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USGS Aerial Resolution Targets

The target array, consisting of bar targets and a Siemens star target painted on the roof of the U.S. Geological Survey's John Wesley Powell Federal Building in Reston, Virginia, is described.

ABSTRACT: *It is necessary to measure the achievable resolution of any airborne sensor that is to be used for metric purposes. Laboratory calibration facilities may be inadequate or inappropriate for determining the resolution of non-photographic sensors such as optical-mechanical scanners, television imaging tubes, and linear arrays. However, large target arrays imaged in the field can be used in testing such systems. Field testing has the advantage of measuring the resolution of the entire imaging process, including the effect of phenomena such as atmospheric attenuation and aircraft motions. The USGS has constructed an array of resolution targets in order to permit field testing of a variety of airborne sensing systems. The target array consists of bar targets and a Siemens star target. The largest bar has a width of 6 feet and the star has a diameter of 140 feet. The average contrast ratio of the targets, determined from photometric measurements, is 2.2:1. The targets are located on the roof of the John Wesley Powell Federal Building, the U.S. Geological Survey National Center, in Reston, Virginia. This site was selected because it is convenient, protected, and in a shadow-free area. The target array permits any interested organization with an airborne sensing system to accurately determine the operational resolution of its system.*

INTRODUCTION

IN THE LAST FEW DECADES a number of non-photographic airborne and satellite imaging systems have been developed and are being used for a variety of remote sensing tasks. Optical-mechanical scanners, television imaging tubes, and linear arrays are typical examples. These systems often have performance characteristics quite different from photographic systems, and the dynamic range and resolution possible under operational conditions are not directly comparable to separate laboratory measurements. However, the procedures for testing aerial cameras and film are fairly well established; the U.S. Geological Survey (USGS) has operated a multicollimator camera-testing facility for almost two decades. Resolution of the lens, filter, and film combination at various field angles can be determined by means of a standard three-bar test pattern at the same time that the geometric parameters of the camera are calibrated. The laboratory environment offers controlled conditions and convenience. Results from testing an aerial camera and film in the laboratory can be translated with high confidence to the expected performance under field operating conditions. However, large target arrays are occasionally constructed in the field to establish or confirm certain camera or film image characteristics that cannot be adequately simulated in a laboratory; aircraft motions, atmospheric attenuation, color response, water penetration, and combinations thereof are typical examples. Field testing, then, has the advantage of measuring the attainable resolution not of the sensor alone, but of the entire imaging process. In the instances in which the sensor is a non-photographic type, and laboratory calibration facilities may be inadequate or inappropriate, ground resolution targets can provide a means of reliably determining the resolution attainable under actual field conditions. It is with this purpose in mind that an array of resolution targets has been painted on the roof of the John Wesley Powell Federal Building, the U.S. Geological Survey National Center, in Reston,

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 48, No. 9, September 1982, pp. 1469-1473.

0099-1112/82/4809-1469$02.25/0

Virginia (Figures 1, 2, and 3). The National Center roof was selected because it provides a relatively large protected site which is in an almost shadow-free area. Its location permits the target to be inspected periodically without the complication of having to travel to a remote site.

TARGET DESIGN

The USGS has conducted prior experiments with large bar-target arrays in order to determine the imaging characteristics of photogrammetric camera systems (Welch and Halliday, 1973). A later study utilized some of the same ground targets for an investigation of the effect on resolution of image motion and devices intended for its compensation (Amos, unpublished report, Topographic Div., USGS, 1976). The targets painted on the roof include bar targets of the same geometric configuration as those used in the two earlier studies and, in addition, a Siemens star target. The Siemens star target is quite useful in determining resolution (Brown, 1965). A half Siemens star with a smaller radius than the USGS version was built by the USAF's Rome Air Development Center (RADC) at a site near Rome, New York (Rochford, *et al.*, 1973).

The Siemens star target offers several advantages over a set of mutually perpendicular bar targets. First, the star target is multi-directional. Resolution, both parallel and perpendicular to the line of flight, can be determined without applying corrections to the photograph or image measurements, regardless of the aircraft's heading. With bar targets, the aircraft must fly parallel to one group of the bars, thus ensuring one group being parallel to the line of flight and the other group being transverse. If the aircraft's heading does not correspond to the heading of one target group, corrections are necessary. Secondly, the Siemens star offers a continuously decreasing line-pair width from the largest dimension at the target's outer edge to an infinitesimal dimension near the center of the target. Bar targets, by their nature, are of discrete dimensions and, therefore, contain gaps in the line-pair widths. Third, when using nonphotographic imaging systems, such as scanners, bar targets may not be properly aligned. These facts probably are the reasons that the Siemens star at the RADC facility (Rochford *et al.*, 1973) has been shown to be more precise in the determination of resolution than the bar targets. Surprisingly, few star targets have been constructed; the larger area required may be a factor.

In addition to the geometric configuration, the target contrast is an extremely important consideration. When the resolution threshold has been reached for any given system, target contrast must be considered; if higher- or lower-contrast targets could have been imaged, it is quite possible that more or fewer line pairs could have been resolved. Recalling that the purpose of constructing these targets is to provide a means of obtaining realistic resolution values for imaging systems, low-contrast targets were decided upon. Such low-contrast targets (contrast ratio = 2:1) are more desirable than high contrast targets (contrast ratio = 100:1 or greater) for performance tests because they more realistically represent actual terrain contrasts (Welch, 1971). The colors selected for the targets were black and gray because these shades more adequately exhibit realistic terrain reflectances than would a white and gray target.

The bar targets have the same dimensions as some of those used in the previous USGS studies (Welch and Halliday, 1973) and are based on a design used by the National Bureau of Standards. They consist of alternating black and gray bars arranged in two groups perpendicular to each other. Each group is 20 feet wide by 100.5 feet in length

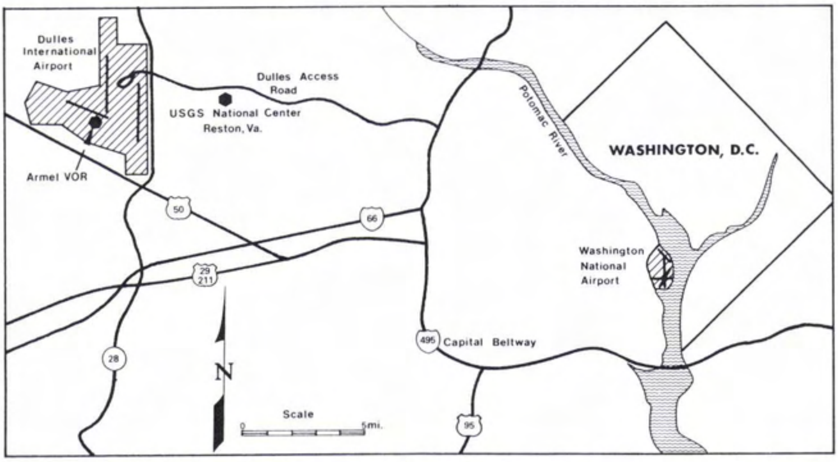

FIG. 1. Map showing the location of the USGS National Center, Reston, Virginia.

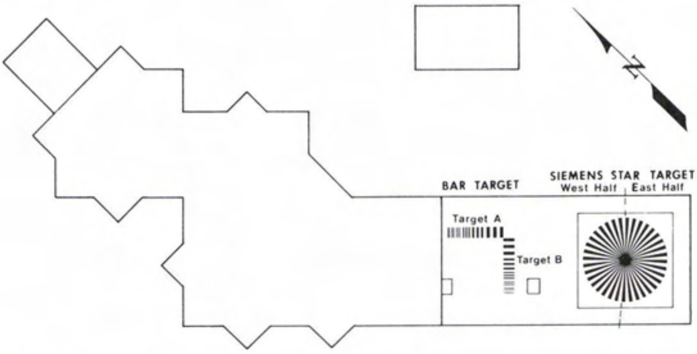

FIG. 2. Resolution target locations on the John Wesley Powell Federal Building, USGS National Center, Reston, Virginia.

and contains six sets of bars (Figure 4). Each bar set contains six individual bars, three black and three gray, which are of equal width. The individual bar widths of each set are, in descending order: 6.0 feet, 4.0 feet, 2.5 feet, 1.5 feet, 1.0 foot, and 0.75 foot. The Siemens star target is based on the USAF/RADC design and consists of alternating black and gray wedges every 5 degrees of arc. The target diameter is 140 feet, yielding a maximum wedge width of 6.109 feet (Figure 5). The design contrast ratio for both the bar and star targets was 2.5:1.

The bar and star targets were constructed by first painting a white base coat on the asphalt and gravel roof. The appropriate distances and angles were then surveyed and marked. Finally, the base-coat areas were overpainted with the gray and black. The east "half" of the Siemens star (Figures 2 and 5) was completed in October 1979. The west "half" of the Siemens star and the bar targets (A and B, Figure 4) were completed in July 1980. The star target was painted with Sherman Williams A-100 flat latex paint.* Due to problems with paint supply, the bar targets were painted with a comparable flat latex produced by Atlas Paint and Varnish Company.*

FIG. 3. Large resolution targets painted on the roof of the John Wesley Powell Federal Building, USGS National Center, Reston, Virginia.

It should be noted that the targets have been painted on an asphalt and gravel roof. Therefore, the target surface is non-lambertian. Consequently, the response can be affected by backscatter. On photographic images, backscatter might occur at high sun angles.

A series of resolution targets comprising a variety of bar targets, gray scales of graduated reflectances, and multi-panel contrast targets are available at various locations throughout the county. This series of targets is known as the Controlled Range Network (CORN). CORN was built for the U.S. Air Force. Documentation detailing the locations and characteristics of the targets should be consulted before use (Data Corporation, 1968).

TARGET CALIBRATION

Measurements of reflected energy (in the visible spectrum) from the individual bars and wedges were made in order to determine the actual contrast ratios and to ensure that the shades of gray and black did not vary significantly from one portion of a target to another, and from target to target.

The measurements were made with a Gossen 1.67-799 photometer during the morning of 12 July 1980. Weather conditions were clear and warm. Measurements were made by holding the photometer approximately four feet above each wedge of the Siemens star. The measurements of the bar targets were made in similar manner, with the measurements being taken in the center of the bar. Due to the size of the area sensed by the photometer (approximately 3 feet by 3 feet), only the 6.0 foot and 4.0 foot bars were measured.

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* Any use of trade names and trademarks is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Fig. 4. Bar targets

The contrast ratios were computed by the following formula:

$$C = M_L / M_D$$

where

C = Numerical value of the contrast ratio in the Form C:1,

M_D = Reflected energy from the dark (black) bars and wedges, and

M_L = Reflected energy from the light (gray) bars and wedges.

It is important to realize that the calibration performed is photometric and not radiometric in nature. That is, it pertains only to the visible portion of the electromagnetic spectrum and as such can only serve to indicate what direct contrasts one could expect using a photographic system. There are no plans to calibrate the target radiometrically at this time nor to calibrate the reflective or thermal infrared response. Furthermore, it should be noted that the reflected energy measurements are dynamic; they will differ with varying atmospheric conditions and will also change with time. The degree of cloud cover and atmospheric haze and the position of the sun all have an effect on how much energy impinges upon the surface of the target, and, hence, how much energy is reflected. With time, the targets will fade from the sun, may become covered by dust and grime, and will become worn by precipitation. The effect of these actions can be seen by comparing the east and west "halves" of the Siemens star, which were completed one year apart. Therefore, it is important to take into account the elapsed time between target calibration and the time they are imaged. Of course, it is desirable to have measurements close to the time that the targets are imaged.

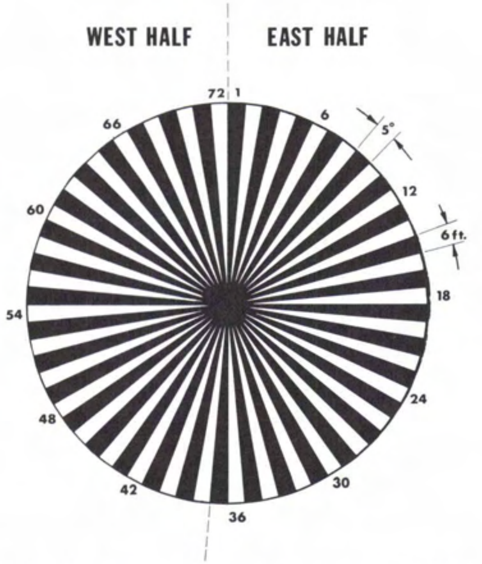

Fig. 5. Siemens star target, diameter = 140 feet.

The results of the initial calibration indicate that the bar targets (A and B) exhibit slightly lower average reflected energy values than the average reflected energy values for the Siemens star (Tables 1 and 2). This is believed due to the bar targets having been painted with a different brand of paint. The east and west "halves" of the star exhibit different average contrast ratios because they were painted nearly one year apart, the east "half" having endured one year of weathering.

Target Use

The resolution of an imaging system may be determined by imaging the target array, making measurements for scale determination, and then applying the following formula:

$$\text{Resolution (line pairs/mm)} = LP \cdot SF$$

where

LP = 1 line pair/width of the smallest set of discernible bars or wedges in ground units, and

SF = scale factor in ground units per millimetre.

Table 1. The Calibrated Average Contrast Ratio for Each Target

Target	Avg. Contrast Ratio
A	2.16:1
B	2.02:1
Star, East "Half"	2.16:1
Star, West "Half"	2.41:1
Full Star	2.28:1

TABLE 2. THE CALIBRATED AVERAGE REFLECTED ENERGY FOR EACH TARGET

Target	Avg. Gray Reflected Energy	Avg. Black Reflected Energy
A	154	73
B	155	77
STAR	240	107

The scale factor, *SF*, should be determined for that portion of the imagery that is near to the location of the imaged targets. It can be computed by measuring the image distance between two points, whose separation in ground units is known. To obtain the quantity *LP*, it is necessary to determine the smallest dimension of the target that is discernible. This is a very subjective decision, and it is often valuable to have more than one interpreter judge this quantity. In the case of the bar targets, this quantity would be the reciprocal of the pair of bar widths (in ground units) of the set of bars that are completely discernible. For example, if all six of the 4.0-foot bars were discernible, and only two or three (but not all six) of the 2.5-foot bars are discernible, then the value of *LP* would be 1/8, since 8 feet is the width of two 4-foot bars, that is, one bar pair. The 2.5-foot bar set does not count because it is not completely identifiable. Similarly, with the star target, the narrowest wedge width must be determined. Rather than measure the wedge width directly, it may be easier and more accurate to determine the radius of the unresolved portion of the star, *R*, by measuring the radial length of the resolved portion of the wedge, subtracting from the total known radius of 70 feet, and then applying the trigonometric relationship

$$S = R \cdot \theta$$

where

S = wedge width
R = radius of unresolved portion, and
θ = 0.08726646 radians (5 degrees).

These targets have been built with the intention that organizations with various sensing systems will fly over the targets. Any measurements and/or other determinations would have to be performed by the organizations themselves. While efforts will be made to monitor the targets, the USGS does not guarantee that the targets will be recalibrated on any particular schedule. The USGS would be interested in any results obtained through use of the targets or any other comments relating to the targets. For further information on the status of the targets, please write to the Chief, National Mapping Division, U.S. Geological Survey, MS-516, Reston, VA 22092.

For those interested in flying over the targets, the USGS National Center is located in Reston, Virginia, approximately 5 nautical miles on the 088° radial of Armel VOR. The location is near the edge of the Dulles Airport Traffic Area and within the Dulles Terminal Radar Service Area, both considerations in planning an overflight.

SUMMARY AND CONCLUSIONS

An array of large resolution targets has been painted on the roof of the John Wesley Powell Federal Building, the U.S. Geological Survey National Center, located in Reston, Virginia. The target array comprises bar targets and a Siemens star target. The targets are of the low-contrast type, with an overall contrast ratio of approximately 2.2:1. This contrast ratio was determined from a photometric calibration of the target array. Although the shade varies slightly between the bar targets and the star target, and "half" the star target has an additional year's worth of weathering, previous experience with large target arrays indicates that the differences are not great enough to prevent use of the targets. Because the reflected energy values and, hence, the contrast ratios, change with time, these values should be checked periodically. Once the target array has been imaged, resolution may be determined by qualitatively determining the smallest target dimension that is discernible, computing the image scale, and then applying a simple formula.

Unlike aerial cameras, which can be adequately tested in a laboratory, non-photographic sensors usually exhibit performance characteristics which preclude direct use of laboratory measurements. Therefore, these targets should prove valuable in determining the achievable resolution of non-photographic imaging systems. However, the targets may also be of interest with regard to photographic systems, because the resolution values obtained are due not only to the sensor itself, but also to the effects of aircraft motion and environmental factors. Such effects are always present when any imaging system is used in practice, and as such, the targets provide a means of determining realistic resolution values for imaging systems.

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(Received 11 September 1981; revised and accepted 15 March 1982)

Forum

Field Measurement of Reflectance Factors: A Further Note

ALTHOUGH not wishing to prolong unnecessarily the debate about the field measurement of reflectance factors (Duggin, 1980; Milton, 1981a; Duggin, 1982), I feel it is most important to add further comments concerning which atmospheric conditions are favorable for the collection of ground data.

Duggin (1982) reports the existence of significant irradiance fluctuations during "clear sky" conditions, and stresses that such fluctuations are of unknown period and amplitude and, therefore, cannot be predicted or retrospectively compensated. This, he maintains, is the main reason why simultaneous measurements of global irradiance and directional radiance are essential to avoid the errors that would be introduced into sequential measurements. Although the physical causes of such short-term irradiance changes are unknown, they presumably result from variations in the transmission properties of the atmosphere within the direct solar beam, variations in atmospheric turbidity, or variations in the solar constant. Because the distribution of irradiation is strongly anisotropic, any variation in atmospheric properties resulting in a possible 10 percent change in total irradiance is likely to result in a change in the distribution of irradiation over the hemisphere, and, as Kriebel (1976) stated, "the directional reflected radiation of natural surfaces may change even if nothing save the distribution of the irradiation over the hemisphere varies." Kriebel was referring to reflectance measurements from light aircraft, although work by Kimes *et al.* (1980) using ground based measurements arrived at a similar conclusion, and clearly showed that "the hemispherical-conical reflectance factor . . . is dependent on the anisotropic distribution of sky irradiance."

Obviously, the significance of changes in the distribution of irradiation on the measured reflectance of natural surfaces will vary due to such factors as canopy geometry, solar zenith angle, wave length, and the difference in reflectance between the canopy and the background. However, the importance of vertical elements in the canopy in controlling reflectance changes with variations in the direction of irradiation has been shown in field measurements by Kimes *et al.* (1981) and in studies of simulated canopies by Verhoef and Bunnik (1981) and Kirchner *et al.* (1981). This work shows that the greatest effect is to be expected for erectophile canopies (i.e., those canopies dominated by vertically oriented leaves) and, in particular, in those wavelengths where both the difference in reflectance between vegetation and background is high and the ratio of skylight to direct irradiation is greatest. Hulstrom (1974) reported a rapid decrease in the ratio of skylight to direct irradiation with increasing wavelength from gound measurements on clear days. This, combined with the high transmittance of infrared radiation by most green vegetation, is likely to mean that the visible part of the spectrum will be most affected, particularly the red wavelengths where transmission through leaves is usually least. In addition, the greatest variations are likely to be found in partially closed canopies, because a dense erectophile canopy merely acts as an "optical trap" and reflects little in the red part of the spectrum (Coulson and Reynolds, 1971). However, a partially closed canopy has a reflectance regime dependent on the relative proportions of the "sunlit-to-shade" mosaic (Vinogradov, 1969), the effect of which is in turn dependent upon the reflectance difference between the canopy and the background. At red wavelengths, typical temperate zone soils have a similar reflectance to the green vegetation growing upon them (Colwell, 1974), whereas arid zone soils at red wavelengths usually have a much higher reflectance than the vegetation they support (Otterman, 1981a). It is, therefore, hardly surprising that only small changes in reflectance were found by Duggin from a barley field, because none greater would have been expected. However, this is not so in other environments; for example, when measurements of semi-arid zone vegetation are studied, it is clear that the ratio of direct to diffuse irradiation is often crucial in determining the directional reflectance, through its control upon intra-canopy and inter-plant shadowing (Vinogradov, 1969; Musick *et al.*, 1974; Otterman and Fraser, 1976; Otterman, 1981b; Milton, 1981).

I would argue, therefore, that the recognition of the importance of short-term irradiance fluctuations is precisely the reason why the proposed "simultaneous measurement" method should be more thoroughly evaluated before being promoted as having the "advantage that it avoids errors due to atmospheric variations, which can cause irradiance changes in the period between successive measurements" (Duggin, 1980). Although I share Professor Duggin's frustration at the difficulties of making measurements during times of variable irradiation, to adopt his proposed method means to presuppose the absence of any significant changes in canopy reflectance due to changes in the distribution of irradiation. This may be a reasonable assumption for a bare surface, a dense vegetation canopy (such as the barley field studied by Duggin), or even an incomplete vegetation canopy growing on a dark soil, but it is unwarranted for more complex canopies growing on highly contrasting backgrounds.

To return to the question of determining whether atmospheric conditions are suitable or not for collecting ground spectral data, I must correct Professor Duggin's statement that I insisted that "all measurements must be made under completely clear skies" (Duggin, 1982); what I actually stated (Milton, 1981a, p. 1225) was that measurements should be performed under *uniform* irradiation conditions by which I meant invariant over the time period of measurements. I agree with Wiegand (1980) that measurements taken under completely overcast conditions are useful in practical terms, although they are obviously different from measurements of the true bidirectional reflectance factor and may be impossible to standardize as the distribution of irradiation is uncertain. Kriebel (1978) addressed this problem and suggested that, whereas for a cloudless sky, reflectance depends on solar zenith angle and atmospheric turbidity, for an overcast sky, reflectance is averaged over all zenith angels of incidence. From results reported by de Boer *et al.* (1973), it seems that values of directional reflectance from most vegetated surfaces increase by about 10 percent under an overcast sky.

In many cases one has to take measurements when there are scattered clouds in the sky. Despite the known effect of any cloud in the sky increasing the diffuse irradiation relative to the direct irradiation (Monteith, 1973), it is probably safe to ignore small clouds near to the horizon because the extra irradiation contributes little to the total. It is impossible to give definite quantitative statements as to when measurements can be made because this will depend upon the sensitivity of the measured reflectance to changes in irradiation, which is site-dependent through the interaction of canopy architecture, soil reflectance, leaf area index (LAI), sun zenith angle, wavelength, and other factors.

When considering the "sequential measurement" method, some researchers have restricted measurements to clear skies (e.g., Pinter *et al.*, 1981; Suits and Safir, 1972). Coulson and Reynolds (1971) noted errors due to the increased variability of measurements on hazy days, presumably due partly to the fact that the delay between measurement of radiance and irradiance was up to two minutes. Markham *et al.* (1981) collected spectral data during clear skies, hazy skies, and scattered cloud, and later screened the data to eliminate those points showing excessive noise. Le Master *et al.* (1980) restricted data collection to either clear or overcast days, while Ahern *et al.* (1981) reported that, providing the radiance and irradiance were measured "within seconds of each other," measurements could be made under thin to moderate cirrus.

The situation where the sun is intermittently obscured by cloud is a difficult one for accurate measurements because, as Monteith (1973) has reported, "for a few minutes before and after the sun is occluded the irradiance tends to be anomalously large . . . ," this being due to strong forward scattering of radiation by water droplets near the edge of the cloud. The presence of clouds close to the sun can also be expected to influence the diffuse flux because most of the skylight originates from this sector. This introduces error into measurements taken using the sequential method because the amount and distribution of irradiation changes between measurement of target and calibration standard. Under these conditions, the simultaneous method would also be prone to errors (although probably not as great) as the strong directional component of irradiation would be reduced.

Unfortunately, the presence of high altitude cirrus clouds passing in front of the sun is very difficult to detect with the human eye due to its relative insensitivity to changes in illumination at high light levels. Often the only indication that this is occurring is a fluctuation of the reflectance standard radiance, which is evident when the sequential method is being used. Such changes would not be evident with the simultaneous method proposed by Duggin, unless provision was made for monitoring the output of the radiometer measuring irradiance over the period of measurement, or a continuously recording solarimeter was operating, as used by Hulstrom (1974).

In conclusion, I fully agree with Duggin (1982) that further experiments are needed to establish the atmospheric conditions during which accurate ground data collection is possible. In the absence of such experiments any strict quantitative statement of suitable conditions is unwise, and, as mentioned earlier, would involve a consideration of site-dependent factors. However, practical experience suggests that the sequential method is capable of collecting useful data under clear skies, overcast skies, and during the presence of scattered clouds, providing the region of the sky near to the sun is not affected. Such measurements should be replicated at least three times per site, and further randomly located sites taken within each plot. A continuously recording solarimeter should be used in close proximity to the field area to record the presence of high altitude clouds obscuring the sun, and data collected during such periods should be subjected to careful screening. The time interval between measurement of target radiance and calibration standard radiance (or hemispherical irradiance) should be less than five seconds, and successive calibration standard radiances should be checked for close agreement.

Significant deviations in the usual barium sulphate calibration standard from a lambertian response limit its use to solar zenith angles less than 55° (Kimes *et al.*, 1980), although several researchers have suggested that barium sulphate is inappropriate as a field standard for other reasons (Milton, 1980; Ahern *et al.*, 1981).

Although the considerable advance in terms of the ease of collecting ground data using the simultaneous method is to be welcomed, such measurements should be restricted either to the atmospheric conditions outlined above for the sequential method, or to measurements over surfaces with known geometric properties. In the majority of cases, where the angular properties of the surface are unknown, replication of each measurement using either method and careful data screening are the best safeguards against the effects of the short-term irradiance fluctuations reported by Duggin.

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