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The Field Measurement of Reflectance Factors

Irradiance and reflected radiance are measured simultaneously with two radiometers between which only relative calibration need be determined.

ABSTRACT: *The literature contains reflectance factors which have been obtained in many different ways and which often disagree. The major error sources may be eliminated by using a simple relative measurement technique in which two radiometers are employed to measure simultaneously irradiance on the ground and radiance reflected from it. It is essential that the calibration between these radiometers and its dependence on sun angle be understood. This report deals with the problems of measurement, calibration, and analysis. Special emphasis is placed upon measurements made in the Landsat bandpasses.*

INTRODUCTION

THE HEMISPHERICAL-DIRECTIONAL reflectance factor (hereafter referred to as the reflectance factor) for a given region of the spectrum is the ratio of radiance reflected from a surface in a given direction to that incident upon it (irradiance). This ratio can be calculated from the two quantities measured either sequentially with one radiometer or simultaneously with two intercalibrated radiometers (e.g., Duggin *et al.*, 1975; Duggin, 1977; Duggin 1979). The latter has the advantage that it avoids errors due to atmospheric variations, which can cause irradiance changes (Kriebel, 1976; Kriebel, 1978) in the period between successive measurements (Slater, 1975; Duggin, 1974; Duggin, unpublished data), giving rise to up to 10 percent error in the calculated reflectance factor.

Many authors still present reflectance data obtained by sequential measurements using only one radiometer. This is possibly one reason why the published data on the reflectance properties of the Earth's surface are so much in conflict (e.g., NASA, 1971).

In a recent paper (Duggin, 1979) the author gave a simple method of measuring reflectance properties in which major error sources were discussed, together with means of eliminating or minimizing them by making simultaneous measurements of radiance and irradiance using two intercalibrated radiometers. The purpose of this publication is to present the method in more detail and to discuss matters relating to the calibration of data in greater detail.

RADIANCE AND IRRADIANCE MEASUREMENTS

Two similar radiometers are used. One measures the total (global) irradiance and the other measures radiance reflected from the ground. The instruments may be either scanning or non-scanning spectroradiometers since the method employed is the same, because both instruments are set at the same wavelength (or bandpass) for the measurement.

The arrangement of radiometers for measurement is shown in Figure 1. The instruments are mounted vertically; the one which measures irradiance is fitted with a cosine receptor and the other with an apertured receptor. The cosine receptor measures irradiance from the hemisphere of the sky, while the apertured receptor measures re-

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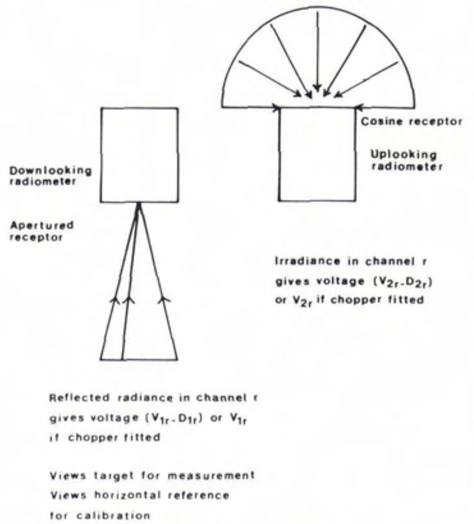

FIG. 1. The arrangement of radiometers for measurement and calibration.

flected radiance in a solid angle which is small, so that radiance may be measured from a given direction. The two instruments are read at the same time. In the case of 4-bandpass (non-scanning) Landsat ground truth radiometers, such as the Exotech model 100, the four voltages from each instrument are read at the same instant (e.g., Duggin *et al.*, 1975). Some radiometers possess a chopper, or like device, which permits the direct measurement of the voltage difference from the instrument for light incident upon the sensor compared to no light incident on the sensor (total darkness). Radiometers such as the Exotech model 100, which do not possess a chopper, record a voltage even when the aperture or the cosine receptor is covered. This is called the dark current, which must be subtracted from the measured voltage.

In collecting reflected radiance data, which may be compared to Landsat data, it is necessary to point the radiometer directly downwards to avoid angle-dependent variations in the detected radiance, which might be caused by angle-dependent variations in the reflectance factor (e.g., Egbert and Ulaby, 1972; Chance and LeMaster, 1977; Duggin, 1977; Duggin, unpublished data; Kriebel 1976; Kriebel, 1978; Kimes *et al.*, 1979).

When calibrating, it is essential to ensure that the field of view of the down-looking instrument integrates only the standard reflector and that there is no reflection of any kind onto the standard plate from (or shadowing by) the operator or his equipment. The use of matte black paint on possibly reflective equipment is recommended. It is similarly essential, when measuring reflected radiance from a real target, to avoid reflections onto (or shadowing of) the target area.

The up-looking radiometer, fitted with a cosine receptor, must be perfectly horizontal to avoid integration of areas below the horizon and must be situated above the experimeter and his equipment so that no artifacts due to reflections from (or shadowing by) the equipment arise.

Most instruments are fitted with mercury batteries. It should be emphasized that these fail suddenly and should be replaced regularly to avoid loss of data.

CALIBRATION

In order to calculate the reflectance factor, R_r, for bandpass, r, the calibration factor, C_r, between the two instruments for that bandpass must be measured. C_r depends strongly upon the solar zenith angle, z. The calibration, K_r, of the reflectance plate used as a field standard is also important. These factors will be dealt with in sequence.

MEASURING C_r

To calibrate the instruments, the down-looking radiometer, which has the apertured receptor, is pointed vertically at a matte, white standard reflector which fills the field of view. The other radiometer, fitted with the cosine receptor, measures irradiance. From a simultaneous measurement of the two radiometers (here taken to be instruments without choppers), we obtain the corrected voltage ratio

$$\left[\frac{V_{2r} - D_{2r}}{V_{1r} - D_{1r}}\right]_{\text{Cal}} = C_r$$

where

V_{1r} = voltage from down-looking radiometer 1,
V_{2r} = voltage from up-looking radiometer 2,
D_{1r} = dark-current from radiometer 1, and
D_{2r} = dark-current from radiometer 2.

For radiometers with chopper, the dark current in this and subsequent expressions is zero.

The calibration factor, C_r, is the ratio of irradiance reading of the up-looking radiometer to the radiance simultaneously reflected by the standard and recorded by the down-looking radiometer. During field calibration a portable, horizontal standard plate, coated with $BaSO_4$ is used. The reflectance of this plate can be measured in the laboratory and expressed, for each bandpass, as a fraction, K_r, of the reflectance of an optical reference standard of $BaSO_4$, which is taken to be a perfect, matte reflector.

DEPENDENCE OF C_r ON SOLAR ZENITH ANGLE

Due to non-Lambertian behavior (i.e., departure from the cosine law) of the standard reflector and of the cosine receptor, the ratio, C_r, depends upon irradiance and, therefore, upon the cosine of the solar zenith angle, z, at the time of measurement. Duggin (1979) reported that, for a pair of Exotech GTR 100 radiometers used by him with the same bandpasses as Landsat, the dependence of C_r on cos z for each bandpass was, where

$r = 1$ relates to Landsat bandpass MSS 4 (400-600 nm),
$r = 2$ relates to Landsat bandpass MSS 5 (600-700 nm),
$r = 3$ relates to Landsat bandpass MSS 6 (700-800 nm), and
$r = 4$ relates to Landsat bandpass MSS 7 (800-1100 nm),

given by the linear regression equations

$$C_1 = 0.422 + 0.158\cos z \qquad R^2 = 0.787$$
$$C_2 = 0.375 + 0.122\cos z \qquad R^2 = 0.788$$
$$C_3 = 0.367 + 0.169\cos z \qquad R^2 = 0.790$$
$$C_4 = 0.366 + 0.170\cos z \qquad R^2 = 0.825$$

where both radiometers have scales set on '×1' and where R^2 is the fraction of the variance explained by the regression. For the case of each bandpass, the calibration factor, C_r, is very significantly related to cos z ($P < 0.001$) and between 78 percent and 82 percent (depending on bandpass) of the variation in C_r can be explained by a linear regression on cos z.

It should be noted that when making reflectance measurements the scale factor is ×1 for all bandpasses on the up-looking radiometer. However, for the down-looking radiometer, the scale factor is ×1 or ×5 for bandpasses corresponding to Landsat MSS 4 and MSS 5, but ×1 for those corresponding to Landsat MSS 6 and MSS 7. The reason for this is that some (e.g., vegetative) targets give reflectance values in bandpasses MSS 4 and MSS 5 which are generally between 10 percent and 50 percent of those in bandpasses MSS 6 and MSS 7. Therefore, greater sensitivity is required for bandpasses MSS 4 and MSS 5. It is essential that the same scale factors apply for calibration and for measurement. Therefore, for targets with low reflectance in MSS 4 and MSS 5 (e.g., vegetative targets) values of C_r corresponding to a scale factor of ×5 on the down-looking radiometer must be used.

$$\text{Since } C_r = \left[\frac{V_{2r} - D_{2r}}{V_{1r} - D_{1r}}\right]$$

$$= \left[\frac{\text{corrected voltage from up-looking radiometer which measures irradiance}}{\text{corrected voltage from down-looking radiometer which measures reflected radiance}}\right],$$

then a change in scale from ×1 to ×5 on the down-looking radiometer should reduce C_r by a factor of 5.00. Measurements by the author on a pair of Exotech model 100 radiometers held by the New South Wales Department of Agriculture (NSWDA) show that this is the case within 2 percent for channels MSS 4 ($r = 1$) and MSS 5 ($r = 2$).

Extensive calibration measurements have been made* using the same (NSWDA) pair of Exotech Model 100 radiometers and employing an identical measurement technique as that reported by Duggin (1979). The author has analyzed these data and found that a third degree polynomial regression best fit the data for channels MSS 4-MSS 6 for the case where all channels were set on a scale of ×1 (a scale of ×5 for MSS 4 and MSS 5 caused saturation of the operational amplifiers in the down-looking radiometer, resulting in meaningless data). A quadratic fit best explained the data for MSS 7. The fraction of the variance, R^2, explained by the regression fits was between 0.87 and 0.97, depending upon the channel. The variance in no case depended upon the independent variable (cos z) and the residuals appear homogeneously distributed with cos z. The regression curves for C_r vs. cos z are shown for all channels in Figure 2. The regression equations were

$$C_1 = 0.347 + 0.465 \cos z - 0.565 \cos^2 z + 0.227 \cos^3 z$$
$$R^2 = 0.874$$

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* Data provided by Mr. K. W. Dawbin of the New South Wales Department of Agriculture, Sydney, Australia.

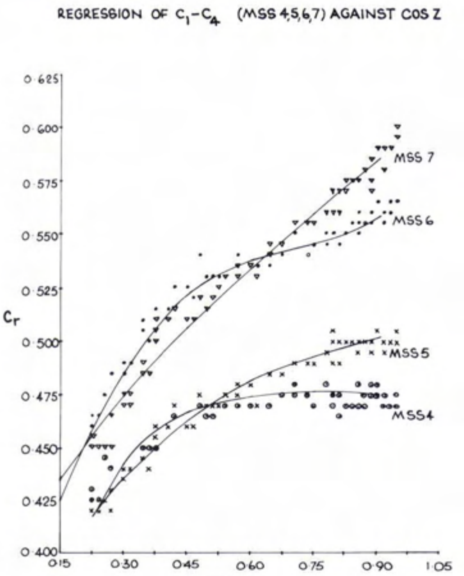

FIG. 2. The regression of C_1-C_4 against cos z.

$$C_2 = 0.336 + 0.463 \cos z - 0.484 \cos^2 z + 0.192 \cos^3 z$$
$$R^2 = 0.955$$

$$C_3 = 0.306 + 0.937 \cos z - 1.297 \cos^2 z + 0.631 \cos^3 z$$
$$R^2 = 0.971$$

$$C_4 = 0.393 + 0.292 \cos z - 0.089 \cos^2 z$$
$$R^2 = 0.958$$

It is seen that the values of C_r are generally only within 10 percent of each other for the two radiometer pairs for any given value of cos z and that the dependence on cos z depends upon the radiometer pair in question. Thus, it is important that calibrations be carried out for the radiometers to be used in a given set of measurements since a calibration from one radiometer pair cannot be expected to hold true for any other radiometer pair.

CALCULATION OF THE REFLECTANCE FACTOR R_r

The calibrated reflectance factor in bandpass r is given (for radiometers without choppers) by

$$\mathrm{R}_r = \left[\frac{V_{1r} - D_{1r}}{V_{2r} - D_{2r}}\right] \times \hat{\mathrm{C}}_r \times \mathrm{K}_r$$

where the estimate, $\hat{C}_r$, is obtained from the appropriate regression equations. As stated above, regression relationships would need to be obtained experimentally for any radiometer pair. It should be noted that changes in C_r due to changes in z of up to 30 percent have been observed. These changes give rise to errors of the same order in R_r if not calibrated for. These effects are instrumental, perhaps due to the departure of the cosine receptor on the radiometer measuring irradiance from true cosine behavior and are not related to the change in the reflectance factors of terrain with solar zenith angle z (e.g., Egbert and Ulaby, 1972; Chance and LeMaster, 1977; Duggin, 1977; Kriebel 1976; Kriebel, 1978; Kiems *et al.*, 1979). K_r is the reflectance (compared to a barium sulphate laboratory standard) of the portable field reflector.

CALIBRATION OF THE PORTABLE FIELD REFLECTOR

Until 1979, the author has used Eastman Kodak barium sulphate paint as a field standard of reflectance (Duggin *et al.*, 1975); the reflector has been calibrated from time-to-time in the laboratory using a spectrophotometer. The portable reflector now used is made up of barium sulphate plates. Typical values for the reflectance of the painted portable reflector, K_r, reported by Duggin *et al.* (1975) were

MSS 4	0.944
MSS 5	0.942
MSS 6	0.934
MSS 7	0.929

A calibration of a standard reflector consisting of barium sulphate paint was recently made in the field as follows:

Two intercalibrated radiometers were used: one was pointed at the portable field standard to be calibrated and the other was pointed at a reflector made up of standard white barium sulphate reflector plates. If the standard reflector, made up of barium sulphate plates, was taken to have a reflectance of 1.00, then the field standard was found to have a reflectance 2-4 percent less in the Landsat channels, which is within 3-4 percent of the laboratory measurements reported above. This level of accuracy is probably acceptable for many purposes. However, when great accuracy is required, laboratory calibration is recommended, since conditions of measurement are more rigorously controlled than is possible in the field.

CONCLUSION

The measurement and inclusion in calculations of the dark current, D_r, for radiometers without a chopper, the measurement of the sun angle dependence of C_r which can be achieved from a measurement of local time of observation*, and the measurement of K_r are vital to the accurate field measurement of the reflectance factor, R_r. It is also essential to measure irradiance and radiance simultaneously to avoid error in R_r due to irradiance changes arising from atmospheric fluctuations, which can occur between sequential measurements.

The simple procedure presented here for accurately measuring R_r involves only the relative calibration of two instruments and is thus independent of their absolute calibration. However, it is desirable that absolute calibration be checked periodically using standard sources of radiance and irradiance to ensure instrumental stability.

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* $\cos z = \sin \phi \sin \delta + \cos \phi \cos \delta \cos$

$$\left(\frac{360}{24}\right)\left(TH + \frac{TM}{60} - SLN\right)$$

where z = solar zenith angle
ϕ = latitude
δ = solar declination
TH = time (hours)
TM = time (minutes)
SLN = solar noon