QA4EO-WGCV-IVO-CLP-004 **Draft**

A best practise guide to land "test-site" characterisation

QA4EO-WGCV-IVO-CLP-004

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1 Abstract

This is a "Best practice guide" to the characterisation of the properties of a land-based test-site, which impact on its radiometric use with optical remote sensors. Such a site may be used as a permanent reference standard test site or simply as "one-off". This document contains the technical aspects of site characterisation based on the reflectance-based approach pioneered by the University of Arizona (Slater et al, 1987). .

2 Scope

This "Best practice guide" presents the technical aspects of the methodology used in the characterisation of a land site used for radiometric calibration and/or validation (Cal/Val) of a remote optical sensor. This guide provides information on the type of instrumentation that is needed, including their technical specifications, as well as sampling strategies, and their optimisation, based on the nature of the terrain and application. Where possible this guidance is based on a consensus view of the community through CEOS WGCV IVOS. In some cases, where there is still debate or significant variability due to the characteristics of different terrain, a range of options will be provided with appropriate discussion to aid the reader.

3 Terminology

The reflectance terminology that is in common usage within the EO community has been defined by Schaepman-Strub (2006)[1]. Some of the key terms used in this document are listed bellow:

BRF (Bidirectional Reflectance Factor): is given by the ratio of the reflected radiant flux from the surface area *dA* to the reflected radiant flux from an ideal and diffuse surface of the same area *dA* under identical viewing geometry and single direction illumination. The BRF can be expressed as π * BRDF.

BRDF (Bidirectional Reflectance Distribution Function): describes the scattering of a parallel beam of incident light from one direction in the hemisphere into another direction in the hemisphere.

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[1] Schaepman-Strub G., Schaepman M.E., Painter T.H., Dangel S., and Martochik J.V. 2006. Reflectance quantities in optical remote sensing – definitions and case studies. Remote Sensing of Environment, 103, pp. 27-42

CEOS: Committee on Earth Observing Satellite, CEOS addresses coordination of the satellite Earth Observation (EO) programs of the world's government agencies, along with agencies that receive and process data acquired remotely from space.

Metrological Traceability: *property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations each contributing to the measurement uncertainty.*

The abbreviated term ‘traceability’ is widely used for “metrological traceability” as well as for other concepts, such as “sample traceability” or “document traceability” or “instrument traceability”, where the history (‘trace’) of an item is meant. It is, therefore, recommended to include an appropriate prefix to ensure the meaning is clear.
Quality Indicator: *a means of providing “a user” of a product, (which is the result of a process) sufficient information to assess its suitability for a particular application. This “information” should be based on a quantitative assessment of its traceability to an agreed reference standard (ideally SI).*

Reference standard: Measurement standard designated for the calibration of other measurement standards for quantities of a given kind in a given organization or at a given location.

Reference test site: A site to be used for the post-flight calibration of the remote sensors fulfilling the selection criteria outlined in Table 1 (to be refined by CEOS WGCV IVOS).

Reflectance Factor: is the ratio of the radiant flux reflected by a surface to that reflected into the same reflected-beam geometry and wavelength range by an ideal (lossless) and diffuse (Lambertian) standard surface, irradiated under the same conditions. Reflectance factors have values under 1.

Vicarious calibration: Refers to the post-launch calibration of a satellite using techniques, which make use of a natural or artificial target on the Earth’s surface.

4 Introduction/Context

The detailed radiometric characterisation of a land surface has to be performed to take account of the requirements of the intended application (spatial resolution of the remote sensing system to be calibrated, frequency of the calibration, long-term future of the site etc.). However the basic methodology in all cases should follow a similar pattern and the results evaluated and reported in a similar way. This will allow the Cal/Val community to have a common understanding and confidence in the results for both site characterisation and their use with a remote sensor. This is of particular importance when relatively high accuracies are sought and where sites are used to evaluate biases between sensors. The most critical examples are the “CEOS reference standard test sites” which serve to provide a network of priority targets for use by the EO satellite community to facilitate interoperability and harmonisation.

The key characteristics that are covered by this guide are:

- Absolute spectral reflectance
- Spatial uniformity of reflectance
- Temporal stability of reflectance

In addition, any ancillary measurements required to enable the surface measured characteristics to be propagated through the atmosphere to the sensor will also be described.

5 Outcomes

The outcome of using this procedure is the radiometric characteristics of a land site derived in a robust community accepted manner.

If full traceability can also be demonstrated it allows the site and its use to be considered traceable.

The user of this guide should also gain an understanding of the techniques used for this type of vicarious calibration[2] [3] and the uncertainties related to it[4].

This guide should also provide the reader sufficient information to enable them to procure the necessary instrumentation and plan for a measurement campaign.

6 Inputs

The inputs to this document are derived from the published literature and the pooled expertise from the CEOS WGCV IVOS team members.

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[2] Slater P.N., S.F. Biggar, R.G.Holm, R.D. Jackson, Y.Mao, et al., 1987. Reflectance- and Radiance-Based Methods for the In-Flight Absolute Calibration of Multispectral Sensors, *Remote Sensing Environment*, 22, pp. 11-37.

[3] Thome, K.J., 2001. Absolute Radiometric Calibration of Landsat 7 ETM+ using the Reflectance-Based Method. Remote Sensing of Environment, 78(1-2): pp. 27-38.

[4] Thome, K. 2005. Sampling and Uncertainty issues in trending reflectance-based vicarious calibration results, Earth Observing Systems X, Proceedings of SPIE Vol. 5882.

7 Standards and Traceability

All instrumentation used to characterise the land site should have clear demonstrable traceability to SI units (radiance, irradiance, reflectance) as appropriate. This is likely to include standard Lambertian reflectance panels as transfer standards. All characterisation should be carried out using a QA4EO endorsed method or with documentary evidence to enable it to be compliant with QA4EO.

8 Process

8.1 Introduction

Before embarking on any site characterisation it is important to define clearly the objective of the characterisation and the intended application, particularly the range of potential view angles and spatial resolution of the remote sensor. It is also important to consider the nature of the terrain under evaluation and its relative temporal stability if the result of the characterisation is intended to have some degree of longevity.

In terms of manpower, a characterisation team is likely to require a minimum of three individuals, although it is possible that two very experienced individuals may be adequate.

Site characterisation can thus be grouped into three thematic areas, which will define the structure of this document:

- **Surface radiometric characterisation** (reflectance factor (RF) and BRDF methodology sampling strategy, instrumentation, source of errors, data and uncertainty analysis, reporting)

- **Atmospheric characterisation** (methodology, instrumentation, source of errors, data and uncertainty analysis, reporting)

- **Autonomous monitoring** (reflectance characteristics, aerosol climatology)

8.2 Site selection/identification

This procedure is only concerned with site characterisation and assumes that the generic location has been selected by other means. For example if the site is seeking to be a reference standard test site then QA4EO-CEOS-IVOS-xxx could be used for this initial selection.

However, once a generic area has been identified a specific target area has to be defined for characterisation. This area should be chosen so that it is:

- of sufficient size to match the needs of the intended sensors (taking account of the sensor flight/observational characteristics e.g. "push-broom"
- free of any unusual features
- surrounded by terrain of similar characteristics. The target area should be at a suitable distance from highly contrasting targets to avoid adjacency effects and at least two sensor pixels wider than the ground area to be observed to minimise the effect of any imperfections in image quality of the sensor.

8.2.1 Site size

The size of the surface area to be sampled is selected depending on the imagers resolution (medium or high-resolution) and whilst the surface area can take many shapes it is important to note that this does not have to be square. In fact if the site is appropriately aligned to the satellite scanning mode this can be fairly narrow in one dimension.

As a rule of thumb an area approximately equal to 3 sensor pixels should be considered a minimum with a further 2 pixels of similar terrain at its periphery. For example MERIS has a 300 m pixel size and so a site of around 1 x 1 km is ideal, whereas for a high-resolution imager (e.g. UK-DMC with 32 m spatial resolution) 10 x 10 pixel, that means 300 x 300 m would be adequate, considering the specific noise system of the DMC. (The size of the selected area has to take into account the source of the uncertainty, noise system, surface variability or others.)

8.2.2 Site identification

The target site should be marked to aid its identification during characterisation using, for example, small flags or posts inserted into the ground at regular intervals. Ideally, the spacing should be such that next post can be seen from the previous one.

If the site is to be used for the Cal/Val of a high-resolution sensor during the time of the characterisation campaign, then it is useful to place high contrast sheeting of sufficient size to be viewable by the sensor at least two corners of the target site and geographically located via GPS. This will aid site location on any image and avoid the re-sampling of pixels by map projection allowing a better comparison of the ground and satellite information.

8.3 Surface radiometric characterisation

Once the target area has been selected and identified it can then be characterised. In general such characterisation involves a measure of the spectral reflectance factor (RF), typically at Nadir, but another angle may be more appropriate dependent on any specific sensor-viewing angle, as a function of position. In addition, for more general applications the bidirectional reflectance distribution function (BRDF) should also be measured at a few locations.

If the site is such that there are specific features e.g. indentations, or occasional vegetation, effort should be made to assess their frequency and radiometric characteristics if they are likely to have a significant impact on the aggregated radiometric properties of the site.

8.3.1 Reflectance Factor

8.3.1.1 Method and Sampling

The Reflectance Factor (RF) of the test site surface is determined from radiance measurements performed with a portable spectroradiometer, generally normalised to reflectance. These measurements are usually made in comparative mode by alternately viewing a Lambertian reflecting panel of known reflectance illuminated by the Sun and the surface illuminated by the “same Sun”. The time interval between such normalising measurements should be made as small as possible, ideally for each measurement, however in practise there has to be a compromise between ideality and available time. Thus this measurement can only be made at specific locations at specific times.

In addition to the use of the reference panel it is important to take account of any differences due to background scatter and sky radiance between measurements made of the surface and the panel. In the latter case the reflectance is near unity and Lambertian, whilst in the former it is likely to be a few tens of percent and be far from Lambertian. This will mean that any inter-reflections of direct or scattered light can have a different impact on the overall measurement and this needs to be accounted for.

This can be evaluated using a small sunshade (solid disk on a pole) positioned several meters from the panel or surface and used to block the direct sunlight. The value recorded by the spectrometer in this condition should be subtracted from those measurements made with direct solar illumination. Note the subtracted value will be different for the reflectance panel and the surface.

For a pole length of say 3 m the opaque disk should be 52 cm in diameter.

When taking measurements care should be taken to avoid light scattered or shaded by any individual, instrument or other entity which is not native to the selected target area. Thus keeping all such entities opposite the Sun is best and as large a distance as possible, for example the spectrometer sampling head ideally should be held at least 1 m from its carrier, which may be human or some automated device. Darkened clothes are thus probably preferable to white although if individuals position themselves sufficiently away from any measurements this is likely to be a second order effect. Measurements of panel reflectance and surface should be made at similar distances, although this is less critical if appropriate sunshade measurements are made. A typical surface to spectrometer entrance optic would be around 1 m.

Surface measurements can in principle be made in near continuous sampling mode by moving the spectrometer and constantly recording a running average as a function of some pre-defined time interval. Alternatively a pre-defined distance can be defined and samples taken at these distance. Changes due to sun illumination angle variation can be accounted for by frequent cross-referencing to the panel, however this relies on relatively small differences in the BRDF characteristics of the panel and the surface being measured.

It is thus important to define a sampling strategy optimised to minimise variation due to temporal changes in illumination whilst maximising the area under test i.e. as short a time as possible. The sampling strategy should take into consideration the features of the test reference site (cracks, stones, vegetation and slopes) ensuring that these are samples in a statistically fair manner ie. not under or over sampled due to operator bias and the time required to sample the selected areas without having great variation in the illumination conditions (sun zenith/azimuth angles). It is recommended that sampling strategies should be devised so that site characterisation can be completed in a timeframe that is less than one hour or as a set of characterisations of similar duration timed to match the same solar illumination angle. This one-hour timescale is such that for near nadir conditions and high solar illumination angles the variation due to solar movement is relatively small. Whilst with accurate BRDF data this can be corrected it adds to the overall uncertainty. If the site characterisation is timed to be coincident with a specific satellite overpass, the nominal 1-hour should be arranged to effectively sandwich that of the overpass i.e. starting 30 mins before and ending 30 minutes after overpass.

The optimum sampling strategy for any given site will be dependent on the site variability, size of site, sensor resolution, and desired uncertainty. As indicated above, if site characterisation is carried out in too much detail and consequently takes a long time, this can be counter productive. However, the basis of this decision is highly dependent on the specific characteristics and variability of each individual site,

As a pre-cursor step it is thus useful to have some initial studies on first arrival at the site. For example, taking one or more transects of a site at continuous or near continuous sampling effectively over samples the site. This data set can then be sub-sampled in a systematic manner to correspond to various spatial frequencies e.g 5 m, 10 m, 100 m etc and any changes in the resultant standard deviation of the mean spectral reflectance, determined and assessed. To a first approximation this standard deviation (over an area commensurate with a particular sensor pixel) represents the best uncertainty that can be achieved for the site.

Sampling patterns

Here are presented some sampling patterns. The first one was used by NPL during the August 2008 measurement campaign for a selected surface of 100m*300m at Tuz Golu, Turkey (Figure 1).

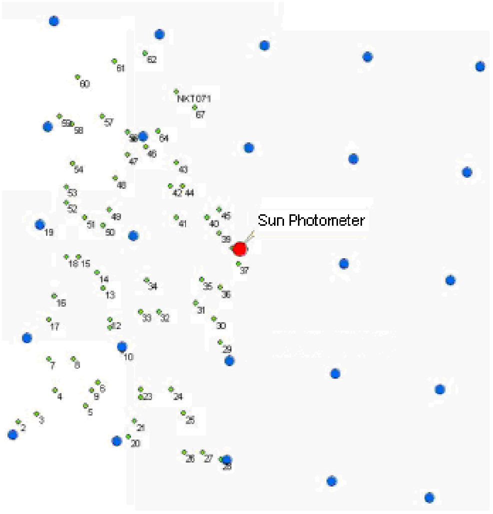

Figure 1: Patchwork of 10*10 m targets used during the 2008 measurement campaign by NPL. (The

blue dots represent the corners of the 10*10m areas, and the numbers are the positions of the measurements).

At Railroad Valley, Nevada a 1arger footprint area of 1km square was selected (Figure 2). The operator begins at the reference panel white and starts taking measurements by initially moving around quadrant 1, continuing with quadrant 2, 3 and 4. After the end of one quadrant the operator returns in the middle of the square to take a measurement of the white panel and pass to the next one[5].

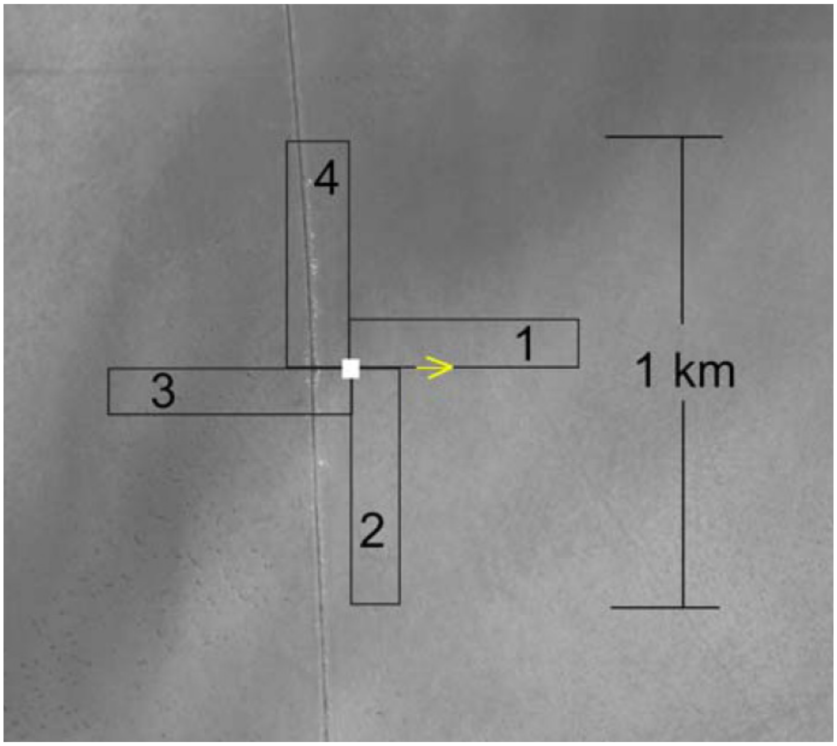

Figure 2: Railroad Valley, Nevada pattern used to perform the measurements with an ASD (Jeffrey S. Czapla-Myers PhD thesis, University of Arizona, 2006)

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[5] Czapla-Myers J.S. 2006. Automated ground-based methodology in support of vicarious calibration, PhD thesis University of Arizona, p 59.

8.3.1.2 Instrumentation

The principle instrument required for the measurement of RF of a site is a portable spectroradiometer operating in the solar reflective (350 to 2500 nm) spectral band. The instrument should be well-characterised, insensitive to thermal effects and readily interfaced to a computer/data logger. Ideally the spectroradiometer should have a variable field of view (or ground sampling size) to suit different terrain characteristics. For most situations on a nominal non-vegetated site used as a radiometric calibration site, a ground sampling area of ~ 10 to 20 cm is reasonable. Such an area corresponds to an instrument FOV of around 8º and is recommended for this application as it provides a reasonable average of fine structure on the surface but is still significantly higher resolution than most remote optical sensors.

However, as a precursor test on any new site, it would be reasonable to carry out an evaluation over a representative area using different spectroradiometer FOVs, ranging from ~ 1º to 10º.

- These instruments should be calibrated traceable to SI units prior to use at the site. For radiance this would typically be with reference to a standard source, which might take a number of forms the most common being a lamp illuminated integrating sphere or the use of an irradiance standard lamp and a lambertian panel diffuser of known reflectance factor. The full traceability of such standard back to a national standards laboratory such as NIST (National Institute for Standard and Technology, USA) or NPL (National Physical Laboratory, UK) must be established and documented, together with the uncertainty of any intermediate calibration steps. It should be noted that whilst such transfer standards appear simple to use, they frequently provide many errors due to stray light, inter-reflections etc.
- In addition to spectral radiance, the wavelength calibration of the instruments should also be checked.
- Many spectroradiometers, particularly those that are relatively small are notoriously poor in terms of internal stray light i.e. the response of the instrument at any one wavelength may be contaminated with radiation from a different wavelength due to internal scattering. Such “stray light” is present during calibration and use of the instrument and if both sources of radiation were similar in spectral shape the resultant error would be small. However, for this type of application the spectral characteristics of the calibration radiation and that of the measurement are very different and may result in significant error particularly in the shorter wavelength region of the spectrum.

- Some instrument manufacturers can provide misleading information on this potential error and advice should be sought from an independent expert before selecting instrumentation for this type of application. The instruments should be calibrated before and after the measurement campaigns, at least to demonstrate stability.

- During measurements, angular drifts and variations due to input solar radiation can be removed through frequent normalisation to a spectrally neutral Lambertian diffuser, such as a spectralon panel. Such diffusers should be characterised traceable to SI prior to use in the field and checked on return.
- Reference diffusers should be mounted in a frame so that they can be easily handled and ideally supported on a tripod like mount for viewing, see figure 1 as an example below. This frame should have some levelling device for example, a spirit level to ensure that it can be properly aligned, with reference to the ground.
- Spectrometers in common usage which have been designed specifically for this type of application are those manufactured by ASD [http://www.asdi.com/products-fshh-fshhp.asp] and SVC [http://www.spectravista.com/index.html]. However, there are many alternatives that can be adopted from other manufacturers.
- In using a spectroradiometer it is important to ensure that all measurements are time-stamped, and geo-located via GPS, and any view angle and optical FOV is specified in the data file.

Figure 1: Reference panel measurements conducted on Tuz Gölü, Turkey, August 2008.

8.3.1.3 Source of errors

There are many potential source of uncertainty associated with measuring surface reflectance and in associating a reflecting value to a site for use by a satellite sensor. At present the best-achieved uncertainty is around 2 to 2.5%[6] [7]. This uncertainty is dominated by traceability of the measurements to SI, assuming that the site is calibrated at the time of use, otherwise the value can easily double or more. The nature of most of the best calibration sites other than for very high-resolution sensors, is such that any small surface variation tends to be random in nature and so does not contribute significantly to the overall uncertainty budget.

The principle sources of uncertainty that can be ascribed to methods of measurement i.e. two different teams are:

- Reference panel characterisation; BRDF, uniformity
- Traceability of the field spectroradiometer and ensuring its calibration and usage matches the environment it is in i.e. temperature, battery power, “warm up” time, cleanliness or damage to fore-optics (particularly fiber optics, where bending can have a serious impact) and of course its stray light and wavelength calibration.
- Incorrect accounting for environmental scattered light, sky radiance etc.
- Operator error in sampling the surface, due to reflections, shadowing, wrong angles, heights
- Biases due to surface variability and non-randomised sampling; missing surface features (cracks, stones, vegetation) slopes and timing sequences due to solar zenith angle variation.

8.3.1.4 Data Analysis, Reporting uncertainties

Average over minimum of 10 values collected over a similar area (1m, 5m, 10m, 100m, etc) should be calculated. The sources of uncertainties are resumed in Table 1.

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[6] Kuester M., Thome K., Krause K., Canham K., and Whittington E., 2001, Comparison of surface reflectance measurements from three ASD FieldSpec FR spectroradiometers and one ASD FieldSpec VNIR spectroradiometer, International Geoscience and Remote Sensing Symposium, Sydney, Australia.

[7] Thome K., 2005, Sampling and uncertainty issues in trending reflectance-based vicarious calibration results, in Earth Observing Systems X, SPIE 5882, pp. 397-407.

Table 1. Sources of uncertainties for the measurement of the reflectance factor

Source of uncertainties	Type	Typical values
Traceability to SI (reference panel reflectance and spectral radiance of the radiometers)	Type B	
Drift from calibration	Type B	
Repeatability	Type A	
Reproducibility	Type A	
Diffuse light correction	Type B	
Spatial/Temporal stability	Type B	
Site characterisation time	Type B	

Traceability to SI: traceability is establishing the relation between the indication of a measuring instrument and the value of a measurement standard.

Drift from calibration: the difference between the radiance values measured before and after the field measurements with the same spectroradiometer using the same standard source in the same measurement conditions.

Repeatability: is the variation in measurements taken by a single person or instrument on the same item and under the same conditions. A measurement may be said to be *repeatable* when this variation is smaller than some agreed limit.

Reproducibility: is one of the main principles of the scientific method, and refers to the ability of a test or experiment to be accurately reproduced, or replicated, by someone else working independently.

Diffuse light correction: the natural irradiance is composed of a direct component (non-scattered radiation) and a diffuse component scattered by the atmosphere and the neighbouring objects of the observed area. The diffuse irradiance should be corrected before calculating the reflectance properties of the objects. Without this correction the measured reflectance characteristics are not intrinsic.

Spatial/Temporal stability: the surface of the test site to be characterised could be non-uniform in space and without stability in time due to weathering.

Site characterisation time: the time required to characterise a selected surface of the reference test site could be different from one to another operator and depends on the skills and method used. The resulted value is influenced by the timeframe used to perform the characterisation.

8.3.2 Bidirectional Reflectance Distribution Function (BRDF)

8.3.2.1 Introduction

If all satellite observations of the Earth were at Nadir, the need to evaluate surface reflectivity variability with angle would be greatly minimised. However, because of satellite orbits, wide swaths and the increasing number of sensors designed specifically to measure the Earth at multiple angles there is often a need to establish surface angular reflectance characteristics ideally its BRDF, although measurements at a few angles may be adequate for some applications.

8.3.2.2 Method and Sampling

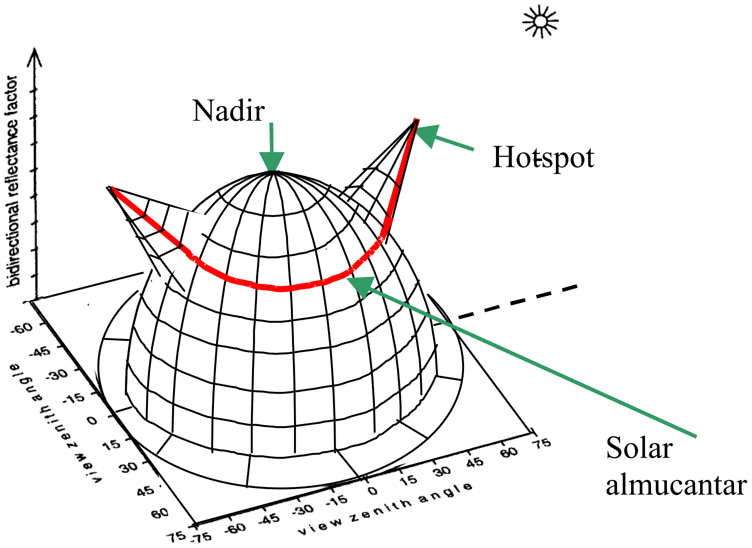
The BRDF of a surface cannot be measured directly as it requires the measurement of the reflected light at infinitesimally small angles over a full hemisphere. Practically, BRF measurements are made in the field, as measurements are usually made relative to a Lambertian reflectance panel, and from these the BRDF can be inferred.

It should be noted, however, that the BRDF that can be derived from multi-angle measurements, are highly dependent on the instrument capabilities and the surface itself. A sampling method tailored to the target should be considered carefully, so that the main features of the surface BRDF are captured during such a measurement.

Most commercially available field instruments are single point sensors. Various sampling strategies and techniques to mover these single point sensors can and have been devised to enable the BRDF to be inferred[8, 9] Figure 2 and Figure 3 show idealised distributions, where the horns are the enhanced forward and backscatter.

Using a fixed zenith angle method of measurement, the following sampling strategies can be used (Figure 2):

> ***Nadir*** *– For these measurements the sensor looks directly downwards. It allows direct comparison with satellite sensors, due to similar measurement geometries to air or space borne sensors* [8]*. It is also a simple measurement to make in the field.*
>
> ***Hot spot*** *– The measurement of the hot spot requires the sensor to be at the same solar zenith and azimuth angle as the Sun. This can be difficult in the field if the sensor and target are close together because of self-shadowing. However the hot-spot can contain useful biophysical information on vegetated sites, such as the leaf angle distribution function*[9]*.*
>
> ***Solar almucantar*** *– The sensor scans 360° around the target at the solar zenith angle, so that it can capture the extremes of the off-nadir reflectance, which can be used to determine an 'index of anisotropy' for a surface* [9]*.*



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[8] Milton, E. J., G. A. Blackburn, E. M. Rollin, et al., (1994). Measurement of the spectral Directional Reflectance of Forest Canopies: A Review of Methods and a Practical Application, Remote Sensing Reviews, 10, 285-308.

[9] Milton, E. J., E. M. Rollin and D. R. Emery, (1995). Advances in field spectroscopy, In: Advances in Environmental Remote Sensing, F. M. Danson and S. E. Plummer (editors), John Wiley & Sons, Chichester, UK.

Figure 2: Fixed zenith angle sampling strategies, adapted from[9].

Further sampling strategies can be developed by developing a sensor that can vary the zenith angle, at which it can measure, (Figure 3).

> ***Solar Principal Plane*** *– This method captures the greatest variation in directional reflectance for the most surfaces. It is fairly easy to set-up whilst in the field as the shadows can be used for the alignment of the instrument. It is also a useful method for airborne sensors that are performing a fly-over of a particular target,*[9].
>
> ***Orthogonal Plane*** *– The sampling geometry for this method is least likely to be affected by surface anisotropy. It is a useful method for airborne sensors, which aim to minimise view-angle effects,*[9].
>
> ***Twin azimuthal planes at 45 ° to the principal plane of the Sun*** *– The albedo can be more accurately estimated, by integrating the directional reflectance data collected in two azimuthal planes at 45 ° to the solar principle plane*[8].

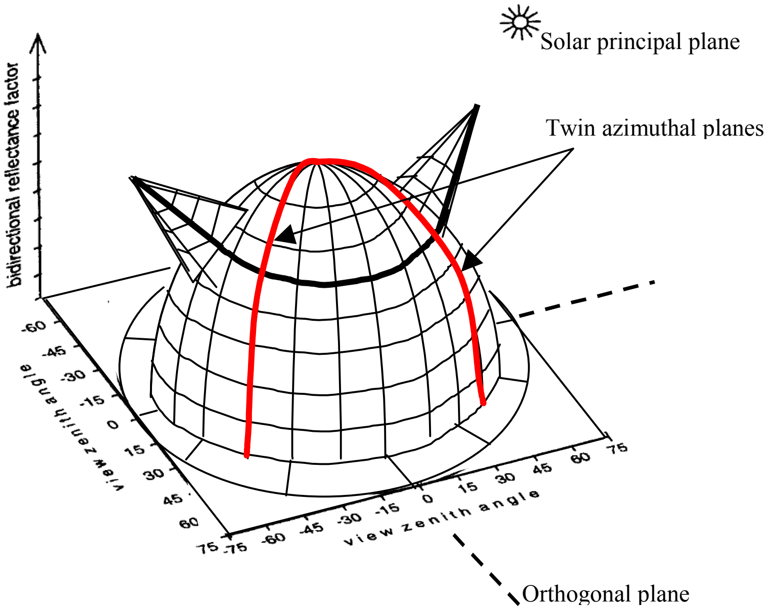

Figure 3: Variable zenith angle sampling strategies, adapted from[8]

It has been shown in laboratory analysis that the angular sampling of 15° and 30° in the zenith and azimuth angles respectively is adequate to characterize the BRDF characteristics of most natural and artificial surfaces[10]. Many research teams have subsequently adapted this. However, characteristics such as the hotspot or specular peak may require a higher sampling resolution.

All the above methods make the assumption that the Sun is the source. Whilst this is true for the resultant information i.e. use of site with a satellite sensor, it does not necessarily mean that the Sun has to be used as the source for characterisation. Artificial sources can and have been deployed for such measurements most notably by ONERA who use a tungsten source at night time[11].

8.3.2.3 Instrumentation

Single point sensors such as the ASD FieldSpec Pro, which are commonly used for the reflectance factor measurements, can be used to make multi-angular measurements, by

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[10] Sandmeier, S. R., (2000). Acquisition of bidirectional reflectance factor data with field goniometers, Remote Sensing of Environment, 73, 3, 257-269.

[11] Xavier Briottet, ONERA personal communication.

following the sampling strategies described above. However, it requires a physical movement of the spectrometer to map out the angular distribution, which is time consuming, leading to errors, and complexity, since in the natural environment the intensity of light in the multiple directions will vary with time. This is due to effects such as the atmosphere and the illumination angle of the Sun, which are constantly changing.

There is also a large contribution to the measured reflectance of a surface due to the diffuse irradiance that is produced from scattered light from the atmosphere. Careful consideration in the field can minimize these errors, but the most important factor is that its contribution should be evaluated and documented; otherwise the data can be devalued and can become a significant source of error[9].

To reduce the errors associated with the imperfect knowledge of the directional reflectance, there have been a number of goniometers designed and used for field measurements over recent years using the Sun as a source. These include the Field Goniometer System (FIGOS)[12], the ground-based Portable Apparatus for Rapid Acquisition of Bidirectional Observations of Land and Atmosphere (PARABOLA)[13] and the Automated Spectro-goniometer (ASG)[14].

One recent addition to these instruments is an instrument called Gonio RAdiometric Spectrometer System (GRASS), developed by the National Physical Laboratory of the UK[15] which provides quasi-simultaneous, multi-angle, multi-spectral measurements of radiance and irradiance and is illustrated below in Figure 4 as an example.

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[12] Sandmeier, S. R. and K. I. Itten, (1999). A field goniometer system (FIGOS) for acquisition of hyperspectral BRDF data, IEEE Transactions on Geoscience and Remote Sensing, 37, 2, 978-986.

[13] Abdou, W. A., M. C. Helmlinger, J. E. Conel, et al., (2000). Ground measurements of surface BRF and HDRF using PARABOLA III, Journal of Geophysical Research-Atmospheres, 106, D11, 11967-11976.

[14] Painter, T. H., B. Paden and J. Dozier, (2003). Automated spectro-goniometer: A spherical robot for the field measurement of the directional reflectance of snow, Review of Scientific Instruments, 74, 12, 5179 - 5188.

[15] Pegrum-Browning, H., Fox, N. and Milton, E., 2008. The NPL Gonio Radiometric Spectrometer System (GRASS), in Proceedings of the Remote Sensing and Photogrammetry Society Conference, University of Exeter 15-17 September.

Figure 4: The NPL Gonio RAdiometric Spectrometer System (GRASS) conducting measurements on Tuz Gölü, Turkey, August 2008.

8.3.2.4 Source of errors

In field based measurements of BRF it is important to note that one of the principle sources of error relates to the timing of the experiment and not simply the instrumentation or method itself. For example, errors can be introduced due to changes in the solar irradiance over short timescales. This, therefore, means that the errors are dependent on the measurement sequence, and time-delay between successive measurements of the target and reference measurements. Careful consideration and good documentation is required to minimise these systematic errors. A common approach is to restrict the field measurements to a period around solar noon when the solar geometry is changing least and when the error due to the angular response of the reflectance panel is at a minimum. Alternately the method established by ONERA using an artificial light source during night time conditions, instead of the Sun can provide the necessary data.

- Using the previous sections' sampling strategies, a single point instrument, can be used to measure the angular variability. The errors associated with these measurements will arise due to the accuracy of the method of acquisition. For example, if a sensor physical location is constant, but the orientation of the sensor is changed to capture multi-angular radiance, the area of the target that is measured is assumed to be spatially and spectrally uniform. Any non-uniformity will introduce errors that can be difficult to determine. Where the sensor is mobile, the errors are associated with the mechanism of the sensor and the uncertainties associated with tilting the sensor and geo-location of the sequential measurements.

- Determining the angular reflectance characteristics of a particular surface can be difficult in the natural environment, due to effects such as the atmospheric conditions and illumination angle of the Sun, which are constantly changing. It is, therefore, critical that the time taken to perform a full set of measurements is kept to a minimum. By reducing the measurement time, the uncertainties associated with the changing environmental conditions can be reduced.

- The angular field-of-view of the sensor should also be kept as small as possible to ensure that the BRF measured is a good estimate of the true BRDF at the specified geometries.

- A particular problem in the field is the diffuse radiation that is produced from skylight and scattered light. The light is hard to quantify as its intensity can vary over the hemisphere and with time due to atmospheric changes. These errors can be reduced if considered carefully, but crucially they should be documented, otherwise the data can be devalued and the diffuse contribution can become a significant source of error.

  There are a few methods for calculating the diffuse irradiance contribution, which include conducting measurements under different conditions (e.g. clear skies/hazy skies). By occluding the solar disc, the difference between the direct and diffuse irradiance can be determined, or the complete sky irradiance can be measured.

8.3.2.5 Data Analysis, Reporting uncertainties

When reporting the results and uncertainties, care should be taken to include all details of the measurements, such as the illumination and measurement geometries, sampling resolution, slope of target, date of acquisition, position of the solar principal plane (SPP), altitude and surface type.

Table 2 Source of uncertainties for the BRDF measurements

Source of uncertainties	**Type**	**Typical values**

Traceability to SI (reference panel reflectance and spectral radiance of the radiometers)	Type B	
Drift from calibration	Type B	
Repeatability	Type A	
Reproducibility	Type A	
Diffuse light correction	Type B	
Angle of view, the absolute value	Type A	
Scattered light from the measurement system	Type A	
Solar variation during the time sequence for hemispherical data collection	Type A	

For the BRDF, retrieval methods such as that described by Martonchik (1994)[16] can be used. The most common way to report the results of the BRDF is through the use of three-dimensional diagrams (Figure 5), which are based on a polar co-ordinate system. Since BRDF effects are often quasi-symmetrical to the SPP, the plots are often referenced to the SPP rather than geographical north. These are highly illustrative plots, which can be used to visualise the general BRDF, however two-dimensional plots can be more suitable for quantitative analysis.

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[16] Martonchik, J. V., (1994). Retrieval of surface directional reflectance properties using ground level multiangle measurements, Remote Sensing of Environment, 50, 3, 303-316.

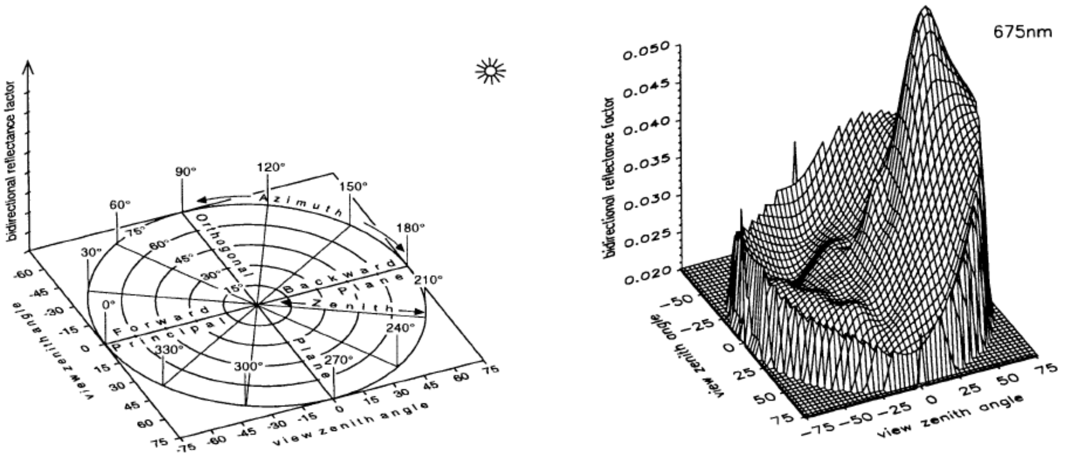

Figure 5: Left: Polar coordinate system used for presenting BRDF data in three dimensional plots, Right: Example of three-dimensional plot showing the BRF data of a grass lawn surface acquired with FIGOS at 675 nm under 35 source zenith angle, (taken from Sandmeier et al, 2000[10])

8.4 Atmospheric characterisation

8.4.1 Introduction

This procedure provides guidance on how to characterise a ground-based surface as a target for viewing by a remote sensor. The methods are all based on measuring the surface reflectance factor. However, any remote sensing instrument can only view this target through an atmosphere, which will distort the values observed, in a spectrally variant manner dependent on absorption and scattering properties of the atmosphere at the time of viewing.

Thus either the remote sensor has to apply a correction to the site data or the site data is corrected to what it will be when viewed at TOA by the sensor. In most cases the latter is the preferred choice, as the remote sensor doesn't have the ability to derive the necessary information to independently determine the correction due to the atmosphere itself.

The atmospheric correction can be calculated in a relatively simply manner through use of a radiation transfer code (RTC) but this in turn is highly dependent on the inputs of a variety of parameters that must be determined locally and at the time of use. The choice of code is also an open question and one, which is under evaluation within the EO community. This guide will only consider the input parameters needed by all RTC's and which can be derived locally at the time of characterisation.

8.4.2 Sunphotometer measurements: Method and Sampling

The principle instrument for measuring atmospheric transmittance is a "sun-photometer". These "Sunphotometers" are in essence spectroradiometers, similar to those measuring surface reflectance, but often limited to a few selected wavelengths using spectral filters. They are used to determine the aerosol optical depth, and water vapour content, by measuring the absorption and scattering of direct sunlight. Ideally such measurements should be performed in an automatic mode and over a continuous time period (beyond that constrained by any field campaign), with the added advantage that this will also lead to a site aerosol climatology record. This is best done as part of a formal network such as AERONET[17] which has well defined operational procedures The aerosol climatology helps in establishing a standard atmosphere containing all aerosol properties that can be used as input to the Monte Carlo simulations of the atmospheric radiance over this site.

However, as a minimum this can be performed with the help of a handheld manual instrument sampling regularly during site radiometric measurements.

8.4.3 Instrumentation

Ideally, the sunphotometer should have a narrow full FOV less than 2º to reduce the diffuse light correction required for desert dust and marine aerosols[18]. Automation, with regular sampling will give a more robust dataset to be used as input in the radiative transfer code for the vicarious calibration.

The sunphotometers should be traceably calibrated; at present all such measurements should be demonstrably linked to the Mauna Loa observatory.

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[17] Holben, B.N., Eck, T.F., Slutsker, I. et al. 1998. AERONET – A federated instrument network and data archive for aerosol characterization. Emote Sensing Environment. 66, pp. 1-16.

[18] Russell B.P, Livingston J.M., Dubovik O. et al., 2004. Sunlight transmission through desert dust and marine aerosols: Diffuse light corrections to Sun photometry and pyrheliometry, J. Geophys. Res., 109, D08207, doi: 10.1029/2003JD004292.

8.4.4 Source of errors

The dominant source of error for atmospheric transmittance comes from the aerosol optical depth measurement, and this is highly dependent on the pointing accuracy and the radiometric calibration of the instrument[19].

Ideally an AERONET compliant sun-photometer would be stationed near to the site and for this an uncertainty in optical depth of about ±0.01 of the average value for wavelengths greater than 440 nm and less than ±0.02 of the average value for shorter wavelengths can be achieved[20].

Similarly water vapour content can be determined from the 940 nm spectral band, with an uncertainty of 10% [21].

A handheld sunphotometer as MICROTOPS has an uncertainty in aerosol optical depth about ±0.01 of the average for all wavelengths and 10% uncertainty for the water vapour content[22].

8.4.5 Data Analysis, Reporting uncertainties

Data resulted from sunphotometry measurements are processed using the Beer-lambert-Bouguer law and the Langley plots as described by Holben et al. (1998)**[23]**.

The operator should report the normalised standard deviation. The operator should provide an estimate of uncertainty based on any traceable calibration and include a component due to potential drift of the instrument. The route of traceability should be clearly documented.

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[19] Holben, B.N., Eck, T.F., Slutsker, I. et al. 1998. AERONET – A federated instrument network and data archive for aerosol characterization. Emote Sensing Environment. 66, pp. 1-16.

[20] Holben, B.N., Tanre, D., et al. 2001. An emerging ground-based aerosol climatology: Aerosol Optical Depth from AERONET. J. Geophys. Res 106, pp. 12 067 –12 097.

[21] Halthore, R.N., Eck, T.F., Holben, B.N., Markham, B.L., 1997. Sunphotometric measurements of the atmospheric water vapour column abundance in the 940nm band. J. Geophys. Res. 102, pp. 4343-4352.

[22] Information from the manufacturer as per February 2009.

[23] See reference 16.

8.5 Other meteorological measurements

Additional meteorological data such as pressure, temperature should also be recorded and this is most easily achieved through an automatic weather station.

The instrumentation used to collect this data should be traceably calibrated and have sufficient accuracy and resolution that it does not limit the overall results of the site characterisation.

In some situations, where there may be high levels of Ozone for example additional measurements may be required.

8.6 Automatic ground-based measurements

This guide describes methodologies and instrumentation needed to characterise the radiometric properties of a ground based site. Ideally once calibrated a site should remain stable so that satellites can regularly use it. However, in practise this is rarely the case and site characteristics change with time. The changes may be real surface changes or simply local meteorological variations. Thus for the most accurate measurements the site should be characterised simultaneously with a satellite sensor overpass. However, this is a highly costly process and so efforts are in progress to establish automated instrumentation and methods to enable a well-calibrated site to have any small changes monitored and corrected with time.

The following test sites now have at least some level of automation: *Railroad Valley*, Nevada, USA[24], *La Crau*, France, Europe, and *Lspec Frenchman Flat*, NV, USA North America[25].

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[24] Czapla-Myers, J.S, Thome, K.J and Biggar, S.F., 2008. Design, calibration, and characterisation of a field radiometer using light-emitting diodes as detectors, Applied Optics, Vol. 47, No.36, p.6753-6762.

[25] Kerola D. X, Bruegge C.J, Gross H. N and Helmlinger M. C, 2009. On-Orbit Calibration of the EO-1 Hyperion and Advanced Land Imager (ALI) sensors using the LED spectrometer (Lspec) automated facility, IEEE Transactiona on Geoscience and Remote Sensing, Vol. 47, No. 4, p. 1244 – 1255.

Atmospheric measurements can easily be made in an automatic mode with the AERONET http://aeronet.gsfc.nasa.gov/ offering a robust database of aerosol optical properties at more than 300 sites worldwide. Unfortunately, not all radiometric test sites are near to an AERONET station at this moment.

9 Long-term evaluation of performance

To ensure that the techniques used by any one-characterisation team or on any one test site are consistent with each other and remain consistent with time it is advisable to undergo regular comparison.

Such comparison can be carried out by teams visiting different sites together or independently and comparing results in a similar manner to those organised by CEOS.

An alternative is to use in-flight sensors to view multiple sites and compare results.

10 Review of the process

This “Best Practice Guide to site characterisation” will continue to evolve in line with the increasing maturity and diversity of the Cal/Val community. It should thus be seen to be a guide to new users who are encouraged to question and challenge its processes and methodologies to ensure that it meets all situations and terrains in the future.

11 Conclusion

This procedure has been compiled from the combined experiences of the Cal/Val community to aid new users and to document best practise for the community as a whole.

The guide describes the methodologies that should be followed and instrumentation that should be deployed to enable the radiometric properties of a ground site intended to be used for satellite gain Cal/Val to be determined and an uncertainty assigned. This includes not only nadir measurements but also multi-angular and the auxiliary data needed to propagate the results through the atmosphere.