A Dual Spectroradiometer System for Measuring Spectral Reflectances[1]

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ABSTRACT

A dual spectroradiometer system for field measurements of spectral reflectances over natural surfaces was developed and tested. Tests show that simultaneous incident and reflected readings are highly desirable to eliminate errors in computing spectral reflectances from both field and laboratory data where changes in incident radiation are likely to occur.

1. Introduction

A knowledge of the spectral reflectances of natural surfaces is important to the meteorologist. Paltridge and Platt (1976) state:

> At the very least he (the meteorologist) needs the mean albedo appropriate to the 300–400 nanometer (nm) band, the 300–800 nm band and the 0.8–2 μm band. These are the spectral regions where surface reflected radiation affects ozone absorption, Rayleigh scatter, and water vapour absorption, respectively.

Spectral reflectance information is also useful in calculating energy budgets and where pertinent ground truth information is necessary for interpretation of remotely sensed data.

Numerous investigators have measured the spectral reflectance of natural materials in the field. A noteworthy characteristic common to most of those studies is the use of only one instrument, thus requiring a significant time period to complete an incident and subsequently a reflected series of measurements. Most of these investigations, including those conducted at an early date (Krinov, 1947), noted possible inaccuracies that might result from changing atmospheric conditions and solar altitudes over that time interval. The usual assumption is that measurements collected under uniform cloudiness or clear skies, near solar noon, with associated careful attention to technique would provide accurate spectral reflectance data.

It is obvious that the period of data collection is severely restricted by the clear day-solar noon criteria. In addition, spectral reflectance data at low and rapidly changing solar altitudes is of great interest in many studies. A more serious problem is the assumption that uniform cloudiness, as observed by

the eye, will allow meaningful spectral reflectance data collection using only one instrument.

The purpose of this paper is to describe a system incorporating two commercially available scanning spectroradiometers to obtain simultaneous readings of incident and reflected radiation. A desk top calculator and software are incorporated as an integral portion of the system. In its present configuration, the system has been specifically designed to provide measurements of spectral reflectances of snow and ice in the Great Lakes. However, similar systems can be used for any field or laboratory application where the incident light is expected to change during the spectroradiometer scan.

In a recent study, Duggin (1980) independently developed a technique similar to that used here but with different equipment. Both studies were apparently conducted concurrently and arrived at similar conclusions with respect to the technique involved. Differences between the studies involve field normalization of the instruments and the degree of description of the software and hardware. Duggin calibrated in the field using a $BaSO_4$ coated plate, whereas in this program both instruments were pointed to the zenith using the sun + sky as a calibration source. In this report there is a detailed description of the instrumentation, including the wiring to control the two spectroradiometers, as well as software to process the data immediately in the field.

2. Instrumentation

Two scanning spectroradiometers (Model 550/555) manufactured by the EG&G Corporation, Electro-Optics Division, were used to measure incident and reflected radiation in the 280–1100 nm range (10 nm bandpass slits). The detector head for each spectroradiometer was a photovoltaic silicon photodiode. Second-order effects were eliminated by

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harmonic rejection order-sorting filters secured in a wheel-mounted assembly designed to switch filters automatically at 350, 400 and 600 nm. A digital wavelength display was mechanically coupled to the grating drive shaft, providing the opportunity to adjust gratings manually before each scan. Monochromator specifications from the manufacturer are provided in Table 1. Standards traceable to the National Bureau of Standards were used by the manufacturer to calibrate each unit on a complete system basis. It should be emphasized, however, that the spectroradiometers as used in this application were field calibrated (as explained later in this report) for spectral reflectances only. The 8° field-of-view of the standard spectroradiometer system was modified by the use of hemispherical cosine diffusers in order to achieve practical results comparable with those reported in the literature.

Motor drive assemblies attached to the grating drive shafts enabled remotely activated automatic scans from 280 to 1100 nm. The motors were programmed by coded signals from a wavelength control module preset to command a wavelength drive speed of 400 nm min^{-1}. The data acquisition rate was slowed for lower radiation levels by operator manipulation of a readout-settling-time control.

Data were stored and processed with a Hewlett Packard 9815A desk top calculator equipped with dual ports to interface with the spectroradiometer system by means of BCD cards. The Hewlett Packard 98133A interfaces provided parallel port input lines to the calculator, transferring data in a half-duplex mode with buffer storage for both input and output data. The software described in Section 3 was used to store both raw and processed data on tape cartridges, with up to 35 spectroradiometer runs stored on each data tape. Paper tape output was available to the field operator, as well as raw incident and reflected spectroradiometer output from a 3.5 digit bipolar display.

Since the spectroradiometers were basically laboratory type instruments, development of a significant amount of support apparatus was necessary to render them operable under hostile conditions, particularly those encountered in ice and snow studies. A sled (0.9 m × 2.2 m) normally used for light polar expedition travel was equipped with a heated, insu-
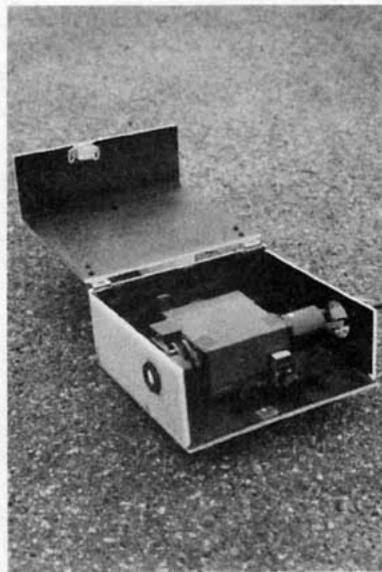

FIG. 1. Protective case enclosing spectroradiometer.

lated, weather-tight shack, which housed the monochromator motor control power and stepping modules, readout apparatus, calculator and operator. Power was provided by 12 V batteries through a 110 V inverter. At the measurement site, the spectroradiometers were mounted on a 4.6 m long boom supported on each end by tripods, placing the reflected unit ~1.5 m above the ice surface. Incident and reflected spectroradiometers were housed in plastic cases, the interiors of which were painted black (Fig. 1). The cases protected the spectroradiometers from the environment and minimized stray light.

In order to produce simultaneous incident and reflected readings, the two spectroradiometers were wired according to Fig. 2. The arrangement used one control module to power both the incident and reflected monochromator drive motors. The scheme proved to be satisfactory for all field operations. During some laboratory tests, however, continuous runs were made over a 3–4 h period, and the system failed to sequence properly during the latter portion of some of those tests. The problem was tentatively traced to overheated power transistors apparently forced beyond their design capacity. Subsequent bench tests and field runs were conducted with the control module shut off between some of the runs. The procedure seemed to remedy the problem. In any event, the digital wavelength display attached to the manual monochromator wavelength control was checked before and after nearly every run to assure proper data acquisition.

3. Software

The software consisted of two related programs to gather and reduce the spectroradiometer data. The

TABLE 1. Monochromator specifications.

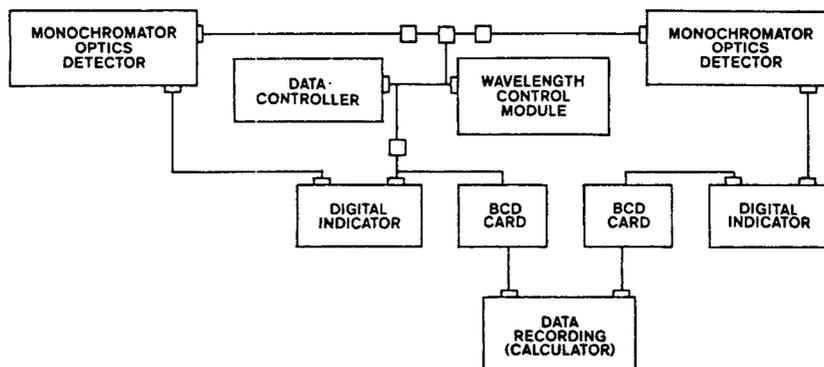| Spectral range	280–1100 nm without grating change	
Dispersion	12 nm mm^{-1}	
Wavelength accuracy	±2 nm	
Wavelength repeatability	±0.5 nm	
Scattered light (worst case— Tungsten source)	280–300 nm	≤3.0%
	300–600 nm	≤0.6%
	600–1100 nm	≤0.3%

FIG. 2. Arrangement of components in a dual spectroradiometer system to simultaneously record incident and reflected flux.

first program obtained incident and reflected flux intensities at wavelengths from 280 to 1100 nm and recorded the data on magnetic tape. Incident and reflected readings were obtained nearly simultaneously (within a few tenths of a microsecond) as the instruments stepped through each of the 83 intervals spaced 10 nm apart. Those readings were then stored on magnetic tape and printed on paper tape.

Corrections for differences in sensitivities of incident and reflected instruments were made by performing calibration runs with both instruments directed toward the zenith. Such calibration runs provided correction factors to be applied later to data runs to eliminate the sensitivity variations. Correction factors at each wavelength interval K_λ were computed from

$$K_\lambda = \frac{I_{\lambda c}}{R_{\lambda c}}, \qquad (1)$$

where $I_{\lambda c}$ is the output of the incident radiometer at wavelength λ during the calibration run, and $R_{\lambda c}$ the output of the reflected radiometer at wavelength λ in the incident mode during the calibration run. The corrected spectral reflectance is obtained by multiplying K_λ and the uncorrected (raw) spectral reflectance at wavelength λ observed during a data run. The program collected and stored both field data and data from calibration runs.

The second program obtained data from calibration and data runs; calculated, printed and stored correction factors [Eq. (1)]; calculated and printed raw spectral reflectances; and calculated, printed and stored corrected spectral reflectances. The program was loaded in the same cartridge in which data were originally stored. Files were pre-marked and used for storage of either correction factors, or corrected spectral reflectances, for calibration and data runs, respectively. The program requested entry of a calibration run number; retrieved the calibration data from the tape; calculated and printed the correction factors, and recorded them back onto the tape for subsequent use. Following calculation of correction factors, the program requested entry of data and calibration run numbers. Data values were retrieved from the data file specified, and raw spectral reflectances were calculated and printed. Correction factors were retrieved from tape and applied to the raw reflectances, and corrected spectral reflectances were printed and recorded on tape. Printouts of correction factors and raw and corrected reflectances could be suppressed, if desired, in any combination. Listings of these programs can be obtained from the authors.

Measurement sequences varied, depending on atmospheric and ice conditions, but a typical sequence is outlined to illustrate the technique as coupled to the described hardware. The first or second run of the day was a calibration run, with both the incident and reflected spectroradiometers pointed to the zenith. Data collection runs preceded and followed, with the reflected unit pointed to the nadir. Additional calibration runs were made whenever atmospheric conditions changed appreciably or at regularly spaced intervals (generally ~ 1 h). In data processing, the calibration run nearest in time to a data run (assuming equal atmospheric conditions) was normally applied.

Fig. 3 shows all calibration ratios K (15 runs) for five data collection days (60 data runs) of the 1978–79 season. Calibration runs were completed under all types of atmospheric conditions, including clear, overcast and partly cloudy skies. The runs are remarkably similar, with only a few obviously bad points. One run was significantly different from the majority of runs owing to a negative zero drift of the reflected unit. Most of the variations in calibration ratios from 1.0 are due to variations in sensitivity between the two units (Fig. 4), which averaged $\sim 15\%$. In addition, the cosine response of the hemispherical diffusers was known to be poor. Accordingly, an extensive series of laboratory measurements
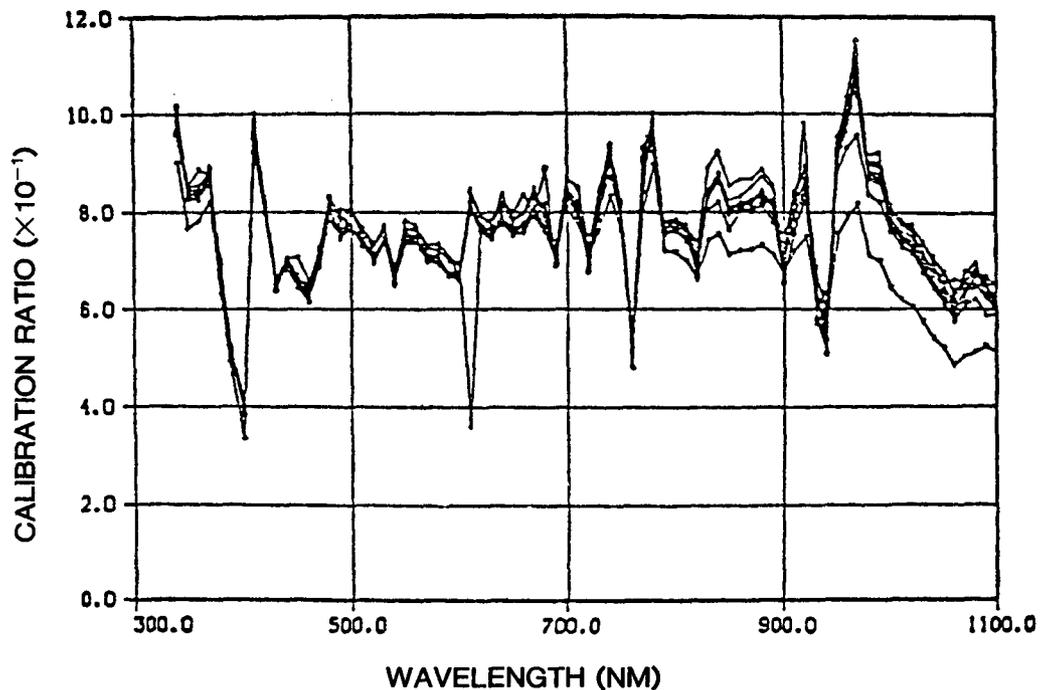
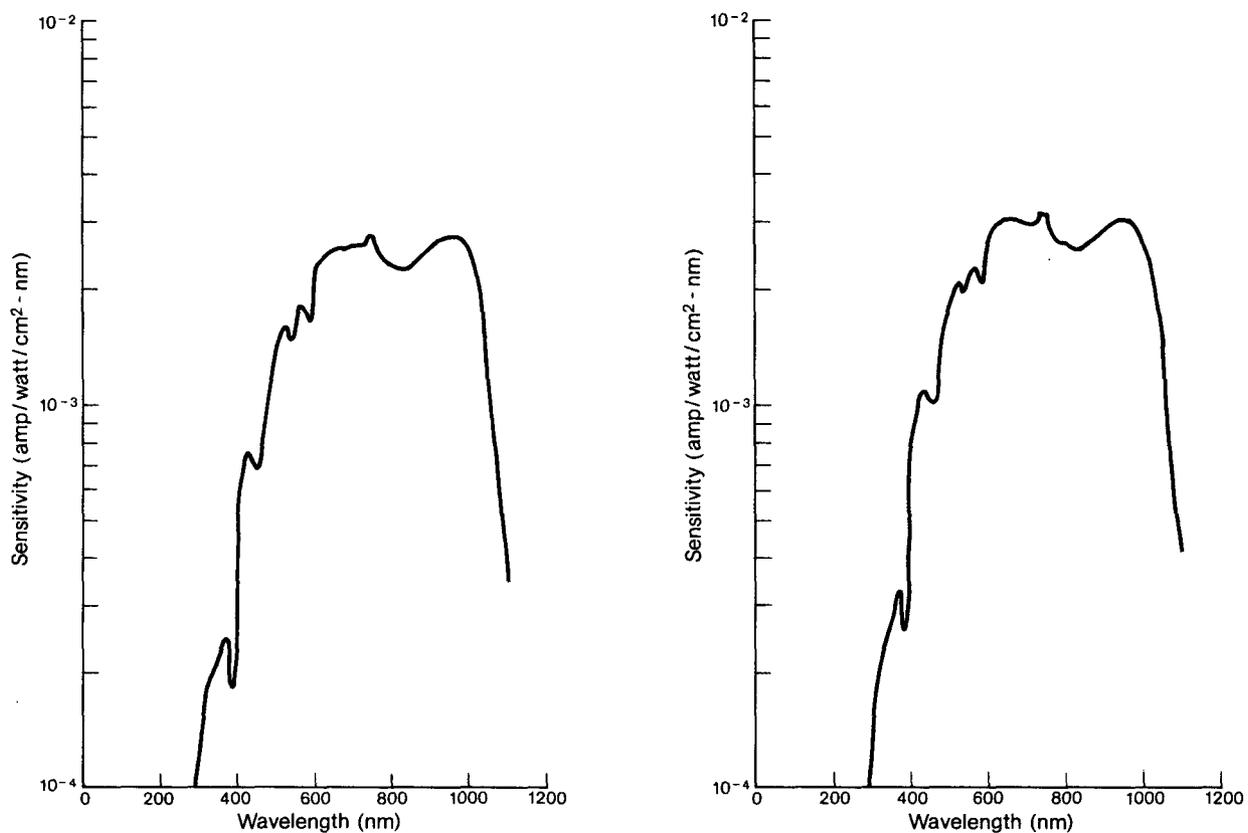FIG. 3. Comparison of calibration ratios from 15 runs during the 1978–79 season.

FIG. 4. Spectral sensitivities of the instruments used in this study.

was made that showed diffuser cosine response differing increasingly from true cosine response with increasing wavelength. Appropriate correction factors were then applied to data collected under clear skies. Diffusers with much improved cosine response are available for other studies, but the characteristics of any diffuser should always be well known and proper corrections applied if such devices are used in this system.

4. Results and conclusions

During the early stages of data collection, incident and reflected spectroradiometer scans were made with a single spectroradiometer. For example, upon completion of an incident run, the same unit was inverted, releveled and used for a reflected run. Runs were scheduled only when the operator anticipated fairly uniform atmospheric conditions for the period of both runs (~15-20 min). Many of the data collected with a single instrument appeared to be accurate; however, if cloud uniformity were not properly assessed, or if atmospheric conditions or solar altitude changed appreciably from the incident to the reflected scans, errors in the final results were manifested by varying degrees of erratic behavior in the spectral reflectance graphs. In direct contrast, snow and ice data collected with the dual spectroradiometer system exhibit a smooth appearance lacking in erratic behavior. No errors due to the hardware

or software described here have been noted, except for an occasional spurious datum point and the sequencing problem described earlier.

Fig. 5 shows spectral reflectances resulting from a separate incident and subsequent reflected scan over refrozen slush ice with the spectroradiometers equipped with hemispherical diffusers. Near the latter portion of the reflected scan, cloud conditions changed substantially. The effects on computed spectral reflectance are obvious. The incident scan readings were collected when solar radiation was relatively unattenuated by clouds, as compared to the last portion of the reflected scan readings. Lower reflected scan readings from 650-1100 nm (due to increased cirrus clouds) produced lower spectral reflectances in that range, since they were divided by previously collected incident scan readings with less attenuation due to clouds. The total albedo of refrozen slush is expected to diminish slightly as the incident radiation varies from mostly direct to mostly diffuse (Bolsenga, 1977, 1980), but not in the magnitude suggested here. In direct contrast to this rather extreme case, Fig. 6 shows spectral reflectances of refrozen slush ice in another area on a totally overcast day. These were acquired by the simultaneously recording, two-spectroradiometer system, which was also equipped with the same hemispherical diffusers. The smooth appearance and lack of abrupt changes in spectral reflectances suggest the improved accuracy of such a system.
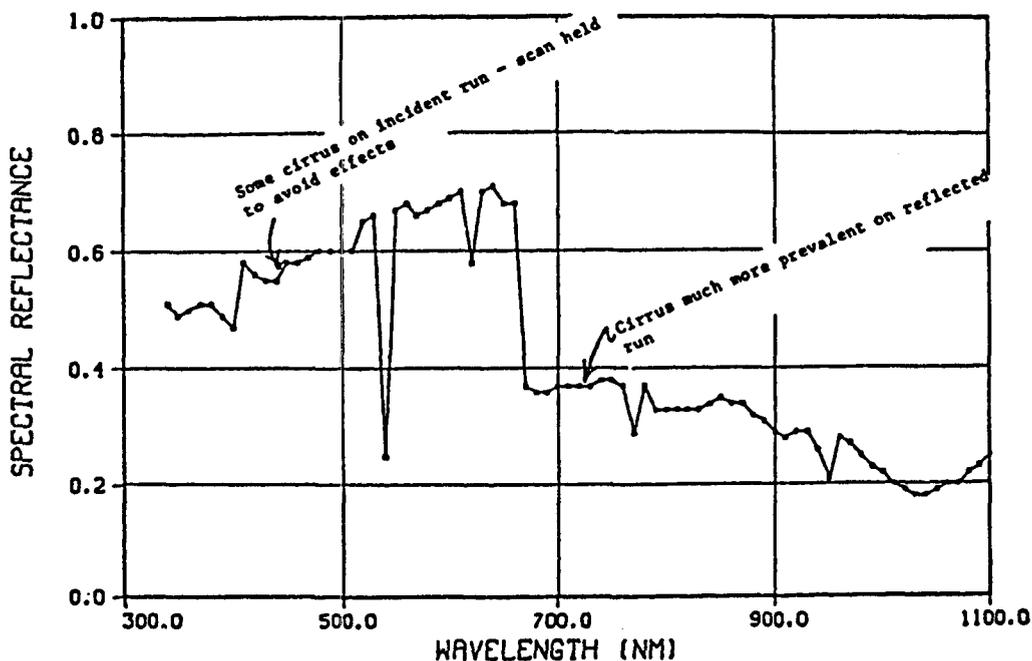

FIG. 5. Spectral reflectances of refrozen slush ice using one spectroradiometer when cirrus clouds became prominent during the reflected run.
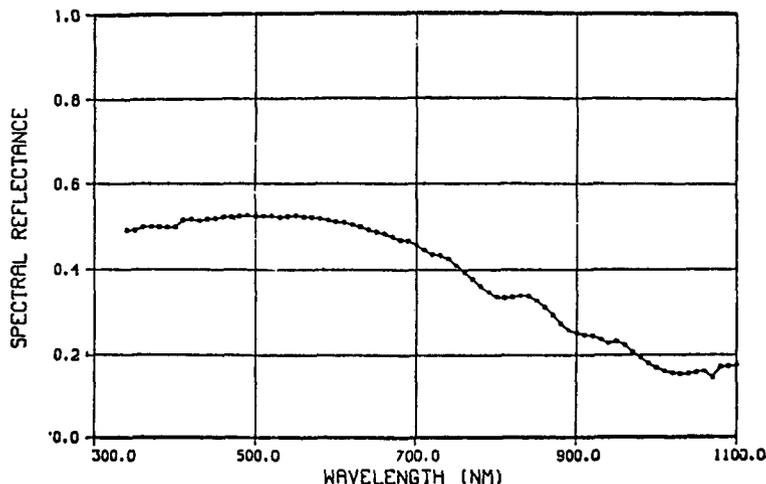
FIG. 6. Spectral reflectances of refrozen slush ice by the dual spectroradiometer system. Calculations for Figs. 5 and 6 are for similar ice surfaces taken during different years. Data from 280–330 nm are artificially suppressed in Figs. 5 and 6 due to a presumed lack of sufficient flux in the natural environment to produce accurate spectral reflectance calculations.

In summary, a simultaneously recording dual spectroradiometer system for measuring spectral reflectances of certain surfaces in the field is considered highly desirable. Because field data can be collected at both low and high solar altitudes, under varying atmospheric conditions (except precipitation), measurements can be made under conditions impossible with only one instrument. It should be noted, of course, that proper correction for less than perfect optical performance of the instruments (such as improper cosine response of diffusers under clear skies) is essential.

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