Sources of Uncertainty in Vicarious Calibration: Understanding Calibration Target Reflectance

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***Abstract*— A field experiment investigated the hypothesis that the nadir reflectance of calibration surface substrates (asphalt and concrete) remains stable over a range of time-scales. Measurable differences in spectral reflectance factors were found over periods as short as 30 minutes. Multi-date reflectance measurements were compared using ANOVA and found to differ significantly ($p = 0.001$). Surface reflectance showed a relationship with the relative proportion of diffuse irradiance, over periods when solar zenith changes were minimal. These findings illustrate the anisotropic nature of calibration surfaces, and place emphasis on the need for collection of diffuse and global irradiance measurements at the time of remotely-sensed data acquisition.**

I. Introduction

The remotely sensed signal measured by satellite or airborne sensors in the visible and near infra-red (NIR) is strongly affected by the Earth's atmosphere along the path from the sun to the target surface, and back to the sensor. As a result of sensor-specific factors and temporally variable atmospheric conditions, image digital number (DN) cannot be assumed to represent the actual surface condition [1]. It is therefore necessary to calibrate image data to absolute physical units [2], such as the surface reflectance factor ($\rho_{s\lambda}$) [3]. Atmospheric correction procedures are typically performed using empirical techniques [4], radiative transfer models [5], or a combination of the two [3]. Where these techniques utilise measurements of reflectance at the ground, several surfaces of different albedo are normally used including a 'dark' surface, such as asphalt. The reflectance of these surfaces is often assumed to remain stable over a range of time-scales. This paper presents the results of an experiment undertaken at a calibration test-site in the UK, where the main aim was to test the hypothesis that calibration surface reflectance does not change significantly over time.

II. Field Site: Thorney Island

Thorney Island is situated in Chichester Harbour, Hampshire, UK. Previous calibration experiments at this site have used asphalt and concrete runway surfaces at the southern end of the island, which are spatially uniform and provide contrasting albedo. The asphalt site has most recently been used for in-flight calibration of a Compact Airborne Spectrographic Imager (CASI) [6]. Figure 1 shows a true colour composite of the site acquired with CASI on 18th June 2002. Three sites on each surface were used, and will be referred to as Thorney Southern Asphalt (TSA 1 to 3) and Concrete (TSC 1 to 3) throughout this paper.

Fig. 1. Thorney Island Calibration Site.

III. Methodology

A. Field Spectral Measurements

The GER1500 is a dual-field-of-view (DFOV) field spectroradiometer, measuring hemispherical-directional reflectance factors (HDRF) in the visible and NIR (350-1050nm). The use of dual-beam spectral measurements offers the most precise means of collecting spectral reflectance factors since it minimises spectral uncertainties associated with changing atmospheric conditions [7], [8]. For this experiment, two calibrated GER1500 instruments were used in DFOV configuration to measure the HDRF of concrete and asphalt calibration surfaces on five dates during 2002.

B. Ensuring Positional Precision in Spectral Measurements

It was necessary to ensure high spatial precision when measuring the calibration surfaces, due to the small field-of-view of the target sensor (3°), combined with localised spatial variations in surface features. For this purpose, a mobile spectroradiometer mounting was designed, and is shown in Figure 2. The mobile base of the unit allowed ease of movement across the calibration surface, while also providing a mounting point for the spectroradiometers at each end of a 2.4m long boom. Tensioned stays were fixed to the base to prevent movement during measurement sequences, and small markings on the calibration surfaces matched with the position of location sightings, giving an estimated positional precision of ±2mm.

Fig. 2. Mobile spectroradiometer mounting for ensuring positional accuracy in spectral measurements.

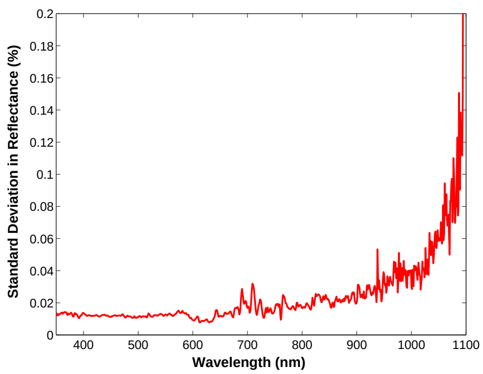

Fig. 3. Reflectance uncertainty in measurements made using the DFOV GER1500 and mobile device under clear atmospheric conditions (n=30).

C. Meteorological Data

In addition to the spectral measurements, an electronic automatic logging weather station was installed at Thorney Island, in accordance with recommendations for calibration sites suggested by [3] and [9]. The weather recorder included standard meteorological sensors, plus a digital sunshine sensor manufactured by Delta-T devices (type: BF2), measuring global and diffuse broadband irradiance in the range 400-700nm.

IV. Results

A. Reflectance Uncertainty

To facilitate quantitative assessment of the data, the reflectance uncertainty was estimated through use of a time sequence of 30 fixed-point reflectance measurements made under very stable atmospheric conditions on 15th July 2002. Uncertainty is represented by the standard deviation of the measurements, across the wavelength range of the instrument. Figure 3 illustrates that the uncertainty of the method is $\leq 0.02\%$ absolute reflectance in the range 350-700nm, after which uncertainty increases to a maximum of $\sim 0.1\%$ at 1050nm. The increase in uncertainty with wavelength is due to a decline in the signal-to-noise ratio of the instrument at the limits of the detector's spectral range.

B. Variability over short time-scales

A 30-minute time sequence of reflectance factor measurements collected over a fixed point at TSA on 18th June 2002 showed variation throughout the time sequence. Figure 4(a) illustrates this variability at 6 wavelengths, chosen since they form the basis of a standardised bandset used in the CASI airborne imaging system ('Vegetation' bands 1-6). These data illustrate that asphalt exhibits a slight but measurable change in absolute reflectance over short time-scales. Due to the high precision of the technique used (Figure 3), these results represent a real change in the surface reflectance factor, rather than a change in instrument sensitivity or measurement position. Subsequent analysis of meteorological data showed that the spectral measurement sequence coincided with a period of changing global and diffuse irradiance, whilst changes in the solar zenith angle were minimal.

The diffuse/global (D:G) ratio was used as an indicator of atmospheric clarity, and was correlated with reflectance measured during the 30-minute period. The two datasets were linked using time stamps within the headers of the spectral data files. This enabled construction of a scatter plot, (Figure 4(b)), where a relationship between reflectance at 670nm and the D:G irradiance ratio was apparent ($r^2 = 0.53$). Identical computations were repeated at a range of wavelengths, and all produced similar results. This finding corresponds with published results, where the reflectance of natural surfaces has been shown to vary according to changes in the hemispherical distribution of irradiance [10]. Furthermore, this result highlights the anisotropic behaviour of calibration surfaces, and is consistent with published results on the effects of skylight intensity distribution on HDRF [11].

C. Variability over longer time-scales

Multi-date reflectance factors of TSA1 were compared using one-way ANOVA at a range of wavelengths, and found to differ significantly ($p = 0.001$) over time-scales of weeks and months. The same was true for TSC1, with post-hoc Tukey tests revealing that for concrete, reflectance factors measured on five dates all differed significantly from each other ($p = 0.001$). Further investigation of TSA1 data revealed that these longer term trends in reflectance were also related to the diffuse irradiance component. Figure 5 illustrates the differences in surface reflectance between four measurement sequences, in relation to the D:G ratio.

These results illustrate that surface reflectance increases with increasing atmospheric clarity. The exception to this trend is seen in the September 2002 data, where the D:G ratio changed throughout the measurement sequence, but the surface reflectance did not. It is postulated that this was caused by a number of factors. Firstly, a lower logging frequency was used for the sunshine sensor on this date, meaning that the data required interpolation prior to use. Secondly, a surface effect such as moisture or algal growth could have affected reflectance [12]. Finally, solar zenith variations need to be taken into account. This requires further validation through collection of additional field spectra, scheduled for 2003.

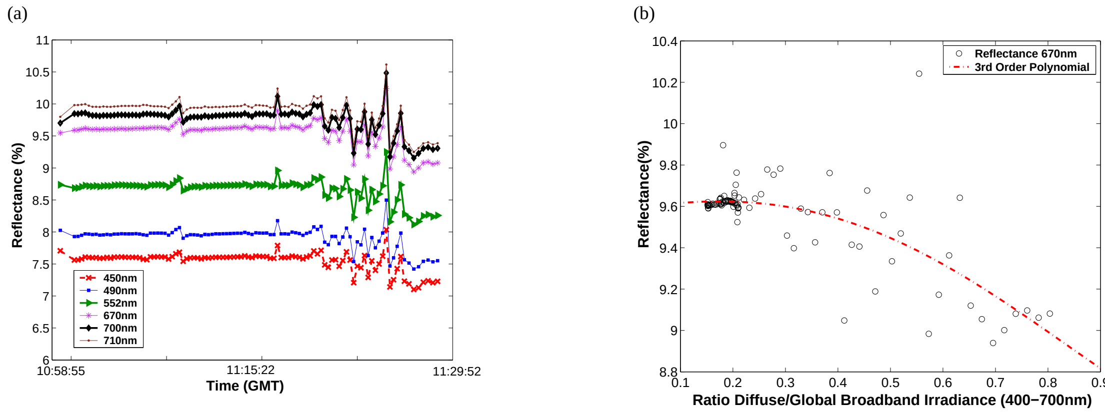

Fig. 4. (a) Absolute reflectance (%) of TSA in central wavelengths of 6 CASI bands, over a 30 minute time sequence; 18 June 2002 (n=100). (b) Absolute reflectance (%) of TSA at 670nm and its relationship with diffuse/global broadband irradiance. Third order polynomial, $r^2 = 0.53$.

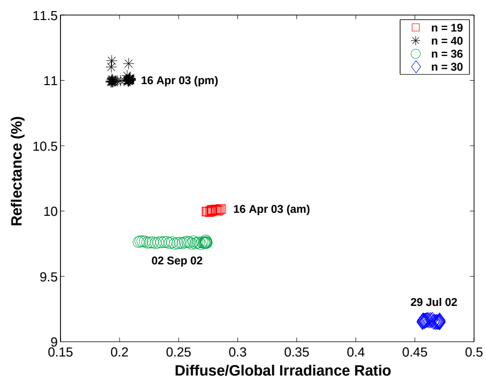

Fig. 5. Field reflectance factors measured at TSA1 on four dates and relationship with diffuse/global broadband irradiance.

V. Conclusion

These results illustrate that calibration surfaces such as asphalt and concrete exhibit measurable changes in reflectance over short time-scales (as short as 30 minutes), as well as over longer time-scales of weeks and months. Furthermore, field reflectance factors have been shown to change according to the proportion of diffuse irradiance, or atmospheric haziness. It is concluded that calibration surface reflectance factors cannot be assumed to remain stable over any period when utilising them for empirical atmospheric correction, or vicarious calibration purposes. In addition, the results have demonstrated that a higher precision in empirical atmospheric correction would be achieved if measurements of diffuse and global irradiance were collected simultaneously with the sensor overpass. Future work will include development of an empirical model to predict the behaviour of calibration surfaces under a range of weather conditions, in order to address the uncertainty in atmospheric correction of historical remotely-sensed data.

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References

[1] P. Slater, *Remote Sensing - Optics and Optical Systems*. Reading, MA: Addison-Wesley, 1980.

[2] P. Teillet, “Image correction for radiometric effects in remote sensing,” *International Journal of Remote Sensing*, vol. 7, pp. 1637–1651, 1986.

[3] M. Moran, R. Bryant, K. Thome, W. Ni, Y. Nouvellon, M. Gonzalez-Dugo, J. Qi, and T. Clarke, “A refined empirical line approach for reflectance factor retrieval from Landsat-5 TM and Landsat-7 ETM+,” *Remote Sensing of Environment*, vol. 78, pp. 71–82, 2001.

[4] G. Smith and E. Milton, “Technical Note: The use of the Empirical Line Method to calibrate remotely sensed data to reflectance,” *International Journal of Remote Sensing*, vol. 20, no. 13, pp. 2653–2662, 1999.

[5] K. Staenz, J. Secker, B. C. Gao, C. Davis, and C. Nadeau, “Radiative transfer codes applied to hyperspectral data for the retrieval of surface reflectance,” *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 57, no. 3, pp. 194–203, 2002.

[6] E. Rollin, E. Milton, and K. Anderson, “Calibration validation of an airborne sensor: an example of the CASI,” *International Journal of Remote Sensing*, Submitted April 2003.

[7] M. Duggin, “The field measurement of reflectance factors,” *Photogrammetric Engineering and Remote Sensing*, vol. 46, pp. 643–647, 1980.

[8] E. Rollin, D. Emery, C. Kerr, and E. Milton, “Dual-beam reflectance measurements and the need for a field inter-calibration procedure,” in *Developing International Connections. Proceedings of the 24th Annual Conference of the Remote Sensing Society*, P. Burt, C. Power, and P. Zukowskyj, Eds. University of Greenwich: Remote Sensing Society, Nottingham, UK, 1998, pp. 552–558.

[9] P. Teillet, G. Fedosejevs, R. Gauthier, N. O'Neill, K. Thome, S. Biggar, H. Ripley, and A. Meygret, “A generalised approach to the vicarious calibration of multiple Earth observation sensors using hyperspectral data,” *Remote Sensing of Environment*, vol. 77, pp. 304–327, 2001.

[10] K. Kriebel, “On the variability of the reflected radiation due to differing distribution of irradiance,” *Remote Sensing of Environment*, vol. 4, pp. 257–264, 1976.

[11] E. Rollin, E. Milton, and D. Emery, “Reference panel anisotropy and diffuse radiation - some implications for field spectroscopy,” *International Journal of Remote Sensing*, vol. 21, no. 15, pp. 2799–2810, 2000.

[12] A. Dubosc, G. Escadeillas, and P. Blanc, “Characterisation of biological stains on external concrete walls and influence of concrete as underlying material,” *Cement and Concrete Research*, vol. 31, pp. 1613–1617, 2001.