, obtained by means of the balloon-borne spectrometer, for a solar zenith angle of 60° and an altitude of 39 km.

The classical Langley method was used to determine the optical depth and the extraterrestrial solar fluxes. Some examples of extrapolation to zero air mass are given in Figure 3.

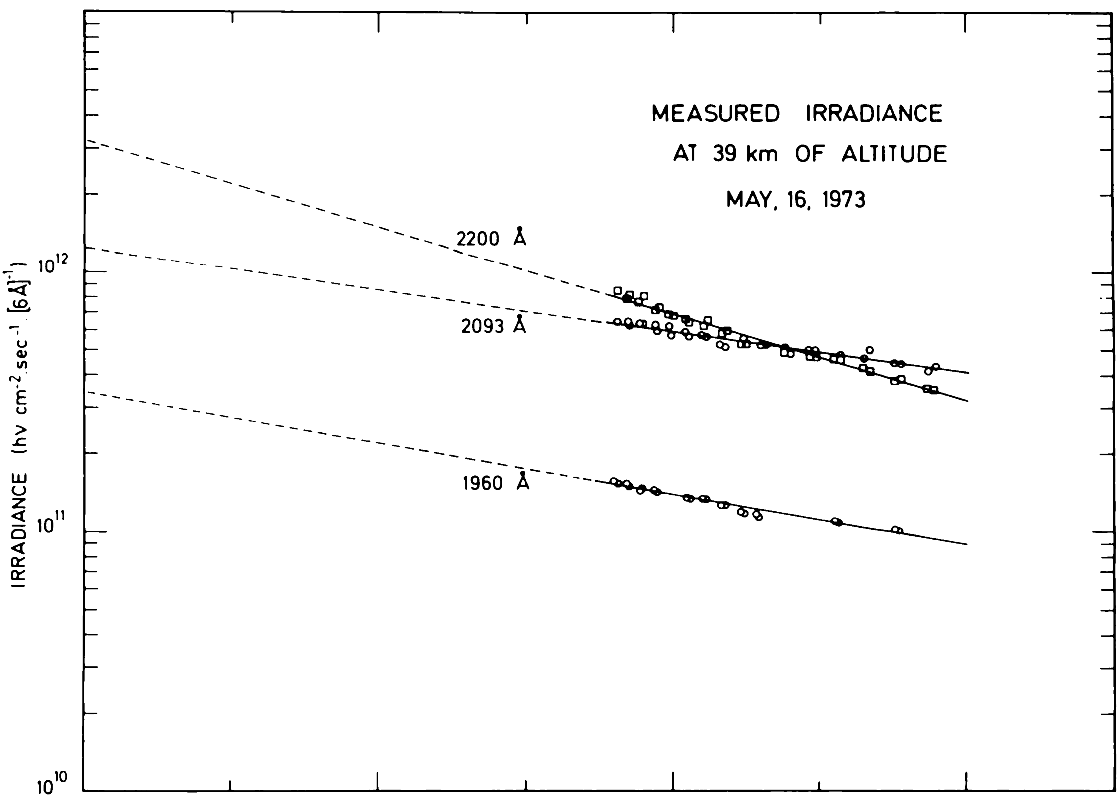

Figure 3. Measured solar irradiances versus the secant of the solar zenith angle, at three wavelengths.

For the first flight, the air masses were calculated using the approximation for large zenith distances given by Swider and Gardner (1967). Since in the wavelength range considered there are two different absorbing constituents, oxygen and ozone, with different scale heights, the contributions at each wavelength of the two absorbers in the air-mass calculation were taken into account. The oxygen and ozone column densities were deduced from pressure measurement and from absorption data around 3000 Å, respectively. Using the ozone absorption cross-sections measured by Inn and Tanaka (1953) and the oxygen absorption cross-sections published by Ackerman (1971), the optical depth was calculated for a pure oxygen-ozone atmosphere between 1900 and 2400 Å. The Rayleigh-scattering extinction was also taken into account. Figure 4 shows the good agreement between experimental optical-depth values and those of the oxygen-ozone absorption model.

The solar-flux results of the two flights are shown in Figure 5. The best-fitting curve is reproduced in Figure 6 for comparison with other determinations of solar fluxes in the 1700-2400 Å wavelength interval. The new values are roughly 40% lower than the previous measurements of Ackerman et al. (1971). They are in good agreement with Broadfoot's values for wavelengths

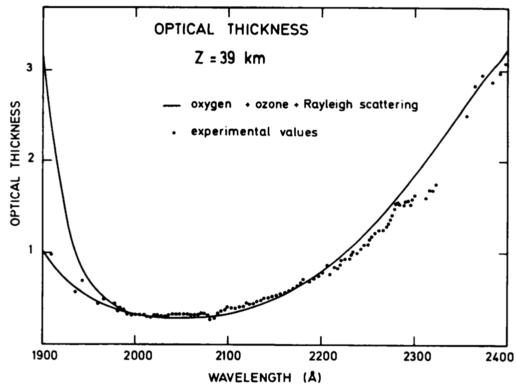

Figure 4. Experimental optical thickness (dots) and a pure oxygen-ozone atmospheric absorption curve in the wavelength range from 1900 to 2400 Å. The full curve was calculated for an ozone content of 4 × 10^{17} molecules/cm^2 and an oxygen content of 1.48 × 10^{22} molecules/cm^2. The splitting of this curve below 2000 Å corresponds to the lowest and the highest values of the oxygen cross-section in the Schumann-Runge band system.

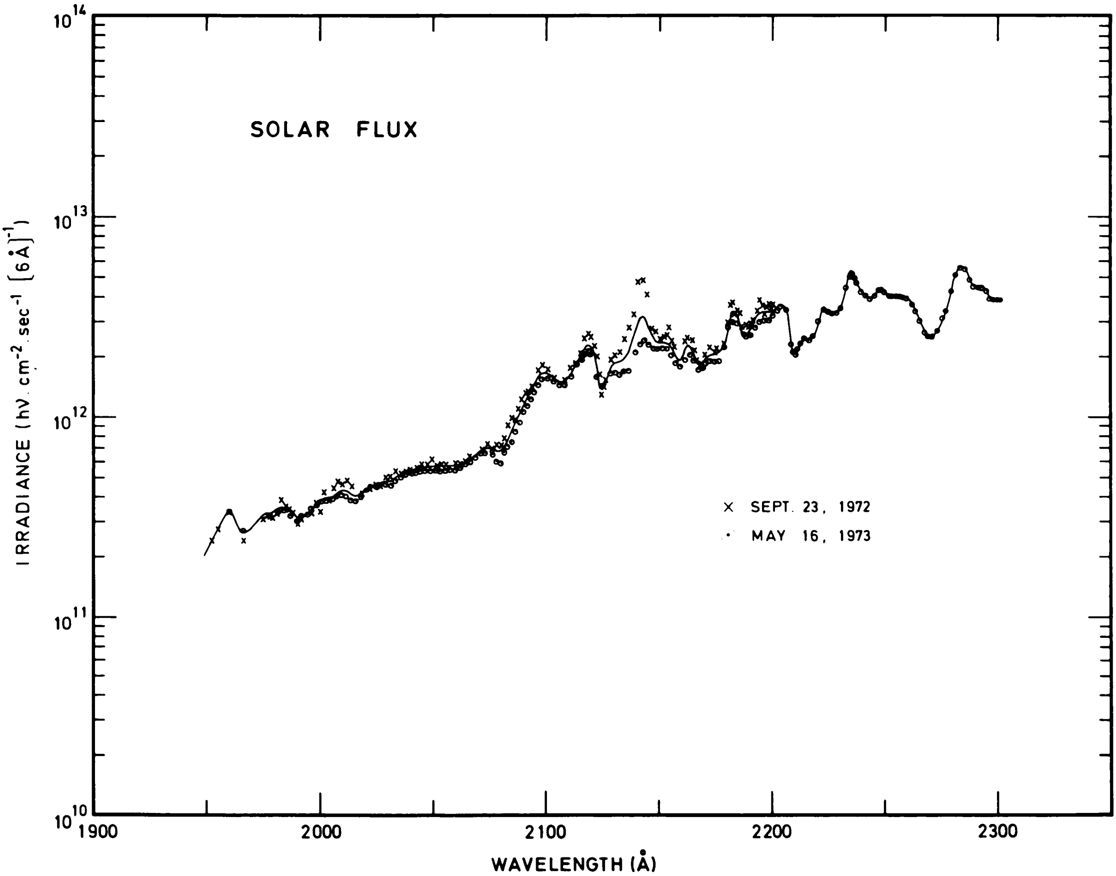

Figure 5. Solar fluxes versus wavelength at one astronomical unit, deduced from the two balloon flights.

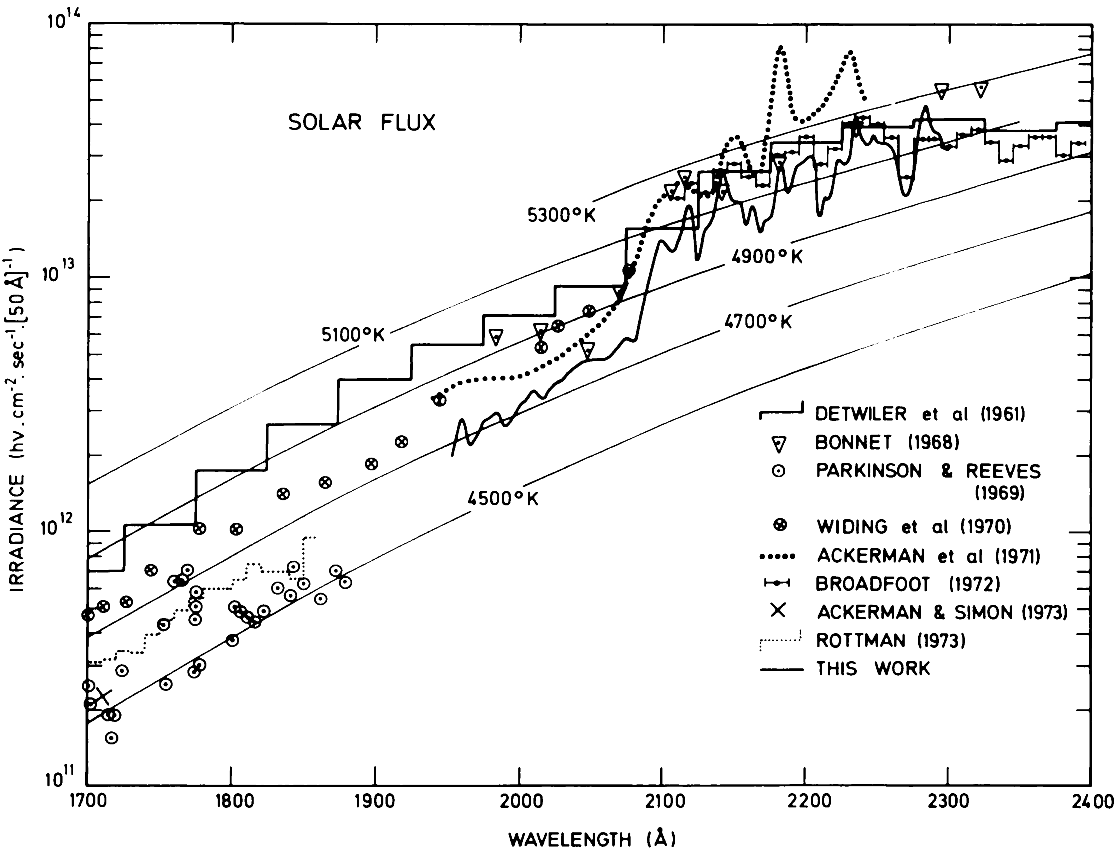

Figure 6. Comparison of ultraviolet solar fluxes reported by various experimenters from 1700 to 2400 Å. Fluxes for different blackbody temperatures are also shown.

longer than 2250 Å, but are lower at the shorter wavelengths. Table 1 and Figure 7 compare the new values with those published by Ackerman (1971) which are generally used in photodissociation-rate calculations. The agreement is fairly good for some wavelength intervals defined in Table 1.

Table 1. Comparison Between the Solar Flux Measurements Reported Here and the Values Published by Ackerman (1971)

Wavelength interval (Å)	Flux ($h\nu$ cm^{-2} sec^{-1}) This work	Flux ($h\nu$ cm^{-2} sec^{-1}) Ackerman (1971)	Ratio of Ackerman's flux to this work's
1961 - 1980	1.01×10^{12}	1.39×10^{12}	1.38
1980 - 2000	1.20	1.53	1.27
2000 - 2020	1.44	1.60	1.11
2020 - 2041	1.80	1.74	0.97
2041 - 2062	2.08	2.31	1.11
2062 - 2083	2.45	4.20	1.71
2083 - 2105	5.09	7.30	1.43
2105 - 2128	7.12	9.42	1.32
2128 - 2150	9.23	1.06×10^{13}	1.15
2150 - 2174	8.42	1.34	1.59
2174 - 2198	1.20×10^{13}	1.32	1.10
2198 - 2222	1.22	1.73	1.42
2222 - 2247	1.77	1.80	1.02
2247 - 2273	1.60	1.82	1.14
2273 - 2299	1.96	2.26	1.15

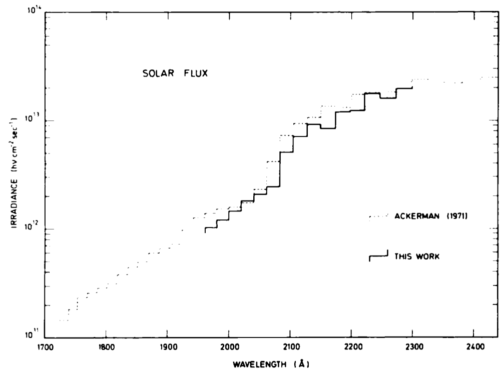

Figure 7. Comparison of solar fluxes reported here with values published by Ackerman (1971). The wavelength intervals are defined in Table 1.

Since the flux values of Parkinson and Reeves (1969) between 1400 and 1900 Å have recently been confirmed by Ackerman and Simon (1973), Heath (1973), and Rottman (1973), the apparent blackbody temperature of the sun appears to be close to 4550°K at 1900 Å. The present results indicate a decrease of only 150°K from 2000 Å down to 1900 Å. The intensity change from 2080 Å to 1700 Å could be nearly exponential, as suggested by Donnelly and Pope (1973).

ACKNOWLEDGMENTS

I would like to express my thanks to Prof. M. Nicolet for his interest in this work, and to Dr. M. Ackerman for his advice in the preparation of the experiment and for the data reduction. I am also indebted to Dr. R. Pastiels, who calibrated the reference source in the IPS 1956 scale, and to Mr. Lippens for his computer-programming assistance.

This work has been sponsored in part by the CIAP office of the U.S. Department of Transportation through the Office of Naval Research under contract N0014-73-C-0076.

REFERENCES

Ackerman, M. (1971), "Ultraviolet solar radiation related to mesospheric processes," in *Mesopheric Models and Related Experiments*, ed. G. Fiocco, D. Reidel Pub., Dordrecht, Holland, 149.

Ackerman, M., D. Frimout, and R. Pastiels (1971), "New ultraviolet solar flux measurements at 2000 Å using a balloon borne instrument," in *New Techniques in Space Astronomy*, eds. Labuhn and Lust, D. Reidel Pub., Dordrecht, Holland, 251.

Ackerman, M. and P. Simon (1973), "Rocket measurement of solar fluxes at 1216 Å, 1450 Å and 1710 Å," Solar Phys. **30**, 345.

Bonnet, R.M. (1968), "Stigmatic spectra of the sun between 1800 Å and 2800 Å," Space Res. **8**, 458.

Broadfoot, A.L. (1972), "The solar spectrum 2100-3200 Å," Astrophys. J. **173**, 681.

Detwiler, C.R., D.L. Garrett, J.D. Purcell, and R. Tousey (1961), "The intensity distribution in the ultraviolet solar spectrum," Ann. Geophys. **17**, 9.

Donnelly, R.F. and J.H. Pope (1973), "The 1-3000 Å Solar Flux for a Moderate Level of Solar Activity for Use in Modeling the Ionoshpere and Upper Atmosphere," NOAA Technical Report ERL 276-SEL 25.

Heath, D.F. (1973), "Space observations of the variability of solar irradiance in the near and far ultraviolet," J. Geophys. Res. **78**, 2779.

Inn, E.C.Y. and Y. Tanaka (1973), "Absorption coefficient of ozone in the ultraviolet and visible regions," J. Opt. Soc. Amer. **43**, 870.

Nicolet, M. (1972), "Aeronomic chemistry of the stratosphere," Planetary Space Sci. **20**, 1671.

Nicolet, M. (1974), "An overview of aeronomic processes in the stratosphere and mesosphere," Can. J. Chem. **52**, 1381.

Parkinson, W.H. and E.M. Reeves (1969), "Measurements in the solar spectrum between 1400 and 1875 Å with a rocket-borne spectrometer," Solar Phys. **10**, 342.

Rottman, G.J. (1973), in R.F. Donnelly and J.H. Pope, "The 1-3000 Å Solar Flux for a Moderate Level of Solar Activity, for Use in Modeling the Ionoshpere and Upper Atmosphere," NOAA Environmental Research Laboratories Technical Report ERL 276-SEL 25.

Simon, P. (1974), "Observation de l'absorption du rayonnement ultraviolet solaire par ballons stratosphériques," Bull. Acad. Roy. Belgique, Cl. Sci., in press.

Swider, W., Jr. and M.E. Gardner (1967), "On the Accuracy of Certain Approximations for the Chapman Function," AFCRL-67-0468 (Environmental Research Papers, No. 272), Air Force Cambridge Research Laboratories, Bedford, Mass.

Widing, K.G., J.D. Purcell, and G.D. Sandlin (1970), "The UV continuum 1450-2100 Å and the problem of the solar temperature minimum," Solar Phys. **12**, 52.

DISCUSSION

KRUEGER: What is the total absorption of the atmosphere above the flight altitude?

SIMON: The optical depth at 2050 Å is 0.2 for the first flight (41.5 kilometers altitude) and 0.3 for the second one (39 kilometers altitude).

(UNIDENTIFIED): Did you attribute the lower values to instrument problems or to shorter flights?

SIMON: Calibration techniques are the most difficult experimental problem in absolute ultraviolet spectrometry. Unfortunately, the difficulties increase in the vacuum ultraviolet wavelength range, which would explain the disagreement between the solar flux measurements.

Dr. Tohmatsu's paper was not available for publication in these *Proceedings*.