Remote Sensing Brief

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Does the Use of Two Radiometers Correct for Irradiance Changes During Measurements?

Yes, but only under conditions of uniform irradiation.

ABSTRACT: *The method of inter-calibrating two field radiometers proposed by Duggin (1980) is critically assessed. It is claimed that by this method it is possible to correct for the effects of variations in total solar irradiation upon hemispherical directional reflectance during a series of measurements. However, this is questioned because, in theory, the non-Lambertian nature of most natural surfaces prevents such a correction. Furthermore, it is shown that in practice, intra-canopy shadow effects are likely to confound the proposed method. Uniform irradiation conditions are seen as the only suitable environment for the field measurement of reflectance factors.*

INTRODUCTION

IN A RECENT PAPER describing the field measurement of reflectance factors, Duggin (1980) described a method involving the use of two intercalibrated radiometers to measure the hemispherical directional reflectance of natural surfaces. Several stages were involved in this method. First, the two radiometers were intercalibrated to match their transfer functions, having previously subtracted the dark-level offset voltages from each of their output voltages. Second, a series of regression equations were derived to account for solar elevation changes affecting the inter-calibration of the radiometers, due to errors in the cosine response of the receptors. The two radiometers were then used to calculate field reflectance factors by ratioing the output of one instrument monitoring total irradiance to the output of the second set up to monitor the target radiance.

The advantage of using two radiometers to measure irradiance and reflected radiance simultaneously was said to be that this avoided errors due to atmospheric variations. It is true that changes in irradiance between successive measurements of irradiance and reflected radiance using a single radiometer do cause errors, but most workers would recognize this and attempt to minimize the effect. Repeating each set of measurements three times, and avoiding collecting spectral data during periods of intermittent sunshine, helps in this respect.

Because of the fundamental importance of data derived from portable multiband radiometers to our understanding of the spectral reflectance properties of natural surfaces, any procedure claiming to increase the precision of such data needs to be carefully considered. One aspect of the method proposed by Duggin will be critically assessed.

CALCULATION OF THE FIELD REFLECTANCE FACTOR

The assumption that the use of two intercalibrated radiometers avoids errors due to changes in irradiation may be true for the hypothetical case where the target is a perfect Lambertian reflector, but its validity in the majority of field situations needs to be questioned. The angular anisotropy of many natural surfaces is well established (e.g., Duggin, 1977; Kriebel, 1976), and this effect, combined with the presence of canopy shadows, will mean that a simple technique using a second radiometer monitoring total irradiation will fail to compensate for all the con-

0099-1112/81/4708-1223$02.25/0

sequences of atmospheric changes. Consider, for example, a cloud obscuring the sun during a series of reflectance measurements over a partially vegetated surface. The relative proportion of direct as opposed to diffuse irradiation will change, changing both the spectral quality and the angular distribution of incoming radiation. The canopy radiance will alter due to its angular anisotropy and, perhaps more importantly, due to the removal of shadows formed by vegetation. The significance of shadows in controlling the reflectance of partially vegetated surfaces has been shown by several workers (e.g., Colwell,, 1974; Egbert, 1977; Milton, 1980). In contrast, the radiometer monitoring irradiation will merely record a change in the overall level of irradiation and a shift in its spectral distribution; no compensation will be made for canopy anisotropy or shadow effects.

To pursue further the example of a cloud passing in front of the sun during a series of measurements, consideration will be given to the likely effect that this would have on the hemispherical directional reflectance of a partially vegetated surface comprising 40 percent vegetation, 20 percent shadowed soil, and 40 percent sunlit soil. Table 1 presents the data to be used in this example.

In general, the hemispherical directional reflectance (HDR) of a surface can be expressed as

$$\text{HDR} = \frac{N_s}{S_t} \tag{1}$$

where N_s is the surface radiance and S_t is the total solar irradiance.

Where the field-of-view of a radiometer is occupied by several discrete surface components, Pearson and Miller (1972) have shown that the total surface radiance is equal to the summation of the individual component radiances, weighted by their area of occurrence, i.e.,

$$N_s = VN_v + ZN_z + SN_s \tag{2}$$

where

N_v is the radiance of the vegetative component,
N_z is the radiance of the shadow component,
N_s is the radiance of the soil component,
V is the proportion of the radiometer field-of-view occupied by vegetation,
Z is the proportion of the radiometer field-of-view occupied by shadow, and
S is the proportion of the radiometer field-of-view occupied by soil.

TABLE 1. SPECTRAL DATA USED IN THE EXAMPLE IN THE TEXT.

		Wavelength	
		650nm	750nm
Oat Leaf[1]	Reflectivity	6%	47%
	Transmissivity	2%	46%
Pedalfer Silt Soil[2]	Reflectivity	32%	38%

[1] taken from Colwell (1974)
[2] taken from Condit (1970)

Most published data are in units of reflectivity rather than radiance, because the latter depend upon irradiation conditions at the time of measurement. For the purposes of this paper, radiances can be re-created from such data by considering the total irradiation to equal 100 radiance units; hence, percentage reflectivity becomes a substitute for apparent radiance.

If the contribution of diffuse skylight is ignored, the radiance of areas shadowed by a single leaf thickness can be calculated as follows:

$$N_z = \tau_v \cdot \rho_s \cdot S_v \tag{3}$$

where τ_v = transmissivity of the leaf,
ρ_s = reflectivity of the soil surface, and
S_v = proportion of total irradiance falling on the leaf surface.

This accounts for incoming radiation being filtered by transmission through the leaf and then being reflected from the soil surface to the sensor overhead. However, most shadowed areas will receive an added radiance input from diffuse skylight. Tooming and Gulyaev (1967) calculated that diffuse skylight accounted for approximately 24 percent of total irradiation in the red part of the spectrum and approximately 22 percent in the near infrared region. The apparent radiance of shadowed areas must therefore be increased to account for this source, and Equation 3 becomes

$$N_z = (\tau_v \cdot \rho_s \cdot S_v) + (S_d \cdot \rho_s) \tag{4}$$

where S_d = diffuse solar radiation striking the horizontal area of leaf shadow (as a proportion of S_t).

When the sun is not obscured by clouds, and shadows are present on the surface, the hemispherical directional reflectance is therefore

$$HDR_1 = [VN_v + ZN_z + SN_s]/S_t \tag{5}$$

For the case when the sun is obscured by cloud, and no shadows are formed on the surface, Equation 5 becomes

$$HDR_2 = [VN_v + (Z + S)\, N_s]/S_d \tag{6}$$

The values of N_z, HDR_1, HDR_2, and ratio HDR_1/HDR_2 for the wavelengths 650 nm and 750 nm are given in Table 2.

These results imply that, for a typical partially vegetated surface, the effect of removing the shadow component (i.e., when the sun is obscured by cloud) is to cause an increase in reflectance of approximately 5 percent in the near infrared and

TABLE 2. THE RADIANCE OF THE SHADOW COMPONENT, THE HEMISPHERICAL DIRECTIONAL REFLECTANCES WITH AND WITHOUT SHADOWS, AND THE RATIO OF THOSE REFLECTANCES, ALL AS A FUNCTION OF WAVELENGTH.

Wavelength (nm)	N_z	HDR_1	HDR_2	HDR_1/HDR_2
650	8.32	0.169	0.216	0.782
750	25.84	0.392	0.416	0.942

almost 22 percent in the red part of the spectrum. The difference in the red band is considerably greater than the 10 percent error estimated by Duggin as attributable to changes in irradiance during a series of measurements.

This example considered shadows formed solely on the exposed soil surface by the passage of solar radiation through a single thickness of leaf. In reality, multiple leaf thicknesses and shadows falling upon leaf surfaces are likely to complicate the problem and possibly cause an even greater difference in surface reflectance between the two irradiation conditions. Equally, the effect of canopy anisotropy was not considered, although this is likely to be an important factor when vegetation with a mainly vertical structure is studied, such as tall grasses.

To avoid the problem of changing proportions of canopy shadow, the simplest solution is to take measurements of the spectral reflectance of natural surfaces under conditions of uniform irradiation, if that is possible. Either consistent bright sunshine or a uniform overcast day give suitable conditions, because they represent the extremes of irradiation regimes. It is for the researcher to choose which condition is more appropriate to the aims of the study.

CONCLUSION

Although two radiometers can be inter-calibrated, using a method similar to that suggested by Duggin, the proposed method of using the system to correct for variations in irradiance is likely to be confounded by the complexity of most natural surfaces. Until the nature of the interactions between irradiation and the major scene components (vegetation, substrate, and shadow) are understood more fully, field measurements of bidirectional or hemispherical directional reflectance are best performed under uniform irradiation conditions.

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(Received 3 November 1980; revised and accepted 11 February 1981)