Broadband and Spectral Irradiance Measurements at the Radiometer Calibration Facility During the 1997 Integrated Intensive Observation Period

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Summary

A unique collection of broadband and spectral solar irradiance measurements was made at the Radiometer Calibration Facility (RCF) during the 1997 Integrated Intensive Observation Period (IOP). Absolute cavity radiometers, ultraviolet photometers, photosynthetically active radiation (PAR) photometers, pyranometers, pyrgeometers, and a scanning spectroradiometer were deployed at the Southern Great Plains (SGP) site to meet the needs of the Shortwave IOP for high-accuracy clear-sky solar irradiance data.

Our paper summarizes the measurement capabilities of the radiometers used during the IOP. We also present several initial data analyses including the following:

- comparisons of four absolute cavity radiometers under clear skies
- effects of wind on unwindowed absolute cavity radiometer performance
- reference downwelling hemispheric shortwave irradiance by summation
- ultraviolet irradiance time-series
- PAR irradiance time-series
- direct and global spectral irradiance distributions for clear and partly cloudy skies.

Instrumentation Overview

Reference Broadband

Beginning September 25, 1997, broadband irradiance measurements were taken in conjunction with the ongoing Broadband Outdoor Radiometer CALibration (BORCAL) at the RCF. Measurements of the shortwave broadband (0.3 µm to 3.0 µm) direct-normal irradiance were made by up to four absolute cavity radiometers manufactured by The Eppley Laboratory, Inc. (see Table 1). These electrically self-calibrating Automatic Hickey-Frieden Model AHF radiometers have a 5.0° field of view and are mounted in automatic solar trackers. Each cavity radiometer is an independent system with an individual controller and digital multimeter (DP-100 or HP-3421A). These radiometers have direct and indirect traceability to the World Radiometric Reference (WRR) via the International Pyrheliometer Comparisons held in 1995 and subsequent comparisons held at the National Renewable Energy Laboratory (NREL).

Table 1. Absolute cavity radiometers.

Serial No.	Latest WRR Factor	Owner/Operator
HF-28552	0.997753	SUNYA/ASRC
AHF-29222	1.0010	ARM/RCF-NREL
AHF-30495	0.9982	ARM/RCF-NREL
AHF-30170	0.9994	NOAA/SRRB

Data from two of the cavity radiometers are available during daylight periods at 30-second intervals as part of the routine BORCALs of the Solar and Infrared Station (SIRS) pyrheliometers and pyranometers. Two shaded Eppley Model PSP (Precision Spectral Pyranometer) radiometers were used to measure the diffuse component. The diffuse irradiance data for the IOP were computed from the mean of the two instruments. The “global” or total hemispheric downwelling shortwave has been computed from:

Global = Direct Normal * Cosine (solar zenith angle) + Diffuse.

Measurements from two additional absolute cavity radiometers were also made during the IOP. Adjusted for their individual WRR reduction factors, the measurement agreement of the four absolute cavities during the IOP was better than 0.5%. Three of the cavity radiometers later participated in the NREL Pyrheliometer Comparison of 1997, confirming this level of performance.

IOP data from AHF 30495 were collected with a window installed to protect the instrument from dust and limit the effects of wind on the responsivity. A window correction factor of 1.05404 has been applied to all data from this instrument.

Ultraviolet and Photosynthetically Active Radiation

Beginning about 17:30 Greenwich Mean Time (GMT) on September 16, continuous 24-hour recordings of 1-minute statistics using 2-second samples of 7 radiometers for hemispheric downwelling ultraviolet (UV-A, UV-B, and Total UV) and PAR irradiance.

Radiometers listed in Table 2 were connected to a Campbell Scientific, Inc. Model CR10X-1M data logger (s/n X4648) programmed to measure differential voltage inputs with 60-Hz noise rejection.

The LI-190SA Quantum Sensor uses a high-stability silicon photovoltaic detector (blue enhanced) mounted in a weatherproof anodized aluminum case with diffuser and stainless steel hardware. A 604-Ω resistor was installed at the data logger connections for each LI-190. The resulting voltages (0-10 mV) are multiplied by 69.4826 (s/n Q20555) and 69.2153 (s/n Q20558) to produce data in W/m^2. The effective irradiance is based on 4.6-μ mol/sec^2 m as supplied by LI-COR.

The Kipp & Zonen radiometers were calibrated at NREL prior to the IOP using National Institute of Standards and Technology (NIST) lamps. The “full” UVA spectrum (315 nm to 400 nm) can be approximated to about ±5% by multiplying the readings from s/n 950006 by 5.0. Similarly, the “full” UVB spectrum (300 nm to 315 nm) can be approximated to about ±15% by multiplying the output from s/n 952010 by 21.

Data from the Solar Light, Inc. radiometers incorporate the erythema action spectra and have accounted for known temperature response characteristics of the sensor. The effective irradiance is based on 1 MED/Hr = 0.0583 W/m^2 as supplied by Solar Light, Inc.

The seven radiometers were mounted on an aluminum plate fastened to the steel safety railing on the northwest corner of the roof top work area of the RCF at the SGP Central Facility (latitude: 36.605 N, longitude: 97.488 W). Mounting adapters were used to permit the installation of these different radiometers to a common detector height of 10.8 cm above the mounting plate. There were no permanent obstructions to the hemispheric field of view for each radiometer.

Scanning Spectroradiometer

Beginning September 25, 1997, spectral irradiance measurements from a LI-COR, Inc. model LI-1800 (serial number PRS-456) scanning spectroradiometer were taken at

Table 2. UV and PAR radiometers.

Manufacturer	Model	S/N	Wavelength Response	Calibration Factor
LI-COR, Inc.	LI-190	Q20555	400 nm - 700 nm	5.18 uA/mmol/s/m^2
LI-COR, Inc.	LI-190	Q20558	400 nm - 700 nm	5.20 uA/mmol/s/m^2
Kipp & Zonen	CUVA1	950006	363 nm - 373 nm	5.85 W/m^2/V
Kipp & Zonen	CUVB1	952020	305 nm - 307 nm	0.130 W/m^2/V
Solar Light, Inc.	501A	1897	250 nm - 400 nm	0.250[V/(MED/hr)]
Solar Light, Inc.	501A	1898	250 nm - 400 nm	0.250[V/(MED/hr)]
Eppley Lab, Inc.	TUVR	28288	285 nm - 395 nm	7.508 uV/W/m^2

least three times a day, two hours either side of solar noon and near solar noon. Data are 1-minute averages of direct normal and hemispheric irradiance from 300 nm to 1100 nm in 2-nm wavelength intervals. The downwelling hemispheric and direct normal spectra are available during cloudless conditions. No direct normal spectra were possible when the solar disk was not visible, but hemispheric data were collected under all sky conditions.

The spectral measurements are the average of three scans (10 seconds each + 5 seconds for monochromator reset) taken in sequence as fast as the system can perform. The total measurement time is between 45 seconds and 1 minute for each mode (hemispheric or direct normal).

The portable LI-1800 was calibrated at NREL for absolute irradiance and wavelength prior to the IOP using a NIST lamp. An internal microcomputer controls the monochromator and stores data from the silicon-based detector. The LI-1800 optical system has three major components: a filter wheel, holographic grating monochromator, and a silicon detector. The holographic grating monochromator has a wavelength range of 300 nm to 1100 nm (300 nm to 850 nm optional) and has selectable wavelength drive intervals of 1 nm, 2 nm, 5 nm, or 10 nm. The instrument's high efficiency silicon detector and autoranging electronics allow scanning rates of over 30 nm per second. The front optics is a Teflon diffuse for hemispheric measurements and a direct beam module for narrow field of view measurements (5.7°)

The detector temperature was not controlled electronically, but the system was kept inside the RCF except for the 15 minutes to 20 minutes required to deploy the instrument, complete the measurements, and return it to the RCF.

The portable LI-1800 system was manually positioned on a radiometer calibration table near the southwest corner of the roof top work area of the RCF. There were no permanent obstructions to the hemisphere field of view. The direct normal spectra were obtained by attaching a view-limiting tube on the standard cosine receptor and manually aligning the system to the solar disk during the three scans used to make the averaged data.

Sample Data

Measurements from the RCF/BORCAL system provide the reference shortwave irradiance for direct normal and diffuse horizontal components. The reference downwelling total hemispheric shortwave is computed for each measurement pair and the corresponding solar zenith angle. The time-series plot for a day with very clear-sky conditions is shown in Figure 1. No adjustments have been made to the diffuse measurements for possible nighttime offsets of the shaded pyranometer.

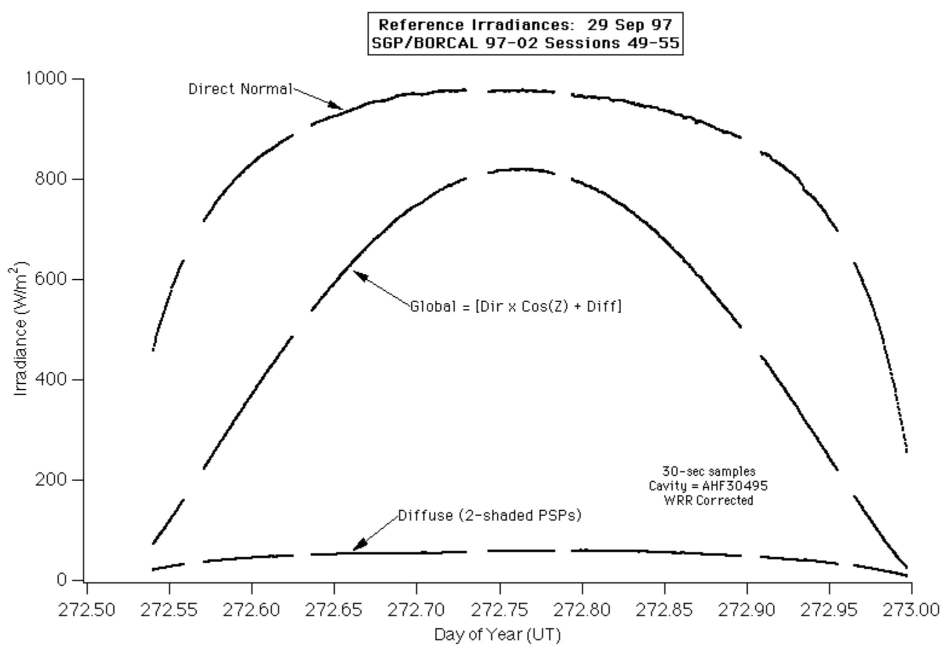

Figure 1. Reference irradiance components for September 29, 1998, based on the BORCAL measurement system. Periodic cavity calibrations result in data gaps.

The effects of increased precipitable water and/or aerosols in the atmosphere are evident from the measurements of direct normal irradiance plotted as a function of air mass (Figure 2). Diurnal differences are also shown by these measurements, which are generally higher irradiance levels in the morning than in the afternoon.

The comparisons of measurements by an unwindowed absolute cavity radiometer (AHF 29222) and another windowed cavity (AHF30495) during calm periods indicate agreement between the two cavities is better than 0.2 W/m^2 at 900 W/m^2 irradiance levels. The data shown in Figure 3 suggest a 0.4% bias between the two radiometers for light winds in the direction of the view-limiting tube. The convective heat transfer effects are apparently reducing the signal from the unwindowed cavity under these conditions.

Clear-sky measurements of UV and PAR are shown in Figures 4, 5, and 6. The peak irradiance values occur at solar noon on September 29, 1997, as summarized in Table 3.

The spectral distributions of direct normal and total hemispheric downwelling irradiance for two clear-sky periods are shown in Figure 7. Note the similarities of the global irradiance for the two days, but the distinctly different values for direct normal irradiance spectral distributions. These measurements suggest increased scattering has repartitioned the irradiance distributions between the two cases between 400 nm and 700 nm.

Table 3. Comparison of UV and PAR measurements from September 29, 1997.

Radiometer Model	Spectral Response	Solar Noon Irradiance (Wm^{-2})
LI-190	400 nm - 700 nm	293.6
LI-190	400 nm - 700 nm	297.1
CUVA1	363 nm - 373 nm	5.87
CUVB1	305 nm - 307 nm	0.04
501A	250 nm - 400 nm	0.178
501A	250 nm - 400 nm	0.176
TUVR	285 nm - 395 nm	33.6

Conclusions

Reference broadband and spectral measurements of the shortwave irradiance were collected at the RCF during the 1997 Integrated IOP. Absolute cavity radiometers operated by the National Oceanic and Atmospheric Administration (NOAA), NREL, and SUNYA/ASRC showed measurement agreement better than 0.5% under clear-sky conditions (800 Wm^{-2} to 900 Wm^{-2}). Reference broadband shortwave irradiance measurements are available form the RCF/ BORCAL system operated during the IOP. Continuous measurements of the UV and PAR irradiance are also available during this period. Spectral irradiance measurements for three time periods each day provide information about the aerosol and water vapor effects on shortwave radiation during the IOP. These measurements will be available on the ARM web site for further research analyses.

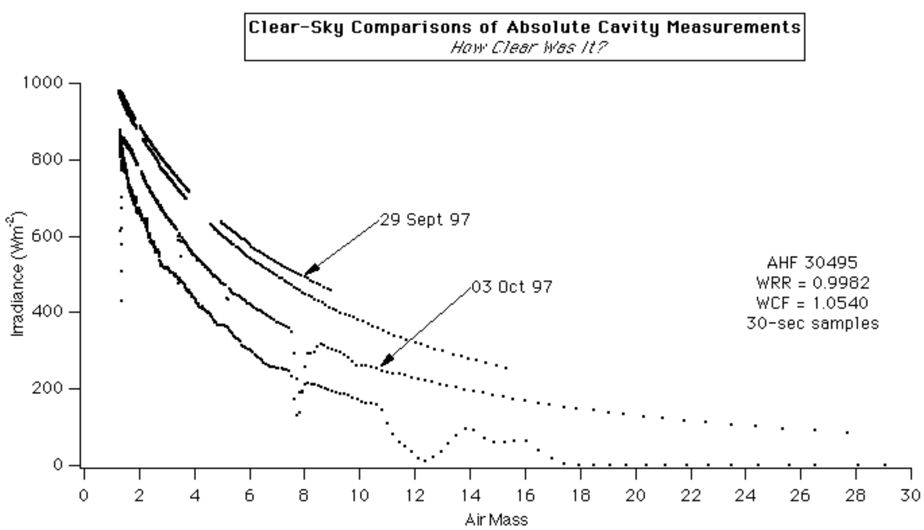

Figure 2. Comparison of direct normal irradiance versus air mass for a very clear sky (September 29, 1997) and a hazy sky with less than one-tenth stratus clouds (October 3, 1997).

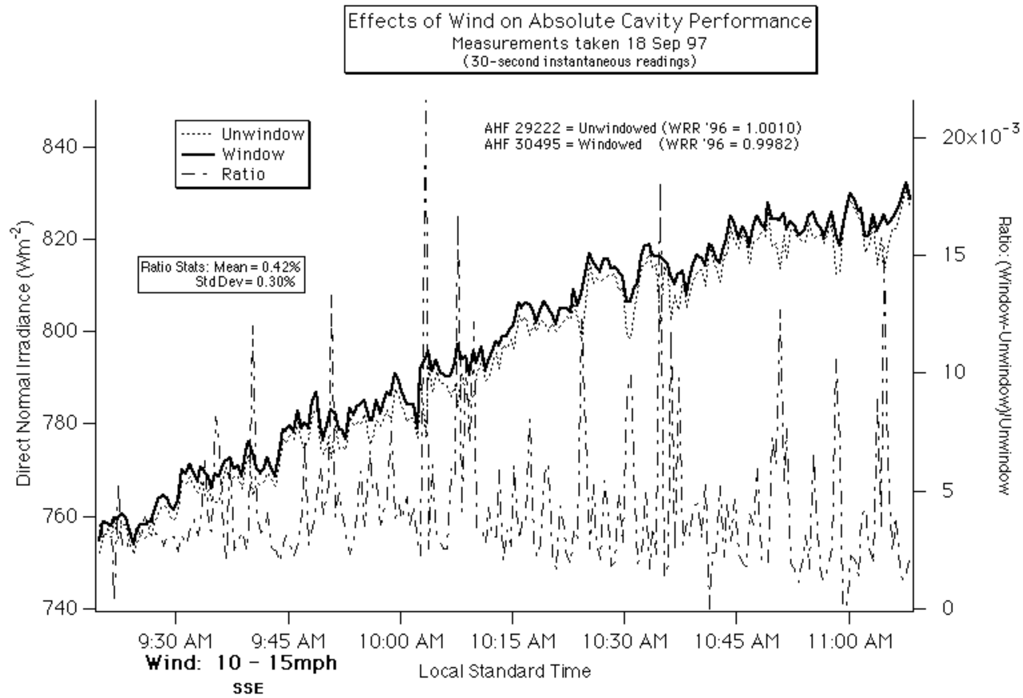

Figure 3. Simultaneous measurements of direct normal irradiance by a windowed and unwindowed absolute cavity during light wind.

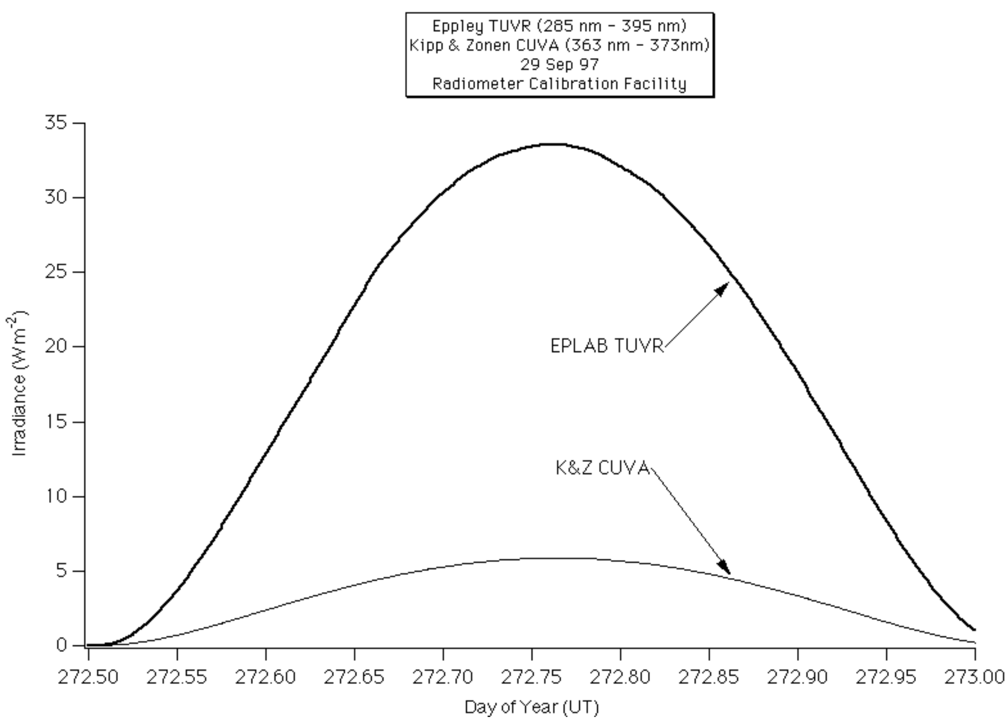

Figure 4. Time-series display of UV irradiance measurements from two radiometers showing the total UV and UVA available on September 29, 1997.

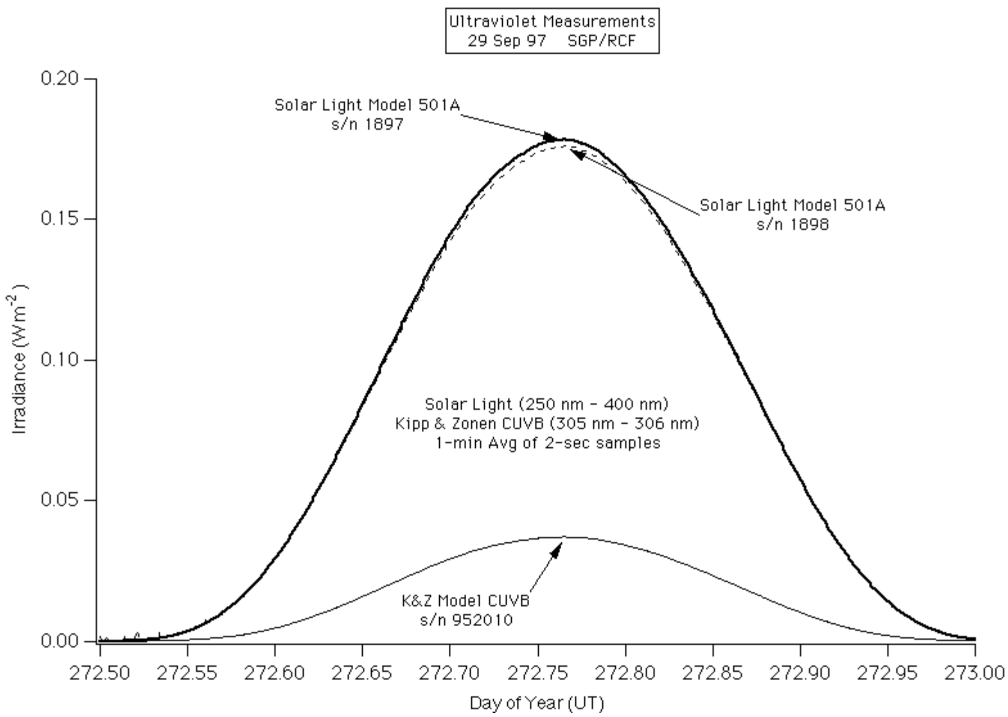

Figure 5. Comparison of two Solar Light UVB radiometers and a Kipp & Zonen CUVA radiometer during clear-sky conditions on September 29, 1997.

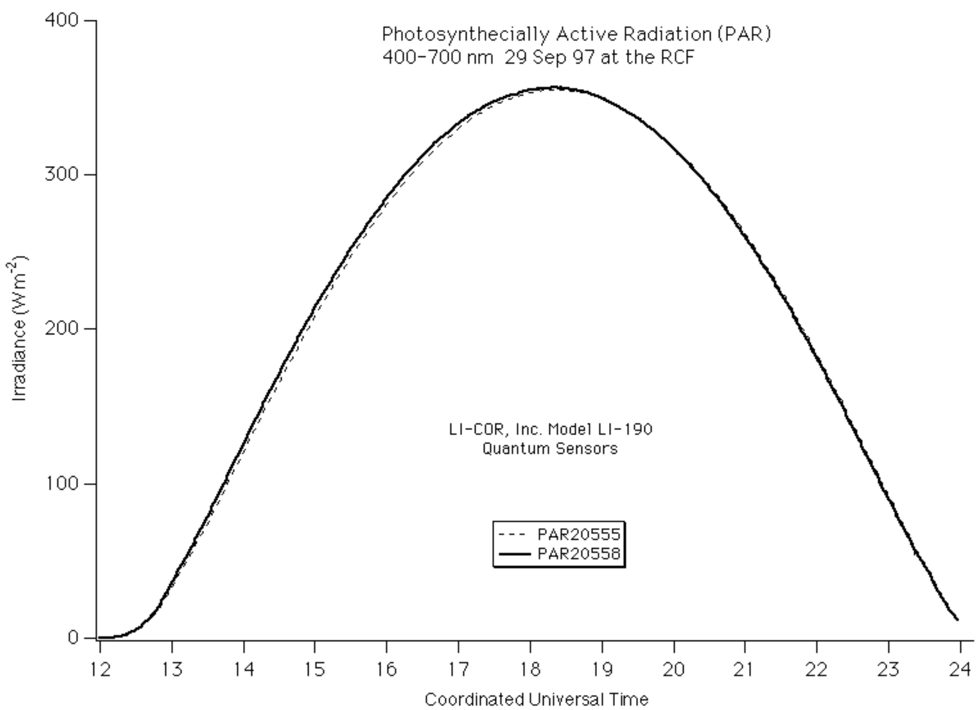

Figure 6. PAR measured by two LI-COR model LI-190 Quantum Sensors on September 29, 1997.

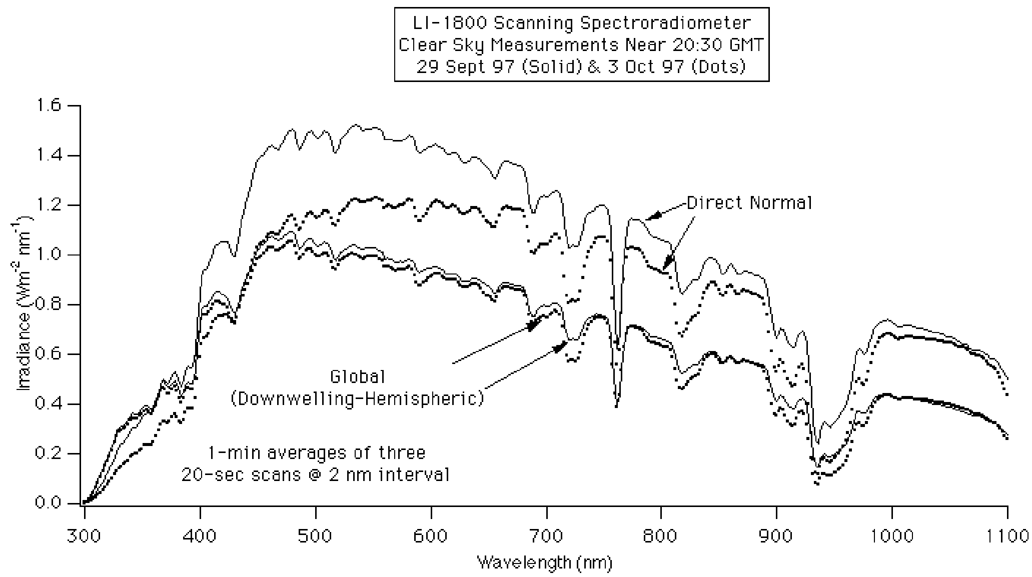

Figure 7. Direct normal and total hemispheric spectral irradiance distributions measured by a LI-COR model 1800 scanning spectroradiometer on September 29, 1997, (clear) and October 3, 1997 (hazy).