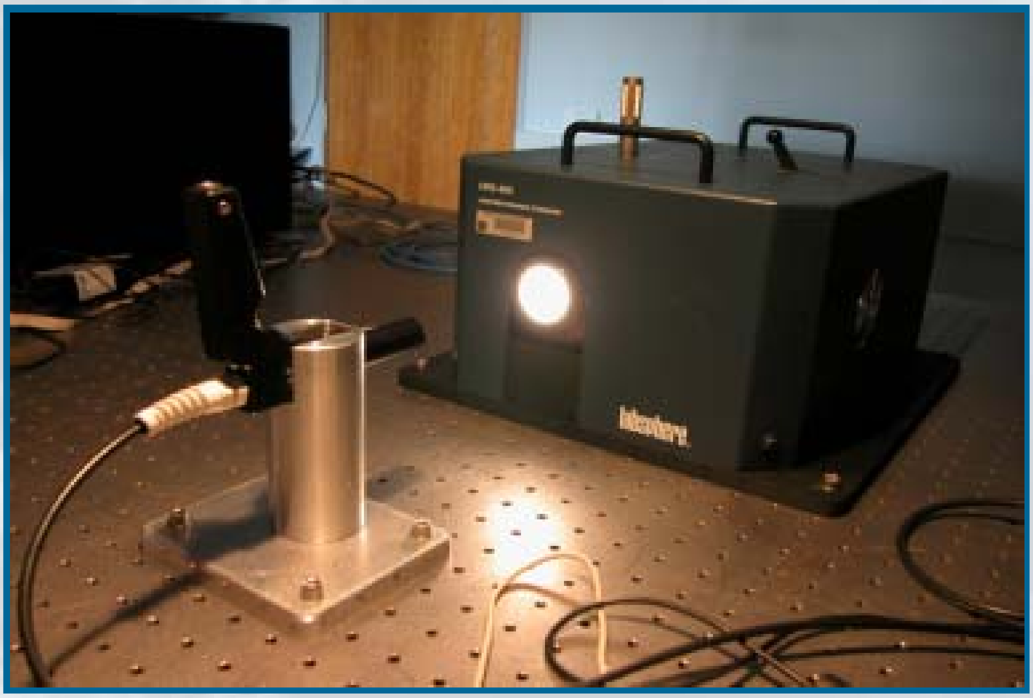
Selection of a Radiance Source for the Radiometric Calibration Facility at the CSIRO Earth Observation Centre

R.M. Mitchell, S.K. Campbell
CSIRO Atmospheric Research

and

P.J. Daniel
CSIRO Land and Water



CSIRO
Atmospheric Research

CSIRO Atmospheric Research Technical Paper No.67

Selection of a Radiance Source for the Radiometric Calibration Facility at the CSIRO Earth Observation Centre

R.M. Mitchell, S.K. Campbell and P.J. Daniel

CSIRO Atmospheric Research Technical Paper no. 67

National Library of Australia Cataloguing-in-Publication Entry

Mitchell, Ross M.
Selection of a Radiance Source for the Radiometric
Calibration Facility at the CSIRO Earth Observation Centre

ISBN 0 643 06886 4.

1. Radiometers – Calibration. 2. Remote sensing –
Australia. I. Campbell, Susan K. II. Daniel, Paul J. III.
CSIRO Atmospheric Research. IV. CSIRO Land and Water. V.
CSIRO Earth Observation Centre. VI. Title. (Series:
CSIRO Atmospheric Research technical paper (Online); 67).

621.3678

Address and contact details: CSIRO Atmospheric Research
Private Bag No.1, Aspendale, Victoria 3195 Australia
Ph: (+61 3) 9239 4400; Fax: (+61 3) 9239 4444

COSSA Earth Observation Centre
GPO Box 3023, Canberra 2601
Ph: (+61 2) 6246 5899; Fax: (+61 2) 6246 5988

E-mail: ar-enquiries@csiro.au

CSIRO Atmospheric Research Technical Papers may be issued out of sequence. From July 2000, all new Technical Papers will appear on the web site of CSIRO Atmospheric Research. Some Technical Papers will also appear in paper form.

© CSIRO Australia electronic edition, 2004

Selection of a Radiance Source for the Radiometric Calibration Facility at the CSIRO Earth Observation Centre

R.M. Mitchell and S.K. Campbell
CSIRO Atmospheric Research,
Earth Observation Centre,
GPO Box 3023,
Canberra, ACT 2601, Australia

P.J. Daniel
CSIRO Land and Water,
GPO Box 1666,
Canberra, ACT 2601, Australia

Abstract

This report discusses the selection of a radiance source suitable for calibrating a diverse group of radiometers commonly used in CSIRO. The chosen system is based on an integrating sphere that enables the mapping of incident radiance against instrument response with known uncertainty. Commercially available candidate source systems are assessed against the physical and radiometric characteristics of the target instruments, with particular regard to the maximum radiance level required and the dimensions of the exit port. The Labsphere URS-600 was found to fit these requirements with the additional advantage of calibration traceable to the National Institute of Standards and Technology (NIST). A further design study was undertaken to ascertain whether a customised system would prove more attractive. However, the alternative system was found to provide inadequate radiant output and to be more expensive. Future work will focus on the development of a multispectral calibration reference system to monitor source performance.

1 Introduction

For some time it has been recognized that the coordinating role taken on by the CSIRO Earth Observation Centre could profitably include the standardisation of radiometric calibration procedures across a range of instruments operated by several divisions within CSIRO. Two prominent divisions in the use of field radiometers are CSIRO Land and Water (CLW) and CSIRO Atmospheric Research (CAR), the latter being the administering division of the Earth Observation Centre (EOC). This report discusses the selection of a radiance source suitable for calibration of a majority of the radiometers currently in use at CLW and CAR/EOC. It is found that a system based around an integrating sphere provides the best choice, having the benefit of being relatively free from errors due to positioning and alignment. After consideration of a commercially available system and an alternative system built up from discrete components, it is found that the former system offers compelling advantages including certified spectral calibration over the wavelength range 300-2400 nm.

2 Terms of reference

Radiometric calibration is taken to mean the mapping (usually linear) between incident radiance or irradiance and the instrument response, usually in digital counts. This report aims at selecting a system to enable this mapping to be tracked over the life of the instrument, thus enabling any set of measurements obtained with the instrument to be rendered into absolute radiometric units with known associated uncertainty.

Other issues such as the cosine response of irradiance sensors are best described by the term characterization and do not fall within the scope of this report. However, provided that the characteristics remain stable over time, meaningful relative calibrations of such sensors can still be obtained by the system described here.

3 Existing calibration tools

The CSIRO Earth Observation Centre maintains a Li-Cor 1800-02 Optical Radiation Calibrator that consists essentially of a baffled quartz-halogen lamp driven by a highly stable power supply. This device was specifically designed (and purchased) for calibration of the Li-Cor 1800 spectroradiometer. Although attempts have been made to use this source to calibrate other instruments, these have proven largely unsuccessful due to the specialized mounting requirements needed to ensure that the instrument samples in the reference plane of the source, where (and only where) the irradiance is known. For radiance sensors there is the added problem that the exit beam is not uniform across the 25 mm exit port, rendering the source essentially useless in this case.

4 Rationale

Integrating spheres are spherical cavities lined with a highly reflective, diffusely reflecting surface, equipped with one or more apertures or ports. Integrating spheres have long enjoyed widespread use for a variety of radiometric measurement and calibration applications. They were originally developed to compare lamp performance by integrating the output of an internally-mounted test lamp over solid angle, the lamp luminance being directly related to the radiance measured at a suitable exit port.

Integrating spheres have found extensive application in radiometry because ideally, the exit radiance is both uniform across the exit port and is isotropic. That is, the exit port appears as an ideal lambertian source. In practice, uniformity and isotropy are realized typically to better than 98% in commercially available systems. This feature removes the rigid dependence on positioning and alignment apparent in the experience of using other calibration sources such as the Li-Cor source mentioned previously.

In designing or selecting an integrating sphere system, the two most significant parameters are the maximum radiance level required, and the size of the exit port. Both are determined by the radiometric and physical characteristics of the instruments to be calibrated, which are therefore considered below.

5 Instruments

This report considers five instruments in current use at CAR/EOC and CLW. Table 1 lists working radiances and physical dimensions of all five instruments.

Instrument	Bands (nm)	Radiance mW cm^{-2} sr^{-1} μm^{-1}	Irradiance mW cm^{-2} μm^{-1}	Condition	Aperture (mm)	Head size (mm)	FOV FWHM	
							Air	Water
Cimel CE318	440	5–40		Clear sky	20	75	1°	
	670	0.9–15						
	870	0.3–6						
	1020	0.1-5						
TRIOS Ramses	320–950							
Radiance head		100@500 nm		Saturation	5	5	16°	12.2°
Irradiance head					7	28	2π	
Hydrorad	200–1100							
Radiance head		10@500 nm		Water (typ)	3	16	8.2°	6.2°
Irradiance head			150@500 nm	Global	6	25	2π	
Li-Cor 1800	300–1100			Obsolete				
Irradiance head					21	70	2π	
ASD Fieldspec	350–2500							
Fibre end		50@500 nm		Ref Panel	2	3	25°	
Radiance head		50@500 nm		Ref Panel	18	20	5.0°	
Irradiance head			150@500 nm	Global	16	38	2π	

Table 1: Some properties of multispectral and hyperspectral radiometers used by CAR, EOC and CLW.

5.1 Cimel CE318 sun photometer

The Cimel CE318 forms the primary instrument of the Aerosol Ground Station Network (AGSNet) consisting of four stations across the Australian continent. AGSNet is affiliated with NASA's Aerosol Robotic Network (AERONET), consisting of over 100 stations worldwide (Holben *et al.*, 1998). The CE318 features both direct sun and sky radiance measurements. While the former can be calibrated by the well known Langley method and variants thereof (Mitchell and Forgan 2003), the sky radiance channels require independent laboratory calibration.

The AERONET instruments are presently calibrated at NASA/GSFC using a 30-inch integrating sphere. While some AGSNet instruments have been calibrated in this way, it is time consuming and severely disrupts the operational routine of the network. Hence, a local means of calibrating the sky radiance channels is required.

In Table 1, the radiances represent typical sky radiance ranges measured at Tinga Tingana and Jabiru, when the sky channel is set to high gain. This occurs during sky radiance scans when the instrument is pointed more than 6° away from the solar disc.

5.2 TRIOS Ramses spectroradiometer

This instrument is an immersible spectroradiometer in use at CLW. Both radiance and irradiance sensors are available, and are usually deployed in tandem, the radiance sensor looking down and the irradiance sensor looking up. The detector characteristics and physical sizes are given in Table 1. The spectral range 320–950 nm is sampled by a 256-element silicon photodiode array. The typical saturation radiance quoted by the manufacturer is $100\,\mathrm{mW\,cm^{-2}\,sr^{-1}\,\mu m^{-1}}$.

5.3 Hydrorad spectroradiometer

This instrument is an immersible spectroradiometer in use at CLW, based on a spectrometer manufactured by Ocean Optics. The spectral range of 200-1100 nm is sampled via a 2048-element linear CCD array. As with the Ramses, both radiance and irradiance sensors are available, and are usually deployed in tandem. The detector characteristics and physical sizes are given in Table 1. Typical in-water upwelling radiance is of order $10\,\mathrm{mW\,cm^{-2}\,sr^{-1}\,\mu m^{-1}}$at 500 nm.

5.4 Li-Cor 1800UV

This instrument represents previous-generation technology, consisting of a monochromator mounted in an immersible but bulky enclosure. Its chief disadvantages are the slow sampling rate (one spectrum takes between 15 and 25 seconds to acquire) and large physical size, leading to unwanted shadowing of the water column below the instrument. Although operationally obsolete, its characteristics are listed in Table 1 since it may play a useful role in a calibration intercomparison.

5.4.1 Li-Cor 1800

This instrument is similar to the Li-Cor 1800UV described above, but is packaged more compactly in the so-called 'lunch-box' configuration.

5.5 ASD Fieldspec FR

This instrument has enjoyed considerable popularity over recent years in a variety of field campaigns. The spectral range extends from 350–2500 nm using a 512-element silicon photodiode for the visible and two InGaAs detectors in the SWIR. Incident light is conveyed to the instrument housing via a permanently attached fibre optic bundle, with subdivisions of the bundle feeding each detector. The 3 mm diameter fibre termination device has a FWHM receptivity cone of approximately 25°. Both radiance and irradiance heads can be fitted. Physical sizes of these are listed in Table 1. The irradiance value of $150\,\mathrm{mW\,cm^{-2}\,\mu m^{-1}}$ at 500 nm is taken from the global irradiance measured during clear sky conditions at the ARM CART site in Oklahoma. The radiance values of $50\,\mathrm{mW\,cm^{-2}\,sr^{-1}\,\mu m^{-1}}$ at 500 nm would arise if the spectrometer were pointed at a perfectly reflecting lambertian panel normally illuminated by a beam with irradiance $150\,\mathrm{mW\,cm^{-2}\,\mu m^{-1}}$, and is meant to suggest a typical operating maximum radiance level.

6 Selection of radiance source

Since the above instruments form a diverse group, it is necessary to consider carefully the physical and radiometric characteristics of the instruments in order to select a suitable radiance source.

6.1 Maximum radiance

For the spectrophotometric sensors, the upper radiance range is dictated by the requirement that the downwelling irradiance from a typical clear sky be within the dynamic range. The corresponding radiance is the upwelling radiance from a perfectly reflecting lambertian panel normally illuminated by this irradiance, or $F_{max} = I_{max}/\pi$. At 500 nm, representative values are F_{max} ~150 mW cm^{-2} μm^{-1}and I_{max} ~50mW cm^{-2} sr^{-1} μm^{-1}.

For the sky radiance channels on the Cimel sun photometer, it will be shown below that the driving radiometric requirement is the sky radiance of ~40 mW cm^{-2} sr^{-1} μm^{-1} at 440 nm.

6.2 Physical size

Table 1 shows that the largest entrance apertures are 21 and 20 mm on the Li-Cor and Cimel respectively. These two instruments also have the largest structural dimension near the entrance aperture. However, these sizes are not critical unless they pose an obstacle in juxtaposing the instrument entrance aperture and calibration source.

The entrance aperture range requires that the exit port on the calibration source be 25 mm or greater, given that relevant manufacturers are likely to work in imperial units. In practice a somewhat larger exit port (say between 38 and 50 mm) appears desirable to accommodate as wide a range of instruments as possible.

7 Commercially available radiance sources

Integrating sphere systems manufactured by Labsphere and Lumetronics were considered. However, the Lumetronics spheres are targeted more toward lamp testing rather than radiometry, so only those from Labsphere were evaluated in detail. Labsphere systems use a variety of coatings, but those considered here use either Spectraflect or Spectralon. The latter provides superior durability and wavelength performance over Spectraflect at somewhat higher cost.

Table 2 lists the characteristics of four uniform source systems made by Labsphere. All spheres listed have exit ports larger than 25 mm, although the USS-400 source at 31 mm falls below the desirable range 38–50 mm stated above.

The spectral radiance output of the systems is compared in Figure 1 where it is seen that only the USS-400 and URS-600 are able to supply the requisite radiance of approximately 40 mW cm^{-2} sr^{-1} μm^{-1} at 440 nm. At 500 nm the radiance of the URS-600 is 63 mWcm^{-2} sr^{-1}μm^{-1}, below the saturation radiance of the Hydrorad (100 mW cm^{-2} sr^{-1} μm^{-1}) but

Model	USS-600	URS-600	USS-400	USS-4000
Maximum Luminance (ft-lm)	600	20,000	125,000	10,000
Peak Radiance	6.5	200	1260	100
Sphere diameter (mm)	150	150	100	1000
Port diameter (mm)	50	38	31	356
Coating material	Spectraflect	Spectralon	Spectralon	Spectraflect
Reference detector	Unfiltered Si	Photopic Si	None	Unfiltered Si
Attenuation	Iris	V-slide	None	10 lamps
Radiance certification	Optional	NIST	None	Optional

Table 2: Comparison of Labsphere uniform source systems. Radiance units are $\mathrm{mW\,cm^{-2}\,sr^{-1}\,\mu m^{-1}}$. The NIST certification covers the wavelength range 300–2400 nm.

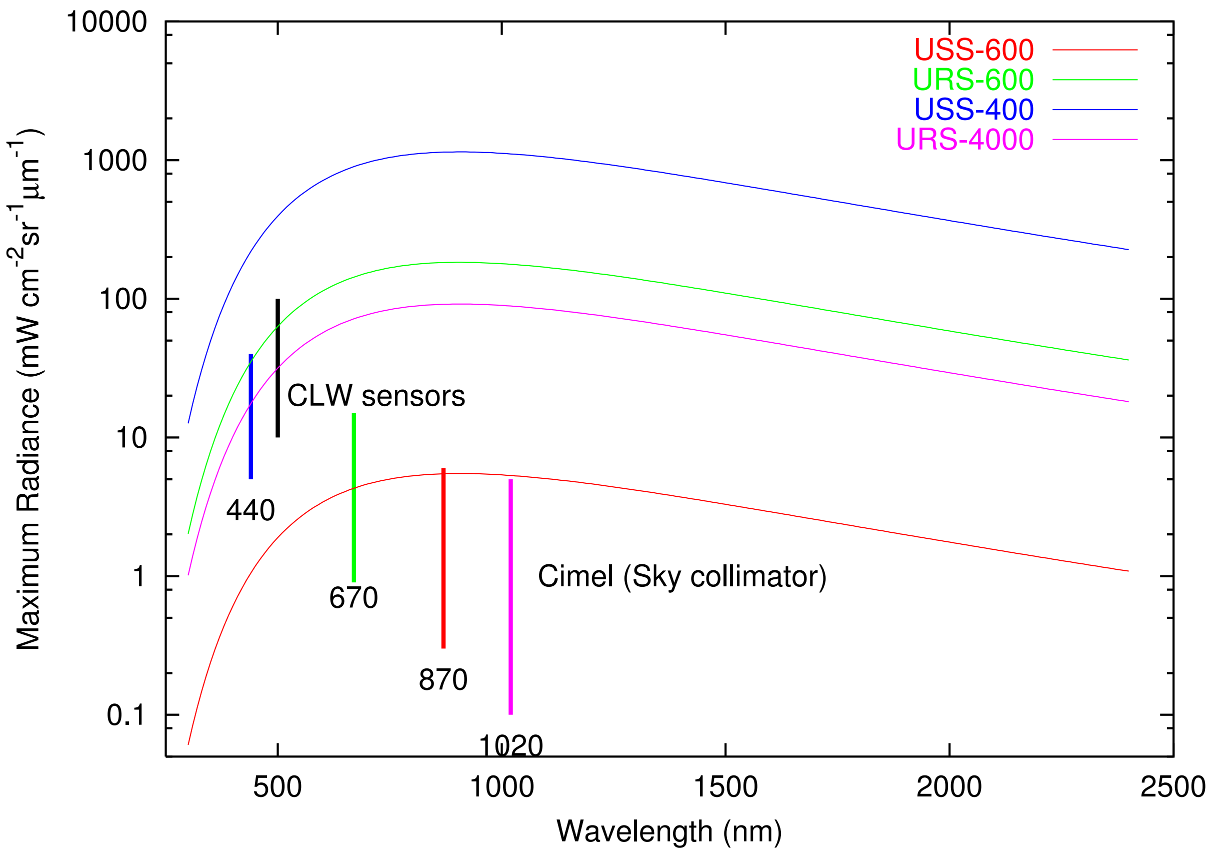


Figure 1: Intercomparison of the spectral radiance output from four Labsphere uniform source systems, together with representative instrumental radiance ranges (see text).

Model	URS-600
Coating material	Spectralon
Luminance range	10-20,000 ft-lambert
Colour temperature	3200° K±25° K
Luminance stability (short term)	±0.1% (4 hours)
Luminance stability (long term)	±0.8% (100 hours)
Luminance calibration uncertainty	±4%
Spectral radiance calibration	300–2400 nm
Spectral radiance calibration uncertainty	<3% @ 350–1600 nm
	<4% @ 2000 nm
	<9% @ 2400 nm
Integrating sphere diameter	150 mm
Source aperture diameter	38 mm

Table 3: Specification of the Labsphere URS-600 uniform radiance source.

Figure 2: The Labsphere URS-600 uniform radiance source.

above the nominated maximum working radiance level of 50 mW cm^{-2} sr^{-1} μm^{-1}. While the higher radiance level of the USS-400 may appear advantageous from this plot, reference to Table 2 shows several egregious drawbacks including the lack of a reference detector, no means of attenuating the output, and no spectral radiance certification. By contrast, the URS-600 has a reference silicon detector (either unfiltered or filtered to give the photopic response), a specially designed micrometer-driven V-slide attenuator, and certification of the spectral radiance output to NIST.

Further specifications of the URS-600 are given in Table 3, while an image of the URS-600 is shown in Figure 2.

8 Design study

The following design study was undertaken partly for heuristic reasons and partly to ascertain whether a system with a somewhat larger exit port than the URS-600 could be configured from off-the-shelf components.

The system explores the attractive concept of obtaining a highly diffuse output by illuminating the main sphere using a smaller secondary or satellite sphere within which the lamp is mounted. This configuration is employed in the Labsphere uniform source system USS-600, which was found above to be unsuitable due to insufficient power. In essence the system evaluated below is a higher powered version of the USS-600.

The system consists of the following Labsphere components:

- Lamps: 125 W quartz halogen, photopic output 2400 lm, colour temperature 3050° K, IHLS-100-125SL. Lower power lamps are also considered.
- Satellite sphere: 150 mm diameter, 50 mm attachment port, Spectraflect coating, SSI-060. Attenuation is by variable iris shutter at the attachment port.
- Integrating sphere: 200 mm diameter, 50 mm output ports, Spectraflect coating, IS-080-SF.
- Detector assembly: unfiltered silicon, SDA-050-U.
- Power supply: 200 W, LPS-200-H-B.

The spectral radiance L_λ of an integrating sphere may be written (Labsphere 2002)

$$L_\lambda = \frac{\Phi_\lambda}{\pi A_s} \frac{\rho_\lambda}{1 - \rho_\lambda(1 - f)} \tag{1}$$

where Φ_λ is the spectral input power, ρ_λ is the spectral reflectance of the coating material, A_s is the internal area of the sphere, and f is the port fraction defined as the summed area of all ports divided by the sphere area.

The spectral power may be calculated from the radiant input power to the sphere Φ and the assumption of a blackbody spectral shape, so that

$$\Phi_\lambda = kB_\lambda(T) \tag{2}$$

where $B_\lambda(T)$ is the Planck function and k is a constant defined by the normalization

$$\int_0^\infty B_\lambda(T) d\lambda = \sigma T^4/\pi \tag{3}$$

where σ is the Stefan-Boltzmann constant, leading to the following expression for the spectral power:

$$\Phi_\lambda = \frac{\pi\Phi}{\sigma T^4} B_\lambda(T). \tag{4}$$

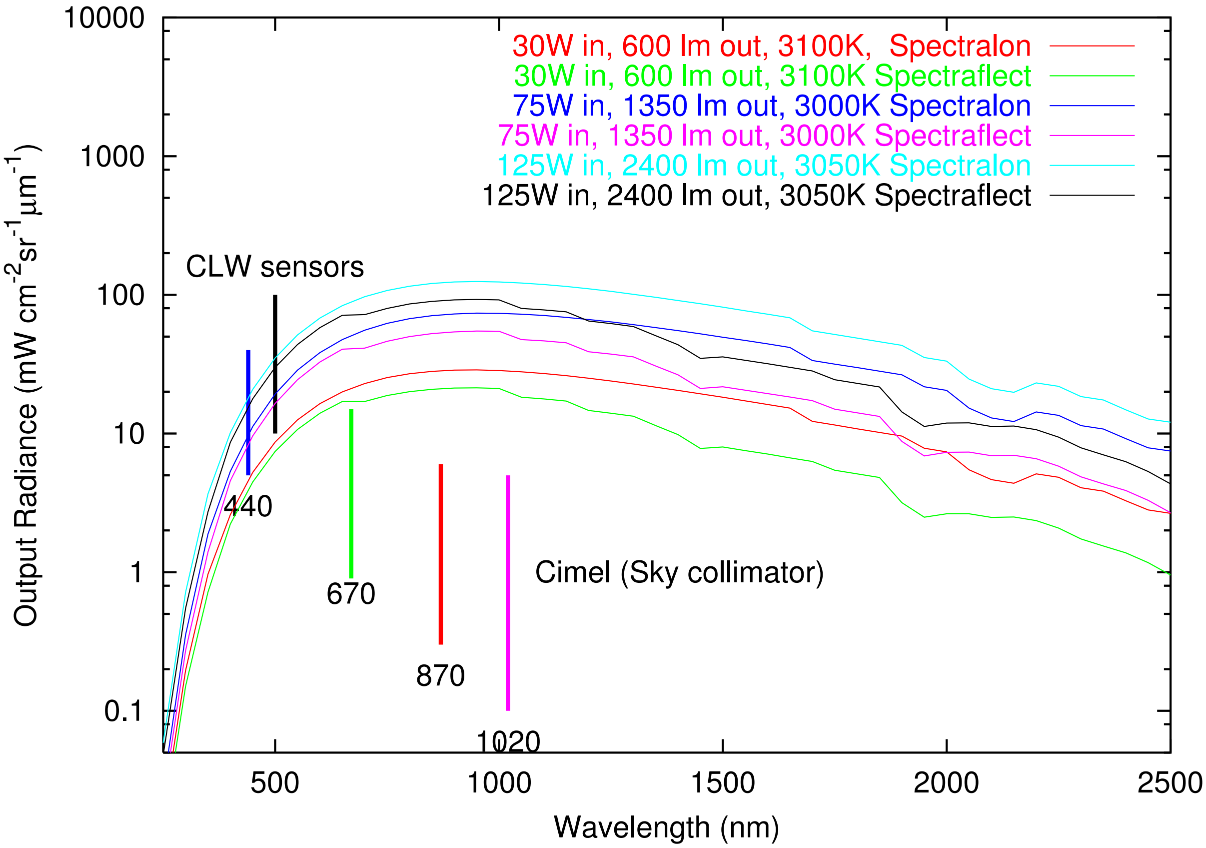


Figure 3: Intercomparison of the spectral radiance output from a system comprising a 200 mm main sphere with port fraction 0.05 illuminated by a 150 mm diameter satellite sphere. Three lamp power ratings are considered for the available coating materials Spectralon and Spectraflect. The vertical bars indicate representative operating ranges of the sky radiance channels on the Cimel sun photometer, and a variety of spectrometric sensors primarily associated with aqueous measurements.

The radiant output of the satellite sphere is given by

$$\Phi = \epsilon \eta P \tag{5}$$

where ϵ is the lamp efficiency in converting electrical input power P to radiant output (typically 80–85%) and η is the throughput of the satellite sphere, typically 40–50%.

The resulting spectral radiance from the specified system is shown for three different lamp powers and for the two sphere coatings Spectraflect and Spectralon in Figure 3. Spectral reflectance data were taken from Labsphere data sheets. The port fraction of 0.05 applies to the Labsphere IS-080-SF. The sphere throughput factor η was set at 0.4, while lamp efficiency was based on Labsphere tabulation of lamp photopic output.

Figure 3 shows that the radiance of this system is inadequate to cover the dynamic range of either the Cimel 440 nm channel or that of the CLW sensors at 500 nm. The output of the system cannot simply be increased by deploying a more powerful lamp. Not only is the 125 W lamp the most powerful available from Labsphere, but discussion with a Labsphere engineer raised the problem of burning the attenuating iris on the exit port from the satellite sphere. This turns out to be a problem plaguing source systems designed along these lines, and was the reason Labsphere developed the micrometer-driven V-slide attenuator featured on the URS-600.

The final drawback of this system is that the onus of obtaining a spectral radiance calibration would fall on the user, leading to additional costs and likely time delays. Moreover, there is no significant cost saving accruing from this approach.

Hence, although ultimately negative, this brief design study served a useful purpose in elucidating design issues and highlighting the merits of commercially integrated source systems with certified radiometric calibration.

9 Recommendation

The conclusion of this report is that an off-the-shelf system has clear advantages over a customised built-up system in the present case. In particular, the Labsphere Uniform Radiance Source URS-600 is attractive, having adequate output to calibrate all instruments considered over most or all of their dynamic range, and comes equipped with a sufficiently large exit port to accommodate all entrance apertures considered. The broad spectral extent of its radiance calibration (300-2400 nm) will prove useful in calibrating instruments used in the SWIR such as the ASD Fieldspec.

The only caveat concerns the use of a photopically filtered reference detector in the system, and the possibility of filter degradation over time, and a limited ability to track filament ageing. For this reason, development of a multispectral calibration reference system, sensitive to spectral shifts caused by filament ageing, will be given high priority.

References

Holben, B.N., Eck, T.F., Slutsker, I., Tanré, D., Buis, J.P., Setzer, A., Vermote, E., Reagan, J.A., Kaufman, Y.J., Nakajima, T., Lavenu, F., Jankowiak, I., and Smirnov, A. (1998): AERONET–A federated instrument network and data archive for aerosol characterization, *Remote Sensing Env.*, **66**, 1–16.

Labsphere (2002): A Guide to Integrating Sphere Radiometry and Photometry, *www.labsphere.com/tech-info/docs/RadioPhoto_Tech.pdf*.

Mitchell, R.M. and Forgan, B.W. (2003): Aerosol measurement in the Australian Outback: Intercomparison of sun photometers, *J. Atmos. Oceanic Technol.*, **20**, 54-66.