LABORATORY PANEL AND RADIOMETER CALIBRATION

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ABSTRACT

This paper presents the results of the laboratory and field based reflectance panel and radiometer comparisons that took place as part of the CEOS 2010 Key comparison of "techniques and instruments used for the vicarious calibration of Land surface imaging through a ground reference standard test site". The results of the comparisons are presented which shows that the different ways in which reflectance panels are calibrated can give different results for the reflectance attributed to a test site and that changing illumination and environmental conditions can effect the measured target reflectance.

Index Terms— Reflectance factor, goniometric, Earth Observation, Vicarious calibration, Field spectroscopy

1. INTRODUCTION

One of the key deliverables [1] of the Key comparison was to identify any bias between the primary calibrations of the participants' instruments using a series of laboratory and in situ cross-comparisons of participants' radiometers and reference panels. White "lambertian" reflectance panels are widely used in remote sensing applications for calibrating the reflectance of reference test sites used to calibrate/validate radiometric characteristics of Earth Observation satellites [2]. Differences in panel calibration, whether it be due to routes of traceability e.g. from the supplier of a panel, independent test facility or as a result of differences in methodology can significantly affect the reflectance attributed to a site. Any surface and in particular natural surfaces used for test sites rarely have full Lambertian reflectance properties and so the reflectance is highly sensitive to both the angle of observation and illumination. It is thus important to characterize a site under the conditions it is to be used. This of course also means that any reference panel must similarly be characterized to take account of this potential issue.

2. LABORATORY PANEL COMPARISON

To reduce sensitivity to environmental effects and illumination conditions it was decided to evaluate the reflectance characteristics of each institute's reflectance panel under controlled laboratory conditions as well as in the field. A laboratory-based comparison of each participant's reflectance panel was performed in a laboratory of the Physics department of the Middle East Technical University (METU) in Ankara, Turkey before and after the field measurements. A fixed measurement geometry for both illumination source and receiver was used and all panels measured using a common spectroradiometer. The reflectance factors of the panels were determined by comparison with a reflectance panel calibrated at NPL [3], which as the UK national standards laboratory could be considered directly traceable to SI. The illumination source was a 1 kW FEL type tungsten halogen lamp set at an illumination angle of 45º at a distance of approx 1.0 m from the panel's surface. The receiver was an ASD spectroradiometer with a 5º FOV set at a viewing angle of 0° from the normal of the panels (nadir view). This measurement geometry is a standard geometry defined by the CIE (International Commission on Illumination) and the 45° illumination angle is consistent with one of the sun zenith angles experienced during the field measurements in August 2010.

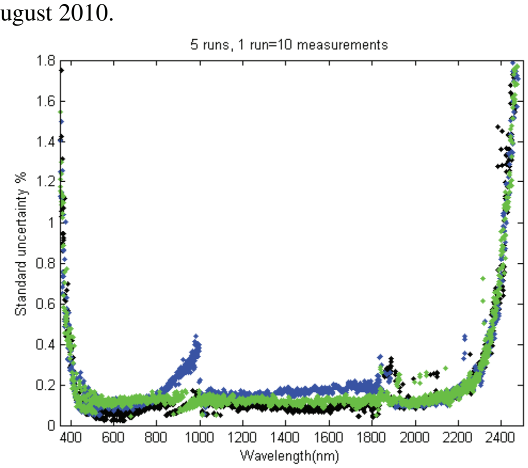

Figure 1 - Standard uncertainty Type A associated with the laboratory panel calibration

The laboratory panel calibration methodology was developed and tested at NPL prior to the CEOS Key Comparison and the results of the Type A standard uncertainty (repeatability and reproducibility) associated with this calibration methodology have been determined to ensure that it would be adequate for this comparison. Two operators performed five independent measurement runs on two separate occasions. After each run the panel under test was removed and re-aligned. The Type A standard uncertainty associated with these measurements was estimated to be less than ± 0.2 % for most wavelengths of interest. Figure 1 shows the Type A standard uncertainty for both operators and also for the replacement and realignment of the reflectance panel.

2.1. Laboratory Panel Comparison Results

The laboratory calibration of the reflectance panels was performed before and after the field measurements. Measuring the reflectance factor of the panels before and after the field campaign not only tests the stability of the panels themselves but also of the calibration methodology used in the laboratory. The percentage difference of the measured reflectance factor of each institute's reflectance panel, measured before and after the field campaign, is shown in Figure 2.

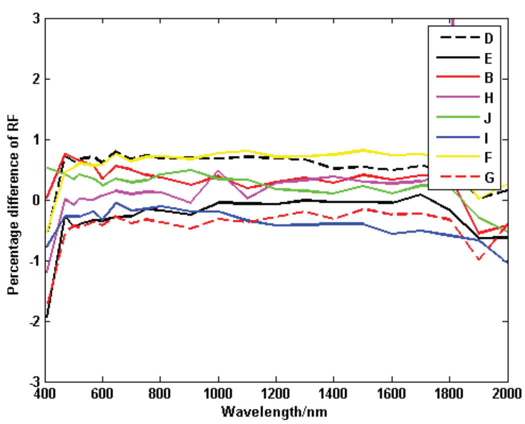

Figure 2 - Percentage difference of panel reflectance factor before and after field measurements

Figure 2, above, shows that the differences in the measured reflectance factor between the measurements in the laboratory before and after the field campaign are small. Most differences are less than 0.5 %. This not only shows that the reflectance panels were stable over the course of the field campaign and that their reflectance did not change significantly but also that the measurement methodology used in the laboratory calibration is also stable. There are no significant offsets in the data, which would indicate a problem with the measurement methodology, nor are there any significant ageing effects seen in the reflectance of the institutes' panels or the reflectance factor of the NPL reference panel. The measured differences in reflectance factor are within the expanded uncertainty associated with the laboratory-based calibration, which is estimated to be ± 0.6 %.

Eight institute's reflectance panels were calibrated in the laboratory. All the panels, except one, was a Spectralon® reflectance panel manufactured by Labsphere. The other panel was made by Hefei Institute of Physical Science in China. Of these eight institutes, six currently use the 8°/hemispherical reflectance values for the panel that are either provided directly by Labsphere or are derived from comparison with other panels that have been calibrated by Labsphere. These 8°/hemispherical reflectance values are used when calculating the absolute reflectance of a test site.

Two institutes South Dakota State University (SDSU) and the National Satellite Meteorological Center/China Meteorological Administration (CMA) use the bi-directional reflectance factor values of the panel, which have been determined by using a goniometric method and provide the reference for the test site. This method enables corrections to be applied to the measured reflectance of the site by taking into account the effect the changing sun zenith angle will have on the reflectance of the reflectance panel. The reflectance factor values that are assigned to these panels are given for a range of incident angles (from 10° to 70°) with the viewing angle normal to the surface (0° or nadir view).

Where the 8°/hemispherical reflectance values have been reported by the participating institutes the reflectance factor is lower than that obtained from the laboratory calibration against the NPL reference panel using the 45/0 geometry. This is as expected as Spectralon® is not perfectly Lambertian which means it has a reflectance factor greater than unity at low sun zenith angles and a reflectance factor lower than unity at high sun zenith angles. The total integrated reflectance will always be lower than 1.00. The reported 8°/hemispherical reflectance values for all the panels are in close agreement which should be the case as all the panels are traceable to Labsphere and demonstrates the consistency of the primary calibration.

The differences between the reported values and the laboratory comparison values are not constant. However, all the panels would not have been calibrated at the same time or subject to same conditions and usage so different amounts of degradation and ageing will have occurred between the Labsphere calibration and the current laboratory comparison. The differences seen between the 8°/hemispherical and 45/0 values are typical of those for Spectralon®. There was one exception; one panel, which was known to be contaminated, was found to have a reflectance factor several percent lower than the other panels. The comparison of the reflectance factor values for the six panels that use the 8°/hemispherical reflectance values is shown in Table 1.

Panel	Reflectance factor at 500 nm	
	8°/hemispherical - reported value	45/0 – laboratory comparison
B	0.949	0.966
D	0.992	0.998
E	0.990	1.004
H	0.990	1.002
I	0.988	1.007
J	0.991	1.009

Table 1 – Comparison of reflectance factor values

The results of the laboratory calibration of the panels supplied by SDSU and CMA can be directly compared with the corresponding 45/0 reflectance factor calibration values reported by these institutes for their panels. Figure 3 shows the reflectance factor of the two panels in the 45/0 geometry as reported by the institutes' and as calibrated in the laboratory against the NPL panel. The agreement is very good considering that three independent methods have been used to determine the reflectance factor and all are traceable to different national standards.

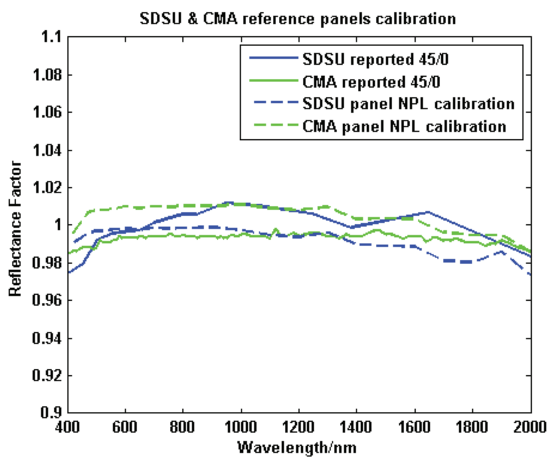

Figure 3 - Comparison of reflectance factor values

3. FIELD PANEL COMPARISON

Three further comparisons of the reflectance panels were carried out in the field [4] on consecutive days during the CEOS Key Comparison. A similar methodology to that employed during the laboratory comparison was used. An ASD spectroradiometer with a 5° FOV was set at nadir (a viewing angle of 0° from the normal of the panel) to view the panels. The panels were placed on the ground and the illumination was provided by the Sun. Each panel was viewed by the spectroradiometer together with the NPL reference panel. The comparison measurements were repeated quickly in order to minimize any changes in the panels' reflectance due to the changing sun zenith angle and also to minimize any changes in the illumination conditions that could be due to atmospheric changes such as those caused by changes in atmospheric precipitable water vapor content and aerosol loading.

During one of these field comparisons an ASD spectroradiometer was set up with a Remote Cosine Receptor (RCR) to monitor the global, downwelling, horizontal spectral irradiance. The instrument and data were provided by CSIR. The variation in irradiance is shown in Figure 4 and is expressed as a percentage deviation from the mean value for the period of the observation.

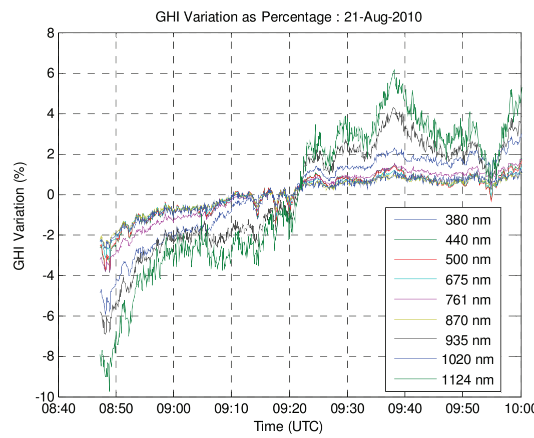

Figure 4 – Variation in global horizontal spectral irradiance

The strongest percentage variation can be seen in the water absorption bands at 935 nm and 1124 nm. This corresponds reasonably well to the trends in precipitable water vapor reported by AERONET (http://aeronet.gsfc.nasa.gov/) for the Tuz Gölü site over the same period. There does however appear to be short-term variations in aerosol optical thickness (AOT) and precipitable water vapor that are not captured by AERONET.

The results from the field based panel comparison show that changing illumination conditions in the field such as variability in sun irradiance recorded using the cosine receptor during this cross-comparison or variability in atmospheric precipitable water vapor content and aerosol loading, together with changing geometrical conditions due to the changing sun zenith angle can have significant effects on the data obtained. This is demonstrated in Figure 5, which shows the results for one institute's reflectance panel. Here the two measurements of the panel reflectance factor with a sun zenith angle (sza) of 30 degrees agree well but the measurement with an sza=35 are higher. This is contrary to the expected result, which would normally see the reflectance factor at 35 degrees lower than that at 30 degrees. In this case the different illumination conditions and short-term AOT and precipitable water vapor variations between measuring the institutes panel and the NPL panel have resulted in an erroneous result. For other panels measured at a similar time the expected results were obtained.

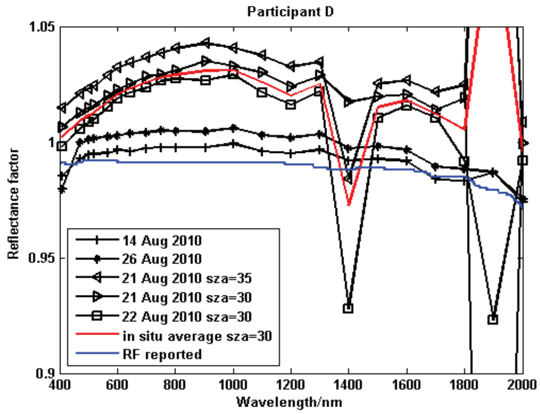

Figure 5 – Comparison of in field and laboratory calibrated reflectance factors of one institute's reflectance panel

4. LABORATORY RADIOMETER COMPARISON

To directly compare the radiometric calibration of the radiometers used in the CEOS comparison, a standard source TSARS (Transfer Standard Absolute Radiance Source) was provided by NPL [5]. The radiometer comparison was performed in the same laboratory as the reflectance panel comparison. The radiometer comparison was performed before and after the field measurements in an attempt to monitor any drift in the instrumentation.

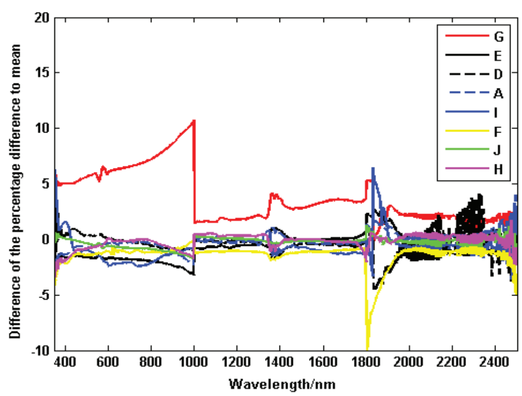

Figure 6 – Difference from relative means of participants' radiometers

The environmental conditions in the laboratory before the field campaign were outside the normal operating conditions for TSARS, which meant that the data from these measurements could not be used for an absolute calibration. However, taking the ensemble of all the participant radiometers to establish a mean value for the source (and consequently a relative bias between each other) it was possible to use this to identify a clear change in the characteristics of one radiometer following the field campaign. Figure 6 shows the difference between the two relative means of the radiometers before and after the field campaign.

As stated above a full comparison of the radiometers was not possible due to the environmental conditions in the laboratory before the field campaign. However as a result of this comparison a number of recommendations concerning radiometer use in the field and in particular performance checking and monitoring are being formulated by CEOS and will be summarized in the 2010 Tuz Gölü campaign report.

5. CONCLUSION

Illumination conditions when in the field should ideally be measured and monitored at the same time as the measurement of the target. However this may not always be practicable, but users should however measure their reflectance panel on a regular basis in order to minimize the possible effects of changes in the illumination conditions that could be due to atmospheric changes such as those caused by changes in atmospheric precipitable water vapor content and aerosol loading.

It is recommended that all panels that are used in the field, where illumination conditions are not close to nadir, have a bi-directional, goniometric reflectance factor calibration or where this is not possible, that a look-up table be created to correct 8°/hemispherical reflectance values.

6. REFERENCES

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