DEVELOPMENT OF THE GONIO RADIOMETRIC SPECTROMETER SYSTEM TO CONDUCT MULTI-ANGULAR MEASUREMENTS OF TERRESTRIAL SURFACES

H. M. Pegrum [a, *], N. P. Fox [a], E. J. Milton[b], M. Chapman[a].

[a] Optical Technologies and Scientific Computing Team, National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, UK.
(Heather.Pegrum, Nigel.Fox)@npl.co.uk
[b] School of Geography, University of Southampton, Southampton, SO17 1BJ, UK. E.J.Milton@soton.ac.uk

KEY WORDS: BRDF, calibration, radiance reflectance.

ABSTRACT:

The requirement for reliability and confidence in Earth Observation data is being recognised by many international organisations e.g. WMO and CEOS, the latter of which endorsed two recommendations at its 14th plenary, which stated that; pre-launch calibration should be performed using equipment and techniques that can be demonstrably traceable to, and consistent with, the SI system of units, and traceability should be maintained throughout the lifetime of the mission, and more recently in a white paper submitted to CEOS plenary 19 summarising CEOS WGCV activities and plans in support of GEOSS. Increasingly, satellites have the capability of measuring surfaces at multiple angles. Due to the variations in slope angle and aspect, there are only a few remotely sensed data sets which are immune to multi-angular effects. To improve the accuracy and traceability of multi-angular field measurements, a new instrument has been designed, in conjunction with the Natural Environmental Research Council (UK) Field Spectroscopy Facility (FSF). The Gonio RAdiometric Spectrometer System (GRASS) is being developed at the National Physical Laboratory, in the Optical Technologies and Scientific Computing Team. It is intended to provide quasi-simultaneous, multi-angle, multi-spectral measurements of Earth surface reflected sunlight to support vicarious calibration of satellite sensors operating in the optical region. The GRASS instrument was first deployed in June 2006 as part of an experiment organised by Network for the Calibration and Validation of Earth Observation data (NCAVEO), this paper will summarise the recent developments of the GRASS instrument, and its initial deployment at the NCAVEO Field Experiment.

1. INTRODUCTION

The Group on Earth Observation (GEO) is an international partnership leading a worldwide effort to build a Global Earth Observation System of Systems (GEOSS) over the next 10 years. The GEOSS vision, articulated in the 'GEOSS 10 year Implementation Plan' (Mitsos, 2005), reflects a global scientific and political consensus that the assessment of the state of the Earth requires continuous and coordinated observation of our planet at all scales.

With global initiatives such as GEOSS it is an exciting time for metrology within the remote sensing community. The development of techniques for the calibration and validation of remotely sensed data is leading to significant improvements in our understanding of the Sun – Earth system.

Satellite sensors generate large amounts of data, but these only become useful for monitoring global climate change when they are quality controlled and users can have confidence in their accuracy and relevance. Data provided from the multitude of satellites are generally used in models to provide information to policy makers, and thus must provide unequivocal evidence to support national and international legislation. To provide confidence in the data from these sources, the data should be referenced to a traceable and internationally accepted standard (Fox, 1999).

Satellite instruments measure the light reflected from the Earth's atmosphere and surface, but despite detailed pre-launch calibration campaigns to establish the satellites' performance, post-launch calibration is vital to validate the instruments' performance once in orbit. The validation of satellite instrument performance, (for example, to monitor any degradation of the on-board calibration diffusers or sources), is often achieved by using field instruments, which measure the light reflected from 'calibration sites', that can be viewed by satellite sensors. These techniques are known as vicarious calibration, which is a method that is independent of on-board calibration, (Thome, 1998).

Vicarious calibration provides a suitable method for the validation of the satellite data, however its accuracy is limited by the ground measurements and the validity of the atmospheric radiative transfer models, (Dinguirard, 1999). The significant error contribution due to directional reflectance effects and traceability to SI, are of particular interest for this project.

Directional reflectance effects are due to natural targets being non-Lambertian, which means depending on the viewing and illumination angles, a surface can appear brighter or darker – for example a mown lawn or a forest canopy. This interaction with light and matter is of key interest in developing the understanding of the reflectance characteristics in the natural environment.

The Bi-Directional Reflectance Distribution Function (BRDF) is the theoretical function that describes the relationship between the incident flux on a surface and the distribution of

* Corresponding author.

that which is reflected, as defined by Nicodemus in 1977, (Nicodemus, 1977). The BRDF is often used in climate models; therefore an accurate understanding of the BRDF characteristics of different surfaces is required to provide confidence in the climate models.

Currently there are several satellite instruments that have the capability of measuring surfaces at multiple angles. For example the MODerate resolution Imaging Spectroradiometer (MODIS) (Schaaf, 2002), the Multiangle Imaging SpectroRadiometer (MISR) (Bruegge, 2002) and the POLarization and Directionality of the Earth's reflectance (POLDER) multispectral camera (Kaufman, 1997). As the data products from these instruments becomes more readily available for investigations into the BRDF of various terrestrial surfaces, it is vital to validate the satellite data using field instrumentation that can also measure at multiple angles, and to ensure traceability to SI.

1.1 Goniometers

There are a few goniometers that are currently used for field measurements, these include the Field Goniometer System (FIGOS) (Sandmeier), the ground-based Portable Apparatus for Rapid Acquisition of Bidirectional Observations of Land and Atmosphere (PARABOLA) (Abdou) and the Automated Spectro-goniometer (ASG) (Painter) .

These Goniometers can be used in the field to determine the angular reflectance characteristics of a particular surface. However in the natural environment it is hard to quantify, as the intensity of light in the multiple directions can 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 the scattered light. Careful consideration in the field can minimize these errors, but the important factor should be that its contribution should be documented, otherwise the data can be devalued and can become a significant source of error (Milton, 1995).

2. THE GONIO RADIOMETRIC SPECTROMETER SYSTEM (GRASS)

The UK Natural Environmental Research Council, Field Spectroscopy Facility (NERC FSF), which is based at the University of Edinburgh, currently has a suite of instruments that can be borrowed by researchers to conduct field or laboratory based experiments. The NERC FSF also provides researchers with calibrated reference reflectance panels that are traceable to the National Physical Laboratory (NPL). This is particularly important for long-term studies, and satellite imagery verification so that measurements can be inter-compared and be traceable to SI. The instruments are predominantly used to make nadir measurements in the field. They are either hand-held or portable (via the use of a back-pack) so they can be used in remote locations. The users of the facility have particular requirements for an instrument to be able to measure at multiple angles, which should be lightweight and be able to perform rapid sampling.

2.1 GRASS Design

The Gonio RAdiometric Spectrometer System (GRASS) is being developed at the National Physical Laboratory, in the Optical Technologies and Scientific Computing Team. It is intended to provide quasi-simultaneous, multi-angle, multi-spectral measurements of Earth surface reflected sunlight to support Remote Sensing based activities.

The instrument is being designed to be easily and quickly assembled in remote situations, be robust and able to be transported by "estate car". GRASS will provide the structure and optics to collect the radiation, which will then integrate to a variety of spectroradiometers (not part of GRASS).

GRASS is being designed to measure the Earth's reflected sunlight over half a hemisphere, at 30-degree intervals i.e. 0°, 30°, 60°, 90°, 120°, 150°, 180°, on a series of seven arms (Figure 1). Six of these arms will have five collecting optics (referred to as a "camera"), and the seventh will have six, to be able to capture the nadir measurement, as well.

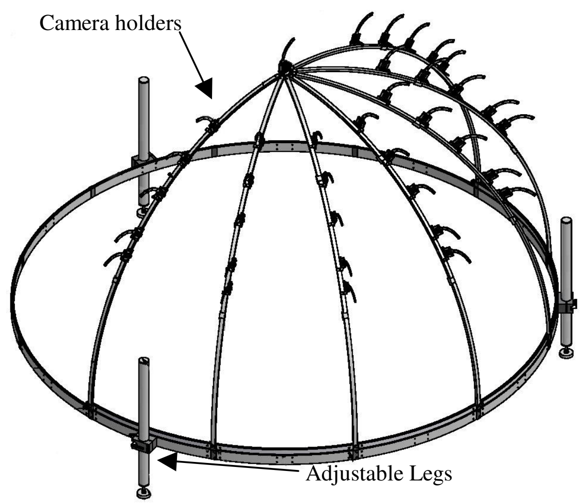

Figure 1. Schematic diagram of the Gonio Radiometric Spectrometer System (GRASS).

This results in 36 cameras / measurement angles, within the half of the hemisphere. Each camera consists of a collimating lens and an optical fiber. The fibers from the entrance optics feed to a series of multiplexers that result in one optical output that can be coupled to a spectrometer. The spectrometers that will be initially considered for integration with the Goniometer are those available from the NERC FSF.

The height of the structure is designed such that the focus of the nadir-viewing camera is 2 m from the centre of the target. The hemispherical structure of GRASS is designed with a series of legs that are adjustable, such that the working height can be altered. The application of this design feature is so that a spectral measurement can be taken of the top of a vegetation canopy, for example.

To be able to take measurements at all chosen geometries, the arms of the Goniometer are being designed so that they can rotate on the circular base of the structure allowing the forward and backward scattered radiation to be measured (Figure 2). The positions of the entrance optics on the arms are also designed to be moveable so that effectively any five-zenith angles (up to 60°), can be chosen to be captured during each measurement sequence. This allows detailed studies of particular BRDF characteristics, e.g. the specular peak.

Figure 2. Photograph of the GRASS in the Laboratory.

2.2 Diffuse Irradiance

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 it can vary in intensity over the hemisphere and can vary 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 it, 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.

For these reasons, another design feature of GRASS is that the lenses on the end of each of the fibers can be removed, and replaced with a cosine diffuser, and the orientation of the viewing optic rotated such that the entrance optic can then measure the down-welling irradiance. This means that the instrument can measure both the radiance and irradiance at concurrent angles, (Figure 3).

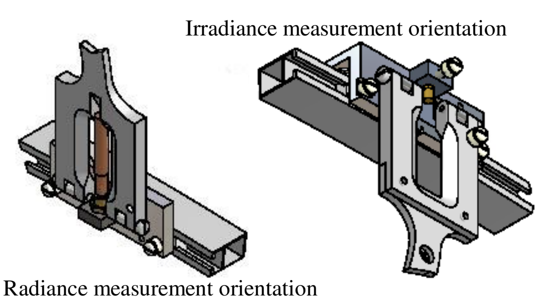

Figure 3. Schematic diagram of the radiance and irradiance orientations of the entrance opticc.

3. NCAVEO FIELD EXPERIMENT 2006

3.1 Introduction

The Network for the Calibration and Validation of Earth Observation data (NCAVEO) (Milton, 2006), planned a national field campaign that took place in June 2006. The experiment was a scoping exercise for the establishment of one or more VALERI (*Validation of Land European Remote sensing Instruments)* (Baret, 2006) sites in the UK as well as an opportunity to learn and share best practice amongst NCAVEO partners and the wider earth observation community.

NPL was involved in a couple of aspects of the experiment. To provide traceability to SI, all of the field spectroradiometers used, were compared against the NPL Transfer Standard Absolute Radiance Source (TSARS) (Pegrum, 2004). Secondly, the goniometer was used to perform multi-angular, multi-spectral measurements of the main calibration site used for the experiment that will later be compared with data that was acquired by others during the experiment.

3.2 Traceability

At NPL all optical radiation measurement is traceable to the cryogenic radiometer, as shown in Figure 4. The cryogenic radiometer is used to calibrate solid-state detectors as transfer standards. These detectors, in effect, establish a spectral responsivity scale, forming the top of the calibration chain. Usually the transfer standard calibrated directly against the cryogenic radiometer is a trap detector (Fox, 1991). Trap detectors are used to calibrate filter radiometers and photometers and, from there, provide other scales or services for end-users, within industry and the earth observation community.

For spectral emission scales, the filter radiometers are used to measure the temperature of a high temperature blackbody (up to 3500 K) and this, through Planck's law, provides a known source of spectral radiance. In this way the source emission scales, based on the blackbody, are linked to the more accurate detector scales.

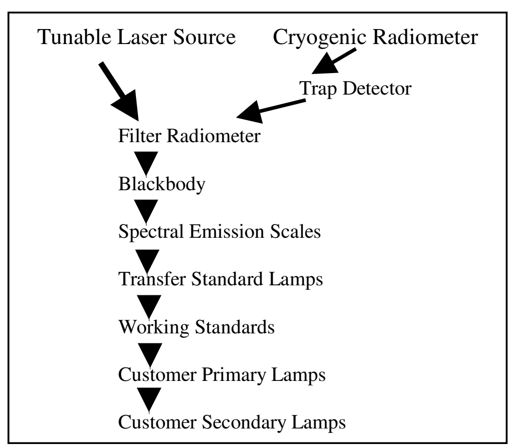

Figure 4. Traceability Chain to the NPL's Primary Standard Cryogenic Radiometer.

The Spectral Radiance and Irradiance Primary Scales (SRIPS) facility (Woolliams, 2005) is used to transfer the scale from the blackbody to lamp and integrating sphere sources through an intermediate spectrometer (Figure 5). These sources are then used as spectral radiance and irradiance standards for the calibration of customer instruments, for example satellite instruments.

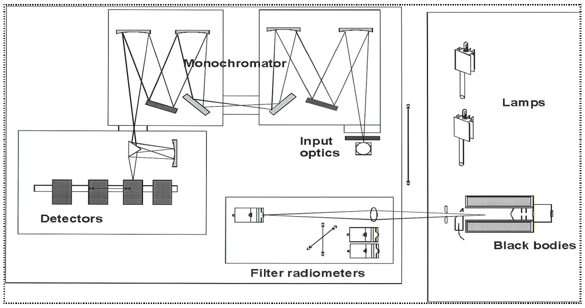

Figure 5. A schematic layout of SRIPS for irradiance measurements

3.2.1 The Transfer Standard Absolute Radiance Source (TSARS): has been developed by NPL, to provide customers with a transfer standard that is calibrated on the SRIPS facility, and traceable to the NPL primary standard cryogenic radiometer. The TSARS consists of an integrating sphere that is illuminated by a number of external lamps and has a large area circular exit port. Although this design is common with other such sources, NPL has put significant effort into selecting and positioning sources to improve the uniformity (Hunt, 2001). In addition a set of filter radiometers has been included to allow active stabilisation and monitoring of performance. Versions of this design were used to calibrate the Geostationary Earth Radiation Budget (GERB) (Mossavati, 1998) instrument now flying on Meteosat Second Generation and also at Applied Spectral Research Inc of Canada for calibration of a range of EO instruments. A small compact version was also used in the calibration of the Global Ozone Monitoring Experiment (GOME 2) – FM3 (Pegrum, 2004).

The TSARS was used as calibration source for the spectroradiometers that were used during the NCAVEO field experiment, since the radiance calibration of a spectroradiometer requires a large area, uniform source of known radiance. The TSARS has a uniformity of ± 0.5% across the exit port, and is stable to ±0.2% over a period of a few hours. The TSARS was calibrated on the SRIPS facility shortly before the Field Experiment. All of the spectroradiometers that were used during the Field Experiment were calibrated against the NPL TSARS, in a laboratory at the Council for the Central Laboratory of the Research Councils (CCLRC) Chilbolton Facility for Atmospheric and Radio Research (CFARR), Hampshire, UK. This ensured that all instrumentation had been calibrated and be traceable to SI.

3.3 Multi-angular Measurements

The full GRASS structure was not completed in time for use in the NCAVEO Experiment; however the base structure and three camera holders were ready. These were used (with an ASD FieldSpec Pro, on loan from the FSF), to acquire some multi angular data that will later be compared with data that was acquired by others during the experiment. The three camera positions available were set up as follows: one at the nadir, and two other cameras positioned at a 50° zenith angle, on two arms at 90° to each other. These positions are shown in Figure 6.

The three cameras (lens and fiber) were mounted in a camera holder on the arms, and the fibers were then run back to a multiplexer unit, which was operated by the NPL software. The limited data will later be compared with other data from the experiment.

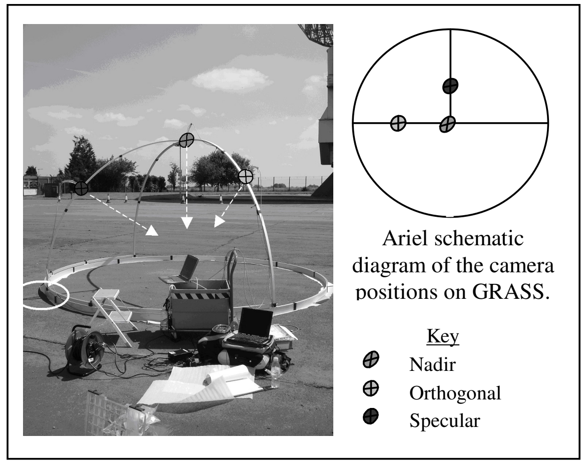

Figure 6. Picture of the GRASS set-up on the calibration site.

4. CURRENT STATUS

The full structure of GRASS has now been completed, as shown in Figure 2. Some initial testing of the angular alignment of the instrument showed that the system was flexing, and therefore the angular orientations had significant errors associated with them. Modifications to the instrument have been made, and the instrument is currently being tested in the laboratory, before being utilised in the field.

5. CONCLUSIONS

As more satellites have the capability of measuring surfaces at multiple angles, it is vital the field instrumentation can provide in-situ data to validate the satellite measurements. This in-situ data also needs to be made at multiple angles. The design of the Gonio RAdiometric Spectrometer System has led to the provision of quasi-simultaneous measurements of a surface at multiple angles, and through the involvement in the NCAVEO field experiment, it is hoped to provide data for comparison with satellite measurements which will develop an understanding of the anisotropy of natural targets.

REFERENCES

Abdou, W. A., Helmlinger, M. C., Conel, J. E., Bruegge, C. J., Pilorz, S. H., Martonchik, J. V. and Gaitley, B. J., 2000. Ground measurements of surface BRF and HDRF using PARABOLA III. Journal of Geophysical Research-Atmospheres, 106(D11), pp. 11967-11976

Baret, F., Weiss, M., Allard, D., Garrigue, S., Leroy, M., Jeanjean, H., Fernandes, R., Myneni, R., Privette, J., Bohbot, J. M. H., Bosseno, R., Dedieu, G., Bella, C. D., Duchemin, B., Espana, M., Gond, V., Gu, X. F., Guyon, D., Lelong, C., Maisongrande, P., Mougin, E., Nilson, T., Veroustraete, F. and Vintilla, R., 2006. VALERI: a network of sites and a methodology for the validation of medium spatial resolution land satellite products. Remote Sens. Environ, Submitted.

Bruegge, C. J., Chrien, N. L., Ando, R. R., Diner, D. J., Abdou, W. A., Helmlinger, M. C., Pilorz, S. H. and Thome, K. J., 2002. Early Validation of the Multi-angle Imaging SpectroRadiometer (MISR) Radiometric scale. IEEE Transactions on Geoscience and Remote Sensing, 40(7), pp. 1477-1492

Dinguirard, M. and Slater, P., 1999. Calibration of Space-Mulitispectral Imaging Sensors: A Review. Remote Sens. Environ, 68(3), pp. 194-205

Fox, N. P., 1991. Trap detectors and their properties. Metrologia, 28(3), pp. 197-202

Fox, N. P., 1999. Improving the accuracy and traceability to SI of space-based radiometric measurements, both pre-flight and post-launch. Advances in Space Research, 23(8), pp. 1471-1476

Kaufman, Y. J., Tanré, D., Gordon, H. R., Nakajima, T., Lenoble, J., Frouins, R., Grassl, H., Herman, B. M., King, M. D. and Teillet, P. M., 1997. Passive remote sensing of tropospheric aerosol and atmospheric correction for the aerosol effect. Journal of Geophysical Research, 102(D14), pp. 16,815-16,830

Milton, E. J., 2006. Network for the Calibration and Validation of Earth Observation data (NCAVEO). http://www.ncaveo.ac.uk/. (accessed 29 Jan 2007).

Mossavati, R., Harries, J. E., S. Kellock, Wrigley, R. T., Mueller, J. and Fox, N. P., 1998. Radiometric calibration of the GERB instrument. Metrologia, 35(4), pp. 603-607

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

Pegrum, H., Woolliams, E., Fox, N., Riel, L. V., Otter, G. and Kowalewski, M., 2004. Calibration of the NPL Transfer Standard Absolute Radiance Source (TSARS) and its use with GOME 2 – FM3 Spectral Radiance measurements. 11th International Symposium on Remote Sensing, Sensors, Systems, and Next-Generation Satellites VIII, Maspalomas, Spain. Proc. SPIE, 5570-72, pp. 503-514.

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

Schaaf, C. B., Gao, F., Strahler, A. H., Lucht, W., Li, X., Tsang, T., Strugnell, N. C., Zhang, X., Jin, Y., Muller, J.-P., Lewis, P., Barnsley, M., Hobson, P., Disney, M., Roberts, G., Dunderdale, M., Doll, C., d'Entremont, R. P., Baoxin Hug, Liang, S., Privette, J. L. and h, D. R., 2002. First operational BRDF, albedo nadir reflectance products from MODIS. Remote Sens. Environ, 83(1-2), pp. 135-148

Thome, K., Schiller, S., Conel, J., Arai, K. and Tsuchida, S., 1998. Results of the 1996 Earth Observing System vicarious calibration joint campaign at Lunar Lake Playa, Nevada (USA). Metrologia, 35(4), pp. 631-638

Woolliams, E. R., M, G., Cox, Fox, N. and P, M., Harris, 2005. Final Report of the CCPR K1-a Key Comparison of Spectral Irradiance 250 nm to 2500 nm. http://kcdb.bipm.org. (accessed 19 Mar. 2007).

ACKNOWLEDGEMENTS

The authors would like to thank NERC and the National Measurement System Directorate of Department of Trade and Industry for financial support of this project. The authors would also like to thank The Tintometer Limited.