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MEASURING SOLAR SPECTRA: PROBLEMS AND SOLUTIONS

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January 1991

Reprinted from Laser & Optronics,
Elsevier Communication

Measuring Solar Spectra: Problems and Solutions

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In recent years, researchers involved in many unrelated scientific disciplines have needed to determine the ultraviolet spectral irradiance of sunlight accurately. It has become more evident that solar radiation (along with the changing level of its UV component due to changes in the concentration of ozone in the stratosphere) is causing a multitude of far-reaching effects.

The accurate measurement of solar UV spectral irradiance is considerably more difficult and much more complex than measuring the spectral output of most other types of light sources. The exponential decrease in the spectral irradiance of sunlight with decreasing wavelength, coupled with the relatively large amount of solar irradiance at longer wavelengths, puts very stringent requirements on the measurement instrumentation. The region of particular interest is the UVB band, ranging from 280 to 320 nm. For extraterrestrial solar radiation, the UVB portion comprises about 1.4% of the total solar flux. After attenuation by the earth's atmosphere, however, the percentage of UVB reaching the surface (including direct and scattered solar flux) is reduced to about 0.4% of the total.

Critical Optical Parameters

The figure shows a spectral scan of sunlight, from 295 to 800 nm, normalized to 1.0 at the peak. A quick analysis of the spectral plot (and the underlying values of spectral irradiance measured in W/cm^2-nm) identify the critical parameters.

Wavelength Accuracy and Repeatability. A small error in the wavelength accuracy of the monochromator will lead to relatively large errors in the measured spectral irradiance. For example, a 1-nm error in the wavelength calibration of the monochromator will produce an irradiance error of almost 100% at 297 nm. At longer wavelengths, the effect of a 1-nm calibration error is less severe – 10% to 20% at 325 nm and a couple of percent at 600 nm. The ability to set and reset a particular wavelength is similarly critical at the shorter wavelengths.

Stray Light. The out-of-band rejection of the monochromator is even more critical than wavelength accuracy and repeatability. The integrated irradiance over the entire band from 295 to 800 nm is 2.914×10^{-2} W/cm^2, while the irradiance over a 1-nm measurement bandwidth at 295 nm is 9.822×10^{-9} W/cm^2. The ratio of the two values is about 3×10^{-7}. If the stray-light rejection of the monochromator at 295 nm is 10^6, the out-of-band flux incident on the detector will be 10 times greater than the actual spectral irradiance at 295 nm, producing an error of 1000%.

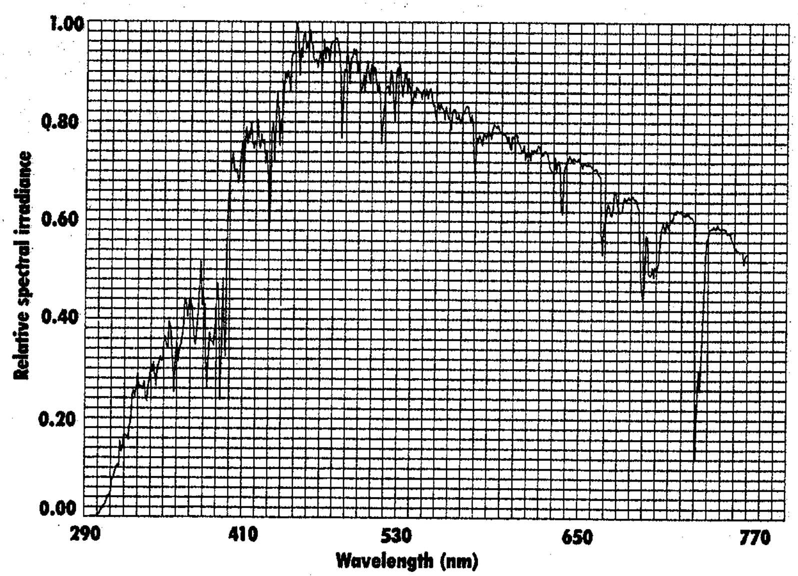
Bandwidth. The half-bandwidth (HBW) of the monochromator must be relatively narrow in any region where the flux is changing rapidly with wavelength. However, as the bandwidth is decreased, the flux incident on the detector is also decreased. Reducing the monochromator slits from a 10-nm HBW to a 1-nm HBW actually decreases the flux on the detector by a factor of 100. Depending on the situation, 1- to 5-nm HBWs generally work best.

Sensitivity. An extremely low noise-equivalent irradiance (NEI) is desirable. To measure a spectral irradiance of 9.822×10^{-9} W/cm^2 with a 100:1 signal-to-noise ratio requires an NEI of 9.822×10^{-11} W/cm^2. For measurements below 295 nm, an even lower NEI is required.

Dynamic Range. As can be seen from the figure, the dynamic range of the detection system must be linear for at least six orders of magnitude.

Scan Speed. Since the spectral output of sunlight changes with time, scanning time must be minimized. For the UVB range, it appears that recording data at a rate of about 1 data point per second is sufficient.

Stability. A spectroradiometric measurement system must maintain its calibration, for both wavelength and spectral irradiance response, over prolonged periods. To reduce both long- and short-term changes in sensitivity and drifts in detector dark current, temperature stabilization of the detec-



Relative spectral irradiance of sunlight in Orlando, Florida, Mar. 10, 1990, at 2 p.m. HBW was 1 nm.

Reprinted from Lasers & Optronics®, January 1991, pages 63-65.

tor and auto-zeroing of dark current are essential.

System Calibration. Wavelength calibration can be performed using any of a number of different line-emission sources – mercury arc lamps, lasers, and so on. High-accuracy standards of spectral irradiance are available for calibrating the system for spectral irradiance response. However, extreme care in aligning and operating these lamp standards is mandatory to realize the accuracies associated with them. In general, it is possible to calibrate a spectroradiometer relative to the standard lamp and at the lamp's irradiance level to about ±1%.

Input Optics. For measurement of global solar spectral irradiance, the input optics or collecting optics must have a good cosine response. In addition, the diffuse solar radiation produced by Raleigh scattering is polarized, with the degree of polarization dependent on the scattering angle. Thus, the collecting optics should also serve as a depolarizer.

Although a number of transmitting-type cosine collectors are available, by far the most efficient is the integrating sphere. A properly designed integrating sphere with a highly diffusely reflecting coating will serve as a near-perfect cosine collector and will also depolarize the incident radiant flux. However, the overall efficiency of throughput of an integrating-sphere cosine collector is relatively low. When looking at a point source, the attenuation in detector signal with and without the integrating sphere attached to the monochromator can be as much as 1000.

Portability a Must

In the past, making spectroradiometric measurements was a tedious, time-consuming task. Many hours were required to calibrate the system, collect the data, and calculate and plot the final results. Present-day spectroradiometric systems can be automated in either of two ways: by interfacing the spectroradiometer to a computer or by employing complete on-board microprocessor control of all crucial functions. Both options require appropriate software.

Since most solar spectral irradiance measurements are made in nonlaboratory environments, an automated spectroradiometric measurement system should have the following four features.

First, the system should be truly portable, rather than merely movable. The system should be compact and sufficiently rugged for shipment and use under extremely difficult conditions.

Second, battery operation is highly desirable, although not truly essential for all measurement situations.

Third, the capability of performing field calibration checks is extremely critical. The key optical parameters most susceptible to change during shipment or when subjected to adverse handling are the monochromator wavelength calibration and the gain of the electro-optical system. The ability to verify both in the field is essential.

Fourth, environmental protection is also a key factor. If the system will be left unattended for extended periods in the field, all exposed components of the system (including the computer) should be mounted in an environmental enclosure.

Meeting the Criteria

The UV-visible solar spectral irradiance measurements shown in the figure were made using Optronic Laboratories' recently developed OL 752 spectroradiometer. A compact, portable stand-alone microprocessor-controlled unit optimized for the 200-800-nm region, the OL 752 meets all of the above criteria.

Features that make the unit suitable for solar radiation measurements include its prealigned NIST-traceable plug-in standard of spectral irradiance, the dual plug-in optical gain and wavelength calibration check source that operates off the battery pack, and User Intimate™ Software on ROM, enabling total control of the optical head and basic arithmetic data manipulations.

Before taking the OL 752 into the field for the measurements, the system was calibrated for spectral irradiance response using the plug-in irradiance standard. The calibration was done using 1-nm-bandwidth slits. Wavelength range was 290-800 nm at 1-nm intervals.

Once the system was transported to the field location, the check source was used to determine the wavelength accuracy and to check the optical gain. The wavelength was off by 0.1 nm and the gain had changed by 0.2%. Corrections, under software control, were made for both prior to beginning the solar spectral scans. These measurements were performed using a "fast" time response that was equivalent to 1 second per data point. Accordingly, the instrument scanned the UVB region in 26 seconds and the entire 295-800-nm region in 8 minutes 46 seconds.

Optical performance of the OL 752 features wavelength accuracy of ±0.2 nm, wavelength precision of ±0.1 nm, bandwidths of 1-5 nm, a PTFE-coated integrating sphere cosine collector, sensitivity of 10^{-11} W/cm^2-nm and a dynamic range greater than 10^6. *L&O*

William E. Schneider is president and cofounder of Optronic Laboratories, Inc., a specialist in spectroradiometeric instrumentation, NIST-traceable standards and calibration services.