Consultative Committee for Photometry and Radiometry (CCPR)
23rd Meeting (22 - 23 September 2016)

Questionnaire on activities in radiometry and photometry

Reply from: National Physical Laboratory

Delegate: Nigel Fox

1. *Summarize the progress in your laboratory in realizing top-level standards of:*
   - *(a) broad-band radiometric quantities*
   - *(b) spectral radiometric quantities*
   - *(c) photometric quantities*

NPL continues to realise, maintain and disseminate measurement scales and transfer standards in all of these areas, using a range of measurement facilities developed over the past 20+ years. A rolling programme of upgrades to these facilities is underway, to ensure that they can meet the uncertainty levels and range of capability demanded by EO users in particular, as well as other stakeholders at the cutting edge of technology. For example, work has just commenced to upgrade the National Reference Reflectometer, which underpins the UK scales for spectral reflectance, to improve its sensitivity, spectral coverage, wavelength tuneability and goniometric positioning capability so it can meet latest needs for high-accuracy, traceable BRDF measurements.

Over the past 2 years work to improve NPL's primary optical radiation capability has been focused in the area of cryogenic radiometry. Our primary cryogenic radiometer now has a new reference cavity with a carbon nanotube black coating and improved superconductor based leads, electronic control systems and thermal links. As well as replacing obsolete parts, this has made the cavity more sensitive and more absorptive. Final testing is underway, including measurements to provide a formal linkage to our previous radiometer and thus confirm the stability of our spectral responsivity scale. Significant upgrades have also been made to the Cryogenic Solar Absolute Radiometer (CSAR) and the associated measurement of the window transmittance through the MITRA system designed and built at PMOD, leading to a factor of ten improvement in the thermal stability of the detector and removal of background noise effects. CSAR is a specially–designed radiometer (built in collaboration with METAS and PMOD-WRC) which is used for direct measurements of total solar irradiance.


Measurements at WRC prior to IPC, 2015

Ultimately it is intended that this will replace the current artefact-based standard (World Standard Group, WSG), not only establishing true SI-traceability for these measurements but also reducing the uncertainty of the current standard (0.3 %) by approximately a factor of ten. The upgraded CSAR was delivered to the World Radiation Center well in advance of the International Pyrheliometer Comparison (IPC) in 2015, which allowed extensive in-situ testing, optimisation and preparation for the comparison exercise on the solar tracker. In the IPC, a difference was found between the current standard and CSAR (representing SI), with the WSG measuring 0.26% higher than CSAR; this is consistent with a number of other investigations into the difference between WSG and SI. The overall estimated uncertainty achieved for the CSAR measurements (including window transmittance measurement) was 0.04 % (k=1), and the overall uncertainty of the comparison of CSAR and the WSG was 0.05 % (k=1).

Work has continued to develop and evaluate new methods and transfer standards for disseminating scales to customers, particularly for in-situ measurements for EO applications. For example, an in-depth investigation has been completed into the performance of ASD field spectrometers, which are widely used as transfer standards for monitoring solar surface reflected radiance and in some cases down-welling irradiance. The results are being used to improve the best practice guidance for their operation and for analysis and correction of results.

As well as developing our own facilities, we have a well-established programme of ‘instrument sales’, providing reference facilities and training to other organisations. For example, in March 2015 NPL successfully delivered and installed an integrating sphere facility at the Hong Kong Standards and Calibration Laboratory (HKSCL), to establish a calibration capability for total spectral radiant and luminous flux, and in the next couple of months an NPL-designed primary standard cryogenic radiometer system will be installed at the National Institute of Metrology, Thailand (NIMT). This latter facility includes a laser stabilisation system and krypton ion laser, together with a detector uniformity and linearity facility for use over the UV/VIS/NIR, as well as transfer standard trap detectors, infrared detectors, and irradiance and radiance standards.

2. *What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?*

NPL’s primary research focus is in meeting the needs of the Earth Observation and climate community. NPL chairs the international space agencies’ committee on calibration and validation of optical sensors (CEOS WGCV IVOS) and in this role has been able to influence stakeholders to take on the principles of SI traceability and rigorous uncertainty analysis. It is also engaged in support of WMO and its satellite calibration activities through the GSICS group.

NPL led the EMRP project MetEOC-1, which developed calibration techniques for the preflight, inflight and vicarious calibration of satellite instruments, and now leads a follow-on project MetEOC-2. See http://www.emceoc.org for specific details and achievements.

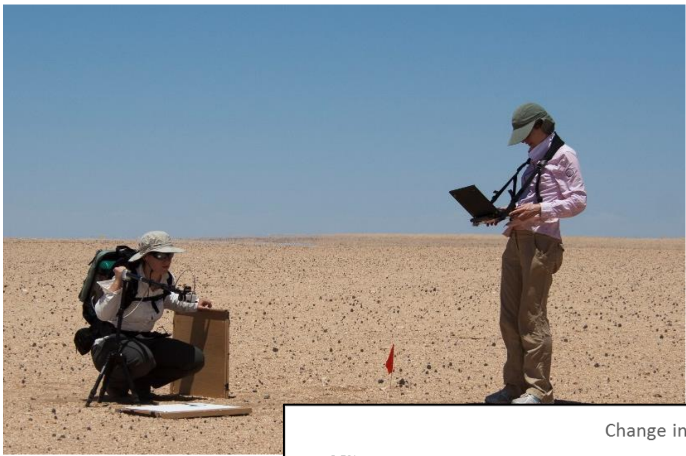
NPL provides pre-flight calibration services for several satellite sensors. In the last few years this has involved the calibration of, for example, the EarthCare BBR radiometer and Sentinel 3, as well as work (now nearing completion) to develop bespoke assembly, integration and testing facilities for Sentinel-4. These projects not only require uncertainties that are lower than those requested by any other sector, but also the development of best practice guidance that takes account of the specific problems associated with ensuring traceability for a range of in-situ measuring instruments, including those deployed in relatively hostile environments such as on platforms at sea, in rain forests, or in deserts.

In a related project we are involved in setting up RadCalNet – a global network of radiometric calibration sites (monitored and characterised deserts) that will be used for inter-satellite comparison and satellite vicarious calibration. RadCalNet will provide values for the spectral resolved reflectance of the site as viewed at top of the atmosphere every 30 minutes, together with an associated uncertainty. Our work is focused on validating the performance of the radiometric instrumentation and providing traceability to SI, but has also included studies to identify a suitable location for the ESA RadCalNet site by searching against specific criteria. Following this search the NPL team together with colleagues from the French space agency CNES, have performed a radiometric characterization of the new site, located in Namibia, and are in the process of setting up autonomous facility to measure the surface BRDF and associated atmospheric conditions (see below).

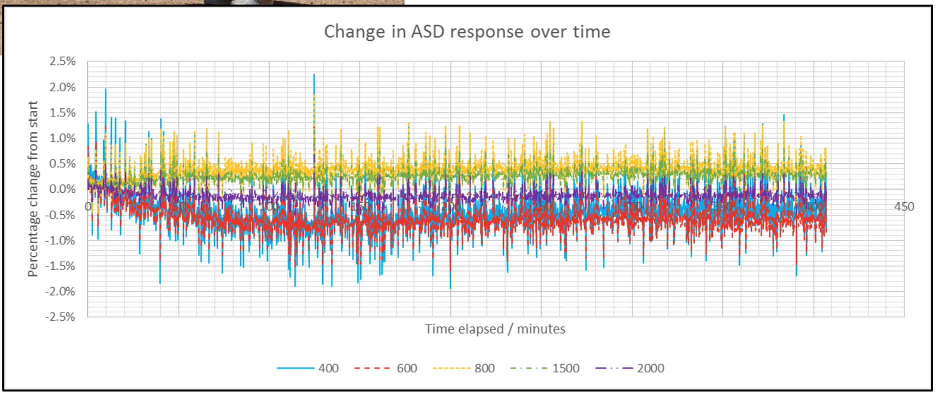
Our work with the EO community has shown that radiometric instrument calibration is only the very first step in a long complex analysis chain. Increasingly we are looking at "end-to-end" analysis of uncertainties, traceability and validation to support improvements to our understanding of climate change and the environment. An important aspect of this work is to provide training to those researchers involved in EO measurements and their analysis and manipulation to derive basic radiance or reflectance ('level 1 product') data and biophysical indicators ('level 2 products'). This has included the provision of a training course on Uncertainty for Earth Observation, which has been delivered twice at NPL to groups of about 50 participants each time, presented at the Academy of Opto-Electronics in Beijing and is now being further developed as an on-line course on the NPL website.

We are taking the lead in a number of projects related to ensuring the quality of the data used to establish the Essential Climate Variables (ECVs) and Climate Data Records (CDRs) that underpin improved models and understanding of the global climate system, including parameters such as sea, land and Ice surface brightness temperature, ocean colour, and leaf area index.

For surface temperature measurements we have recently completed an international comparison of the instruments (IR radiometers and Black bodies) and methods used to validate satellite measurements. Twelve participants (those making the field measurements) from across the globe visited NPL to take part in a series of comparisons (laboratory and external – reservoir/sports field) following protocols seeking to mimic best practice as established by the guidelines of CCPR. Space agencies recognize the importance of SI traceability and the rigour needed to demonstrate it and are starting to use the specific terminology 'fiducial reference measurements' to emphasise the distinction. More information can be found at www.FRMS4STS.org. A similar project has just started relating to ocean colour.



Field campaigns form an important part of our EO-related activity. For example, we recently successfully completed a field campaign in the Namib Desert in collaboration with the Centre National d'Études Spatiales (CNES), to identify the optimum location for a permanent measurement site that will be installed next year to continuously



ASD measurements

monitor the atmosphere and surface reflectance as part of RadCalNet. This involved making reflectance uniformity measurements using an ASD portable spectro-radiometer and HDRF (Hemispherical Directional Reflectance Factor) evaluations using GRASS, the Gonio-Radiometric Spectrometer System which was developed at NPL several years ago. Prior to the field measurements we had carried out an in-depth investigation of the performance of the ASD, including responsivity stability over time, temperature stability, wavelength calibration and absolute spectral responsivity. And in another project we carried out a 4 week intensive field campaign at Wytham Woods, Oxford, in which six hectares of forest were sampled with a range of optical devices, including terrestrial Lidar to estimate forest structure, leaf/canopy area and the spectral properties of individual foliage elements as well as tree bark and forest understory, with a view not only to use the site as a vegetated calibration target but also to create a representative virtual site for simulations to evaluate uncertainty due to scale and sampling for example.

Progress has also been made with the TRUTHS (Traceable Radiometry Underpinning Terrestrial and Helio Studies) satellite mission proposal (http://www.npl.co.uk/truths). Following some significant investment from the UK space agency most of the mission's critical concepts are now being protoyped and a new bid for its full implementation has been submitted to ESA in response to a call for future 'Earth Explorer' missions in June this year. If launched, TRUTHS would be the first EO satellite to provide SI-traceable measurements from space; of both incoming and outgoing solar radiation spectrally resolved. It would provide a benchmark for evaluating radiative balance, and a range of other radiation based climate sensitive parameters to provide improved data to understand human-induced climate trends and model future climate change. In addition, it can provide an in-orbit reference calibration for other satellites, facilitating an upgrade in the performance and interoperability of other missions.

Finally, we have conducted work on novel sensing technologies and photovoltaics. This includes developing the concept of self-calibration of LED systems (this technology has been used for the LED radiometer as part of the MetEOC-1 EMRP project and is now being developed in collaboration with Surrey University for solid state lighting control) and pioneering a technique called compression mapping that uses a micro-lens array to image different patterns on a PV to determine the location of malfunctioning areas with considerably more sensitivity and much more quickly than a raster-scan approach.

3. *What work in PR has been/will be terminated in your laboratory, if any, in the past /future few years? Please provide the name of the institution if it has been/will be substituted by a DI or accredited laboratory.*

We undertook a detailed review of our measurement capabilities at the end of 2015, taking account of the need to focus our resources to meet the specific needs of our priority (and most demanding) application area of Earth Observation whilst still providing essential traceability and support to all sectors of the UK economy that rely on our optical radiation metrology services. As a result of that review, it was clear that NPL's goniophotometric measurement services are no longer a critical part of the traceability chain in the UK, since several UKAS-accredited laboratories have now been established that are able to provide uncertainties only slightly higher than those available from NPL's primary goniophotometer. We are therefore planning to decommission our goniophotometric measurement facility and, from the end of 2016, will no longer offer calibration services for total luminous flux, total spectral radiant flux or luminous intensity distribution. We will, however, continue to support traceability routes for these measurements through the provision of calibrated luminous intensity and spectral irradiance standards to other UKAS laboratories and by providing advice on measurement best practice and uncertainty evaluation as needed, particularly in relation measurements for new energy efficient lighting products such as LEDs.

4. *What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.*

Our work is highly multidisciplinary and the CCPR is only one international organisation that we are actively involved with. It is not necessary for the CCPR to change, as it is important that it remains focused on primary scales and quantities. It is, however, also important to ensure that the CCPR has and maintains strong links with other organisations, such as the WMO and CEOS.

5. *What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?*

It is a strength that NMIs are focused on different research and development areas. We consider that whilst there is a need for a significant number of NMIs across the globe to have strong capability in primary underpinning scales, when it comes to tailoring these to specific applications, with limited resources, it is essential that there is sufficient diversity within and across geographical regions to ensure that the all the key requirements of the customer base are met

We agree with the priorities that have been identified as part of the EMPIR programme, and especially the focus that EMPIR has placed on key application areas.

6. *Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?*

Within Europe we achieve such collaboration through the EMPIR programme and we encourage collaboration between EMPIR and other NMIs and international organisations, particularly in projects related to Earth Observation, Climate and low carbon. For example, the EMPIR MetEOC2 project, which is developing robust metrology for Earth Observation and Climate, includes work associated with RADCALNET (an international project to build a network of test sites for EO satellites) which is being carried out in collaboration with a number of other European and international groups (including ESA, NASA, CNES and AOE/CAS).

7. *Have you got any other information to place before the CCPR in advance of its next meeting?*

No

8. *Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (September 2014)?*

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