The NPL Gonio RAdiometric Spectrometer System (GRASS)

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Abstract

Increasingly satellites have the capability and requirement to measure surfaces at multiple angles, and additionally, due to the variations in slope angle and aspect, few remotely sensed data sets are immune to multi-angular effects. Since such measurements need to be calibrated or at least validated against real ground data we need to improve the accuracy of multi-angular field measurements. A new instrument has been designed, in conjunction with the Natural Environmental Research Council (UK) Field Spectroscopy Facility (FSF) and the University of Southampton for this purpose. The Gonio RAdiometric Spectrometer System (GRASS) has been developed at the National Physical Laboratory, which provides 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 instrument will ultimately be available for use by UK researchers through the FSF to provide data to develop a better understanding of the anisotropy of natural targets, which can be used to reduce errors in climate modelling. It will also be utilised for the characterisation of "reference standard" test sites.

Keywords: *goniometer*, *vicarious calibration, validation*

1. Introduction

Post-launch calibration of satellite sensors is vital in order to validate the data they collect once in orbit. Monitoring of any degradation of the on-board calibration diffusers or sources (which are used for in-flight calibration) is often achieved by viewing the light reflected from ground based "calibration sites" characterised through field deployed instruments. This is known as vicarious calibration, which is a method independent of on-board calibration.

The Committee of Earth Observation Satellites Working Group on Calibration and Validation (CEOS WGCV) has identified the need for a globally distributed network of calibration/characterisation reference sites to facilitate interoperability and bias correction of land imaging sensors. The network for calibrating radiometric gain has tentatively been called LandNET. These 'reference sites' are required to be characterised, instrumented and fully maintained to ensure that they meet the needs of current and future sensors. However the accuracy of vicarious calibration that can be achieved from these reference sites will be limited by the accuracy of the ground measurements and the validity of the numerical models used to correct for the effect of the atmosphere. The aim of this project is to reduce (or at least quantify) the error contributed by imperfect knowledge of the directional reflectance of the calibration sites, and the impact of this upon the traceability (to SI) of the resultant EO data products.

2. Multi-angular measurement

Goniometers are used in the field to determine the angular reflectance characteristics of a particular surface. However in the natural environment this 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 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 documented, otherwise the data can be devalued and can become a significant source of error (Milton *et al*. 1995).

Over recent years there have been a number of goniometers designed and used for field measurements, these include the Field Goniometer System (FIGOS) (Sandmeier *et al*. 1999), the ground-based Portable Apparatus for Rapid Acquisition of Bidirectional Observations of Land and Atmosphere (PARABOLA) (Abdou *et al*. 2000) and the Automated Spectro-goniometer (ASG) (Painter *et al*. 2003). However, they all require a physical movement of the spectrometer to map out the angular distribution, which is time consuming, leading to errors, and complexity.

To reduce the errors associated with the imperfect knowledge of the directional reflectance, a novel goniometer has been developed at the National Physical Laboratory, in the Optical Technologies and Scientific Computing Team. The Gonio RAdiometric Spectrometer System (GRASS) is intended to provide quasi-simultaneous, multi-angle, multi-spectral measurements of Earth surface reflected sunlight to support cal/val based activities.

The project has been co-funded by the UK Natural Environmental Research Council, Field Spectroscopy Facility (NERC FSF), which is based at the University of Edinburgh. They currently have a suite of instruments that can be borrowed by researchers to conduct field or laboratory based experiments, and GRASS is intended to become part of the equipment pool to support research into the angular variability of terrestrial surfaces.

2.1 GRASS Design

The instrument has been 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).

Figure 1: *Photograph of the NPL Gonio RAdiometric Spectrometer System (GRASS).*

GRASS has been 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. 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 to give 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.

To be able to take measurements at all chosen geometries, the arms of the Goniometer have been designed so that they can rotate on the circular base of the structure allowing the forward and backward scattered radiation to be measured. 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.

2.2 Diffuse Irradiance

A particular problem in the field is the diffuse radiation that is produced from skylight and other 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.

For this 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.

3. Reference site characterisation

CEOS WGCV as the space arm of GEO (Group on Earth Observation), have been developing an internationally harmonised data quality assurance strategy. This strategy has led to the development of a Quality Assurance Framework for Earth Observation (QA4EO), which consists of a set of guidelines based on the adoption of "best practise". QA4EO is built upon the guiding principle that '*All data and derived products must have associated with them a Quality Indicator based on documented quantitative assessment of its traceability to community agreed reference standards. This requires all steps in the data and product delivery chain (collection, archiving, processing and dissemination) to be documented with evidence of their traceability.*' To implement this strategy it is recognised that there needs to be a global, network of terrestrial reference standard targets, which can be used as benchmark sites for post-launch radiometric calibration of space-based instruments (CEOS. 2008).

One of sites selected to be a 'reference site' for land imagers is Lake Tuz in Turkey (Figure 2), which dries to reveal salt lakebed during the summer months. The site has not previously been used for calibration or validation purposes, so requires characterisation to determine its suitability for particular cal/val applications.

Figure 2: *Lake Tuz, Turkey.(NASA, 2007)*

Part of this characterisation of the site includes the multi-angular, temporal and spatial reflectance of the salt lakebed. The National Physical Laboratory is collaborating with Tubitak Uzay's Space Technologies Group to perform the characterisation during summer 2008. The GRASS instrument will be used to provide the multi-angular characterisation of the site. The measurement campaign will also be used to identify the key characteristics needed of "test sites" to enable them to meet the in-flight calibration and validation requirements of Earth observation sensors. It will also enable the development of a protocol to provide the basis for a future international comparison campaign in 2009 and 2010.

4. Conclusions

As more satellites have the capability of measuring surfaces at multiple angles, it is vital that the field instrumentation is available to 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 will lead to the provision of quasi-simultaneous measurements of a surface at multiple angles. This is a crucial aspect for underpinning the measurements that are performed by satellite instrumentation. Without the baseline characterisation of the satellites sensors, using the calibration reference sites, the data from the satellites cannot be quality assured or traceable to international standards.

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5. References

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