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Protocol for the CEOS WGCV pilot Comparison of techniques/instruments used for vicarious calibration of Land surface imaging through a ground reference standard test site

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1 Introduction

In an era when the number of Earth observation satellites is rapidly growing and measurements from satellite sensors are used to answer increasingly urgent global issues, often through synergistic and operational combinations of data from multiple sources, it is imperative that scientists and decision-makers be able to rely on the accuracy of Earth observation data products. The characterization and calibration of these sensors, particularly their relative biases, are vital to achieve the developing integrated GEOSS for coordinated and sustained observations of the Earth. This can only reliably be achieved in the post-launch environment through the careful use of observations by multiple sensor systems over common, well-characterized terrestrial targets. Through greater access to and understanding of these vital test sites and their use, the validity and utility of information gained from Earth remote sensing will continue to improve.

Earth surfaces with suitable characteristics have long served as benchmark or reference standard test sites, either via so-called vicarious calibration[1] or via cross-calibration, to verify the post-launch radiometric calibration performance of satellite optical sensors. Such reference standard test sites are central to any future quality assurance (QA) and quality control (QC) QA/QC strategy and are explicitly embedded within QA4EO. At present, reference standard test sites are the only practical means of deriving knowledge on biases between sensors and allow, at some level, a means of bridging anticipated data gaps in measurement continuity due to a lack of co-existent in-flight sensors.

CEOS WGCV recently identified and endorsed eight instrumented sites to serve as priority targets for the international EO satellite community and a focus for calibration and validation efforts. The principle criteria in selecting these sites, other than the spatial uniformity, brightness etc. was that they were all fully and regularly calibrated by ground-based instrumentation. In some cases, instrumentation is permanently deployed, in others; it is transported for specific characterisation campaigns. However, in all cases the basis for assigning a value to the surface reflectance and its subsequent propagation to the Top Of the Atmosphere (TOA) as radiance (for comparison to satellite imagers) is derived from measurements made by ground survey teams. It is thus crucial that in addition to ensuring that the instrumentation being used is well calibrated traceable to SI units that the methodologies for its use and ultimate assignment of a value to the site are also well understood and any differences documented. In order to evaluate such differences CEOS WGCV has agreed to carry out a comparison of measurement techniques and instrumentation used for this purpose. This CEOS comparison will be held in 2010 but as such a comparison has not been held before it was agreed that a pilot comparison with relatively few participants would be held in 2009. This pilot will allow an appropriate protocol to be evaluated and refined as necessary and also ensure that all operational logistics are adequate.

Tuz Gölü, Turkey was proposed and accepted to serve as a host for both comparisons as it in relatively easy reach of all participants and particularly those in Europe who will take part in the pilot

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

comparison. A preliminary evaluation of the site was carried out in August 2008 by NPL and TU with support from ESA concluding its suitability.

This protocol describes the set of comparison activities that will be carried out as part of this exercise and the necessary generic details of the procedures that will be followed.

2 Objectives

The overarching objective of the 2009 CEOS pilot comparison is to trial and evaluates the procedures that need to be followed for a full CEOS comparison. However, in doing so it is important to consider the overall objectives of the comparison as a whole i.e. to identify and evaluate any biases between the participants in assigning a "radiometric value" to the test site. This will also lead to knowledge of the practical "state-of-the-art" and establish formal "SI traceability" to the Tuz Golu test site. These objectives in practise, result in a set of tasks and linked but independent comparisons, which apply to both the pilot, and the ultimate CEOS comparison.

The objectives can thus be sub-divided into the following:

1) Evaluate differences in field instrument primary calibrations
   a. Reference standards used and traceability (based on "Laboratory" information)
   b. On-site calibrations/validations
2) Evaluate differences in methods for characterising and assigning "radiometric value" to a site, for multiple view angles
   a. Small area for high-resolution imagers
   b. Large area for medium-resolution imagers
3) Establish formal traceability of Tuz Gölü reference site based on an evaluation of all comparison results.
4) Establish "best practice" guidance for above and/or knowledge of variance between methodologies.
5) A multi-sensor (satellite and aircraft) comparison linked to the ground calibration derived from the multi-team comparison.
6) Identify the minimum and ideal specifications for characterisation/instrumentation for a CEOS "reference standard"

3 Organization

3.1 Pilot

NPL will serve as pilot for this comparison. In this role they will be responsible for the organisation of the comparison ensuring that the logistics and any support equipment is available. They will also be responsible for inviting participants and for the analysis of data, following appropriate processing by individual participants. NPL as pilot will be the only organisation to have access to all data from all participants. This data will remain confidential to the participant and NPL at all times, until the publication of the Draft A (report showing results of the comparison to participants).

3.2 Participants

The list of participants is given in the following section (Section 3.3).

All participants must be able to demonstrate independent traceability to SI of the instrumentation that they use, or make clear the route of traceability via another named laboratory.

By their declared intention to participate in this comparison, the participants accept the general instructions and the technical protocols written down in this document and commit themselves to follow the procedures strictly.

Once the protocol and list of participants has been agreed, no change to the protocol or list of participants may be made without prior agreement of all participants.

3.3 Participants' details

Contact person	Institute	Contact details	Short version
Nigel Fox	National Physical Laboratory Hampton Road Middlesex TW11 0LW United Kingdom	Tel: +44 20 8943 6825 Email: Nigel.fox@npl.co.uk	NPL
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Selime Gurol	Tubitak Uzay Space Technologies Institute 06531 ODTU Kampusu Ankara Turkey	Tel: +90 312 2104600/1190 E-mail: selime.gurol@uzay.tubitak.gov.tr	TU
Andreas Mueller	German Remote Sensing Center Environment and Geoinformation Department Münchnerstr. 20 D-82234 Wessling Germany	Tel: +49-8153 28 1533 E-mail: Andreas.Mueller@dlr.de	DLR

3.4 Form of comparison

This protocol covers a number of individual comparisons. Each comparison will have its own specific characteristics but will all in principle take the same form i.e. they will all seek to observe a common entity, (surface/artefact), and analysis will be made by reference to the mean value observed by all participants. In some cases, to remove potential systematic biases from the measurand under evaluation, results (e.g. instrument responses) will be normalised to a common value, although linkage to the participants "own" values will be fully maintained.

Spectroradiometers operating in the solar reflective spectral region are the principle instrument type that will be used within this comparison. To evaluate any biases in their primary calibration (i.e. as contained within participants equipment) and also to ensure that any biases do not impact on other aspects of the comparison, a standard radiance source from NPL will be used. This source will in principle also provide a direct traceability route to SI for all the spectroradiometers. The initial comparison of participant spectroradiometers against this standard source will not be made visible until all results are completed. However, the pilot will take account of any observed biases when analysing the other aspects of the comparison. If possible this radiance source will be used to provide a link to any other accessible participating radiometer e.g. that of the Hymap airborne sensor.

To ensure robustness of the comparison process and remove the impact of any potential biases due to primary traceability, the measurements aspects of the comparison campaign will be carried out in three phases.

- Phase 1 will take place at Tuz Golu, Turkey before the field measurements, on or near the site and will entail all spectroradiometers viewing the same standard under the same geometry.
- Phase 2 will be the radiometric measurements of the site.
- Phase 3 will be a repeat of Phase 1 to ensure stability.

3.5 Comparison overview

This comparison can be considered to have two overall themes. The following sections outline the principles of each comparison theme; specific details will be described in section 4.

It should be noted that in conjunction with this comparison of site characterisation instruments and methods, the results will be used as part of a sensor to sensor comparison to be carried out in parallel. The details of this are not contained in this protocol other than the determination of top of the atmosphere radiances from the site characterisation, which will only be carried out as an experimental activity and not subject to the formality (in terms of publication etc) as the other comparison aspects.

3.5.1 Comparison 1: Cross-comparison of all instrumentation

In this theme, all spectroradiometers and secondary standards provided by the participants will be compared to each other and also directly to an SI traceable standard from the pilot, a participating national standards laboratory (NPL).

The spectroradiometers will measure consecutively the same SI radiance source and a wavelength standard. Each participant radiometer will be placed in front of the standard source at a predefined

distance, which allows the full field of view of the radiometer to be overfilled by the source. This procedure will be performed before and after the field measurements at Tuz Golu, Turkey. However, some of the repeat measurements may, subject to timing, be carried out in a more indirect route.

To maintain traceability in the field it is normal practise to use a lambertian panel diffuser as a reflectance reference standard. All participant radiometers will view all participant reflectance panels illuminated by the Sun. These reflectance panels will all be viewed at nadir and at 30° with a solar zenith angle commensurate with an 08:00 UTC satellite transition. The measurements will be arranged to take place in a short time frame to minimise the change in illumination conditions, sun zenith/azimuth angles. Ideally the timeframe for this activity should be less than 30 minutes.

One of the reference reflectance panels will be provided by the pilot and will be directly calibrated against the SI primary scale. This panel will have the dimensions 30 cm * 30 cm.

3.5.2 Comparison 2: Site characterisation

This comparison theme is to evaluate the methodologies used to characterise the site rather than direct traceability of the instrumentation. This will be carried out to meet the needs of both medium and high-resolution sensors and be carried out in a number of steps.

The selected areas of the reference test site will be characterised in parallel by all participants using their own methodology. One site area will be 1000 m *1000 m and the others will be 100 m * 300 m, arranged to be in an adjoining grid. Participants will characterise each small area site on a daily rotational basis to ensure a complete comparison, with all viewing a nominal virginal site as part of the process. Together the set of sites will form a relatively large target for the high-resolution satellite sensors.

After all participants have completed an initial set of measurements using their own methodologies a further comparison of the large area target will be carried out by all teams using a common methodology agreed by the participants in conjunction with the pilot.

NPL (on this occasion solely) will perform detailed BRDF measurements over adjacent selected areas when more than one participant is present the locations will be rotated on subsequent days. The illumination source for the BRDF aspect of this comparison will be the choice of the participants, but should be such as to simulate a solar angle commensurate with a nominal satellite overpass of 08:00 UTC or other as defined by the pilot at the time of the comparison.

3.6 Timetable

There are three main phases to the intercomparison activity. The first phase prepares for the measurement and contains all the organisation and logistical activities, the second phase is the measurements themselves at the reference test site and the third phase the analysis and report writing.

Table I Timetable of the CEOS key comparison

PHASE 1: PREPARATION	
Agreement of participant list and instrumentation	April – May 2009
Preparation and formal agreement of protocol	April – June 2009
Participants return completed Appendix A to pilot	June 2009
PHASE 2: MEASUREMENTS	
Pilot cross-compare the radiometers 1 (4 participants)	August 2009
Participants characterise the reference test site	August 2009
Pilot cross-compare the radiometers 2 (4 participants)	August 2009
Participants send all data and reports to pilot	September 2009
PHASE 3: ANALYSIS AND REPORTS	
Pilot sends measurement reports of all participants and uncertainty statements to all participants (pre-draft)	October 2009
Pilot sends relative data to each participant and reported values to participants for checking	October 2009
Participants return to pilot with comments	November 2009
Participants respond to comments on uncertainty statements	November 2009
Revisions to pre-draft closed	December 2009
Draft B distributed	January 2010
Comments on draft due	January 2010
Final Report published	January 2010

3.7 Transportation of instrumentation

It is the responsibility of all participants to ensure that any instrumentation required by them is shipped with sufficient time to clear any customs requirements of the host country. This includes transportation from any port of entry to the site of the host institute site of the comparison and any delay could result in them being excluded from the comparison. The host will arrange transportation from the host institute to the site.

It is recommended that where possible any fragile components should be hand carried to avoid the risk of damage.

The pilot and host laboratory have no insurance for any loss or damage of the instrumentation during transportation or whilst in use during the comparison, however all reasonable efforts will be made to aid participants in any security.

Electrical power will be available to all participants, although the nature of this, including interface sockets will reflect that of the host country and participants should not anticipate that adaptors would be available.

4 Measurement instructions

4.1 Traceability

All participant instruments should be independently traceable to SI units through a national standards laboratory such as NPL or NIST with documentary evidence of the route and associated uncertainty. If this traceability is provided as part of a "calibration" from the instrument manufacturer then the manufacturer should be contacted and asked to supply the appropriate details.

This information should be provided before the comparison as indicated in Appendix A

4.2 Measurement wavelengths

All participants will measure the spectrally dependant measurands of the comparisons using a spectroradiometer of their choice. These measurements should ideally be performed over the full solar spectral reflective range i.e. 380 to 2400 nm, although sub-sets of this are acceptable, providing they are defined at the start with an associated spectral response function (or bandwidth if spectrometer).

4.3 Measurand

There are three primary measurands for this comparison.

1. Spectral reflectance factor of the site surface
2. Projected Top Of the Atmosphere radiance for the site appropriately integrated to enable a calibration of a satellite sensor with both high and medium spatial resolution
3. Spectral radiance measurements by the spectroradiometer.

4.4 Measurement instructions

4.4.1 Comparison 1: Cross-comparison of all radiometers

4.4.1.1 Via radiance source

- NPL will provide the Transfer Standard Absolute Radiance Source (TSARS – Figure 1) for the CEOS Key Comparison.
- All participants' instruments will perform radiance measurements of this source before and after the field measurements at Tuz Golu, Turkey.
- The spectral range and bandwidth used by each participant is there choice but should be stated.
- Participants will each make 3 independent (re-alighned) measurements of TSARS and the average value will be used for the comparison. Participants may make any number of measurements that they feel appropriate in terms of establishing the repeatability of their measurement system, but this number should be recorded in the measurement report, see appendix B.

- Results of this comparison should be provided to the pilot in excel format as soon as possible following the measurements and at the latest within 2 hrs of completion.
- The results of this part of the comparison will remain confidential to the pilot and the results may be used to provide normalisation to enable biases to be removed from other parts of the comparison process.

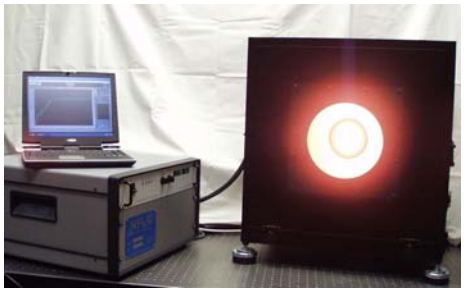

Figure 1: Photograph of the NPL Transfer Standard Absolute Radiance Source (TSARS).

4.4.1.2 Via reflectance panel

- One Spectralon reference panel (approximately 30 cm * 30 cm) will be calibrated at NPL before the CEOS Key comparison at Tuz Golu, Turkey. In addition to the NPL reference panel, all participants will provide their own reference panels for viewing by all participants.
- Panels will be mounted to allow rapid viewing by all participants and to avoid inter-reflections and shade whilst ensuring they are consistent with the spectrometers field of view.
- All participants will perform measurements of solar reflected radiation against the respective panels at nadir and 30 degree using the sun as the source. These measurements will be performed for a nominal solar zenith angle commensurate with a nominal satellite transit time of 08:00 UTC.
- Participants will be responsible to take account of any sky radiance effects by their own methods.
- Any necessary meteorological data will be provided to all participants by the host.
- Radiance factor of participant reflectance panels should be provided to the pilot prior to the comparison in excel format. Measurement results obtained during this comparison should be provided to the pilot in excel format as soon as possible following the measurements but at the latest within 6 hrs to enable rapid evaluation. No results should be provided to any other participant nor discussed without permission of the pilot.

4.4.2 Comparison 2: Site characterisation

Prior to the start of this CEOS Key Comparison, the host, Tubitak Uzay (TU) in conjunction with the pilot, NPL, will select an accessible area with adequate spatial homogeneity for medium and high-resolution imagers. This area will be selected using high-resolution satellite data (Landsat and UK-DMC) and in-situ visits. The test site area will be marked by TU with flags and high contrast sheets of area 50*50 m at two corners of the 100*300m targets to aid identification in remote measured images from aircraft and satellite.

The selected test-site will consist of a single 1000 m * 1000 m area, with 2/3targets of 100 m * 300 m within one sector of the main target, adjacent to one of the high contrast markers. These small target areas will be given a unique identity and each participant will characterise them sequentially using their own method and sampling strategy.

TU will also establish at the site an automated CIMEL radiometer for atmospheric characterisation and a meteorological station. The meteorological and atmospheric data will be made available to all participants in near real time. A second CIMEL radiometer provided by CNES will be placed some distance from the site to evaluate aerosol variation.

The test site will be characterised by participants for its radiance factor at Nadir and if possible also sampled at 30 degrees. The BRDF will be characterised by those providing gonio-radiometers, this BRDF data will be made available to participants for later use in other aspects of the comparison activities

The participants will be invited to take part in four site characterisation activities outlined below.

4.4.2.1 Characterisation of 1000 m * 1000 m target for medium resolution imagers

- The nominal target area will be marked prior to the comparison by the host.
- Participants will determine their own characterisation strategy for a defined satellite overpass condition (nominally a 08:00 UTC transit time to be confirmed). It should be noted that there is likely to be some small defects within the site area.
- Two participants will be able to characterise the site simultaneously.
- Teams will be invited to characterise the site over a period of 4 days in conjunction with the high-resolution site characterisation according to their own strategy for a defined satellite overpass condition.
- Participants will be asked to assign a spectral reflectance to the site for a nadir view for a specific satellite overpass. The exact satellite will be defined by the pilot in consultation with the participants prior to the comparison. This result should be provided to the pilot together with an associated uncertainty budget as soon as possible following site characterisation.
- Results should be accompanied by a description of the sampling strategy and methodology used. An indicative version of this should be provided in advance using Appendix A.
- Following the initial characterisation participants together with the pilot will agree on a common methodology, which may be one originally used by one participant or something different and then each characterise the site following this new “comparison methodology”.

4.4.2.2 Characterisation of 100 m * 300 m target for high resolution imagers

- The nominal target areas will be marked prior to the comparison by the host. There will be two or three adjoining targets each uniquely identified and each characterised in turn by each participant on adjacent days. It is hoped that all sites will be free of any major defects, but this cannot be guaranteed.
- Participants will determine their own characterisation strategy for a defined satellite overpass condition (nominally a 08:00 UTC transit time to be confirmed).

- Teams will be invited to characterise the sites over a period of 4 days in conjunction with the medium-resolution site characterisation according to their own strategy for a defined satellite overpass condition.
- Participants will be asked to assign a spectral reflectance to each individual site for a nadir view for a specific satellite overpass (to be defined by the pilot in consultation with the participants prior to the comparison). This result should be provided to the pilot together with an associated uncertainty budget as soon as possible following site characterisation.
- Results should be accompanied by a description of the sampling strategy and methodology used. An indicative version of this should be provided in advance using Appendix A.

4.4.2.3 Comparison of measurements of site BRDF

- NPL and any other participant will determine the BRDF near the 1000*1000 m site and 100*300m sites for a nominal solar illumination angle commensurate with a defined satellite transit (nominally 08:00 UTC). If more than one participant takes part then the same sites will be viewed by each alternately
- Participants will provide results together with a report describing the instrumentation, methodology and uncertainty as soon as possible following the measurement. This should be supplied to the pilot within two weeks of the comparison.

4.4.2.4 Comparison of methods to establish TOA radiance

- As an experimental exercise, participants will determine the TOA radiance for a pilot specified sensor (s)(to be agreed by participants) of high and medium resolution based on the propagation of a pilot defined set of ground site characteristics. These characteristics will be based on averaged site values measured during the campaign.
- The exact geometric viewing/ conditions of the sensors and their characteristics (bands etc) will be defined by the participant, but this is likely to be a Landsat like imager, MERIS and a generic hyperspectral imager.
- Participants should use their own model and code, but where site-specific variables are used these will be based on a common value as provided by the pilot.
- The results and appropriate description of the methodology applied will be provided to the pilot before circulation and discussion amongst the participants.
- The results of this activity will remain confidential to the participants unless all agree to publication or more open discussion.

5 Measurement uncertainty

The uncertainty of measurement shall be estimated according to the *ISO Guide to the Expression of Uncertainty in Measurement* (QA4EO-QAEO-DQK-006). In order to achieve optimum comparability, a list containing the principal influence parameters for the spectral reflectance/radiance measurements for a selected target is given below. An example template, which should be completed by participants, is included as **Appendix C**. The participating laboratories are encouraged to follow this breakdown as closely as possible, and adapt it to their instruments and procedures. Other additional parameters may be felt appropriate to include dependent on specific measurement facilities

and these should be added with an appropriate explanation and/or reference. As well as the value associated with the uncertainty, participants should give an indication as to the basis of their estimate. All values should be given as standard uncertainties, in other words for a coverage factor of $k = 1$. Participants are asked to make three independent measurements of spectral radiance on TSARS and record the results separately.

Type A

Repeatability of measurement - repeatability of measurement process without re-alignment of the participants instrument. This component should be largely caused by the instrumentation stability/resolution related to the output from the reference standard and any associated measuring instrument. In effect the standard deviation of a single set of measurements made on the reference standard, or on a specific part of a target surface. This should be presented as a relative quantity.

Reproducibility of measurement - reproducibility (run to run) following re-alignment of the instrument with the comparison transfer standard. This should be, largely caused by the measurement set-up related to the output from the transfer standard. This should be presented in terms of percentage of the assigned result.

Type B

Participants disseminated scale - This is the total uncertainty of the participants' instrument. This includes its traceability to any primary reference standard, underpinning scale as disseminated by them. This should include the uncertainty in the primary SI realisation, or in the case of a scale originating from another laboratory, the uncertainty of the scale disseminated to it by that laboratory. It should of course reference the originating laboratory. All uncertainties contributing to this parameter should be itemised as part of the report, or if published a copy of this publication attached. This should include both spectro-radiometers and reflectance panels as appropriate.

Drift - This is an uncertainty component related to any potential drift of the calibration of any instrument or standard from its original calibration date.

Wavelength - This is the uncertainty in the absolute value of the wavelength used for the comparison. This should only be taken account of in terms of the instrumentation being used and should include details relating to bandwidth where appropriate.

6 Reporting of results

During the comparison provisional results will be provided to the pilot and an analysis carried out in real time to ensure no significant issues exist in the data collection process. Only if results indicate a serious problem will participants be informed and only then in a manner so as not to indicate where, what or who might have an issue.

As soon as possible after the set of field measurements has been made, the final results should be communicated to the pilot laboratory and at the latest within 4 weeks in electronic form. The pilot will

reconfirm these values to the participant to ensure that the pilot is using the correct participant values and that no error in interpretation has occurred.

The participant should provide a full measurement report using the supplied word-document template Appendix A. This should include a schematic diagram of the facility and full uncertainty analysis see **Appendix B** and **C**. These documents will be collated and sent to all participants as the pre-draft A report. Participants will then comment on each other's measurement methodology and ask questions. Following this peer-review process, which will be completed within 4 weeks of the comparison, participants will have the opportunity to increase their uncertainty statements should they consider this necessary. It is anticipated that much of the description of any instrumentation, traceability etc can be prepared prior to the comparison so that only specific details related to the measurement campaign need to be updated.

The measurement results are to be supplied in the Excel Template provided by the pilot laboratory at the beginning of the comparison with the final draft of the protocol. The measurement report is to be supplied in the Word Template provided by the pilot. This will simplify the combination of results and the collation of a report by the pilot and reduce the possibility of transcription errors.

Understanding that the participants are unlikely to have a native English speaker on their staff, the pilot offers to review and advise on the English of the supplied reports. To simplify the job of the pilot, however, if you have the opportunity to have the report checked separately by someone with good English, please do so.

The measurement report forms and templates will be sent by e-mail to all participating laboratories. It would be appreciated if the report forms (in particular the results sheet) could be completed by computer and sent back electronically to the co-ordinator. **In any case, the signed report must also be sent in paper form by mail.** In case of any differences, the paper forms are considered to be the definitive version.

If, on examination of the complete set of provisional results, the pilot institute finds results that appear to be anomalous, the corresponding institute is invited to check their results for numerical errors without being informed as to the magnitude or sign of the apparent anomaly. If no numerical error is found the result stands and the complete set of final results is sent to all participants. Note that once all participants have been informed of the results, individual values and uncertainties may be changed or removed, or the complete comparison abandoned, only with the agreement of all participants and on the basis of a clear failure of an instrument or travelling standard or some other phenomenon that renders the comparison or part of it invalid.

Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyse the results and prepare a first draft report on the comparison. This will be circulated to the participants for comments, additions and corrections. Subsequently, the procedure outlined in the QA4EO-QAEO-DQK-004 Guidelines will be followed.

7 Comparison analysis

Each comparison will be analysed by the pilot according to the procedures outlined in QA4EO-QAEO-DQK-004. In some cases, analysis will be carried out based solely on results declared by the participant, in others there will be further analysis based on modifications of the instrument calibration as a result of previous comparisons e.g. normalisation to a common radiance or reflectance panel. In this way all available information will be presented and the final results will be transparent to all readers of the report.

Unless an absolute traceable reference to SI of sufficient accuracy is a-priori part of the comparison and accepted as such by all participants, all participants will be considered equal. All results will then be analysed with reference to a common mean of all participants weighted by their declared uncertainties.

In this comparison an absolute standard source and reflectance panel of NPL will be used. The participation of this source will allow a direct linkage and the consequential establishment of formal traceability to be established for all measurements.

8 Appendix A: Template for participants to CEOS Key comparison

This appendix contains the template to be completed by each participant before the start of the comparison to be held in 2009 at the land reference standard test site Tuz Gölü, Turkey (38 50˚N, 33 20˚E centre latitude, longitude).

A. Participant

Name:
Organisation Address:
Email Address:
Telephone:

Deleted: ¶

B. Instrumentation & Method for reflectance factor

Instrument used and optical fibre length:
Size (volume for transportation) and weight
Wavelength and Bandwidths:
Field Of View (FOV):
Route of traceability for instrumentation (lab & intercalibration):
Method of calculation of the site reflectance factor and any corrections applied:
Baseline uncertainty budget expected (indicative repeatability values) & breakdown of uncertainty contributions:
Estimated time to characterise medium resolution target
Estimated time to characterise one high resolution target:

C. Instrumentation & Method for BRDF

Instrument used:
Size (volume for transportation) and weight
Wavelength and Bandwidths:
Field Of View (FOV) (ground sample area):
Angular resolutions and number
Route of traceability for instrumentation (lab & intercalibration):
Baseline uncertainty budget expected (indicative repeatability values) & breakdown of uncertainty contributions:
Estimated time for one BRDF characterisation:

D. Site characterisation strategy
Brief description of anticipated site characterisation sampling strategy

E. Radiative Tranfer Code (RTC)
What RTC code do you plan to use to calculate TOA radiance from ground-based reflectance measurements?
Site atmospheric variables required to allow TOA radiance determination:
Please provide answers tailored to the following sensors: Landsat 7 ETM+ or similar e.g. SPOT, DMC etc (to be agreed), MERIS and a generic hyperspectral imager (380 to 2400 nm (10 nm bandwidth). In all cases a Nadir observation should be assumed and 08:00 UTC unless otherwise indicated by the pilot. Exact observing and viewing conditions will be defined at time of comparison.

9 Appendix B: Measurement results

The attached measurement summary should be completed for each participant and each completed set of measurements. A complete set being one, which may include multiple measurements on the same surface (1000 m*1000 m, 100 m*300 m, etc). For each day of the field campaign a separate measurement sheet should be completed, containing all measurement details (UTC, sun zenith, sun azimuth angles, height, FOV, etc).

For clarity and consistency the following list describes what should be entered under the appropriate heading in the table.

Wavelength	The assigned centre wavelength of the measured spectral radiance/reflectance.
Spectral Radiance	The value of the spectral radiance of the “target” as measured by the participating laboratory
Spectral Reflectance Factor	The value of the spectral reflectance factor of a specific defined target
Bandwidth	The spectral bandwidth of the instrument used for the comparison defined as the Full Width at Half the Maximum.
Std Deviation	The standard deviation of the number of measurements made to obtain the measured value
Number of Runs	The number of independent measurements made to obtain the specified std deviation.
Uncertainty	The total uncertainty of the measurement of the measurand (reflectance factor, radiance, BRDF) separating this into Type A and B for a coverage factor of k=1.

B1 Measurement results: Cross comparison of radiometers against the calibrated reference panel

Type and identification of reference panel……
Participant institution……..…….
Day……UTC……View angle……..

Spectral region nm	Spectral radiance W m^{-2} nm^{-1} sr^{-1}	Bandwidth nm	Std Dev.	Num of Runs	Uncertainty A % B	
380						
390						
400						
450						
500						
550						
600						
650						
700						
750						
800						
850						
900						
950						
1000						

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2400						
2500						

Participant: ……
Date: …… Signature: ……..

B2 Measurement results: Cross comparison of radiometers against NPL TSARS (Transfer Standard Absolute Radiance Source).

Participant institution…….……
Day……UTC……

Spectral region nm	Spectral radiance W m^{-2} nm^{-1} sr^{-1}	Bandwidth nm	Std Dev.	Num of Runs	Uncertainty A % B	
380						
390						
400						
450						
500						
550						
600						
650						
700						
750						
800						
850						
900						
950						
1000						
1100						

1200						
1300						
1400						
1500						
1600						
1700						
1800						
1900						
2000						
2100						
2200						
2300						
2400						
2500						

Participant: ……
Date: …… Signature: ……..

B3 Measurement results: Site characterisation (ground)

Reference panel identification……Participant institution …….
Day……UTC……Sun zenith……Sun azimuth……..
FOV……Height……Site reference…….

Spectral region nm	Spectral radiance W m^{-2} nm^{-1} sr^{-1}	Spectral reflectance factor	Bandwidth nm	Std Dev.	Num of Runs	Uncertainty A % B	
380							
390							
400							
450							
500							
550							
600							
650							
700							
750							
800							
850							
900							
950							
1000							
1100							
1200							

1300							
1400							
1500							
1600							
1700							
1800							
1900							
2000							
2100							
2200							
2300							
2400							
2500							

Participant: ……

Date: …… Signature: …….

B4 Measurement results: TOA radiance projection

Participant institution ……Atmospheric code…….
Day……UTC……Sun zenith……Sun azimuth……..
Site reference……Nominal sensor……..…….

Spectral region nm	TOA Spectral radiance W m^{-2} nm^{-1} sr^{-1}	Solar irradiance model W m^{-2} nm^{-1}	Bandwidth nm	Uncertainty A % B	
380					
390					
400					
450					
500					
550					
600					
650					
700					
750					
800					
850					
900					
950					
1000					
1100					
1200					

1300					
1400					
1500					
1600					
1700					
1800					
1900					
2000					
2100					
2200					
2300					
2400					
2500					

Participant: ……

Date: …… Signature: …….

10 Appendix C Uncertainty of measurement

Parameter	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in radiance/reflectance
Repeatability of measurement	u_{Repeat}		u_{Repeat}
Reproducibility of measurement	u_{Repro}		u_{Repro}
Site variability		U_{Site}	u_{Site}
Model uncertainty		U_{Mod}	U_{Mod}
Primary calibration		u_{Prim}	u_{Prim}
Drift since calibration		u_{Drift}	u_{Drift}
RMS total	$((u_{ref})^2+(u_{Trans})^2))^{½}$		

The above table is a suggested layout for the presentation of uncertainties for the various comparisons. It should be noted that not all the uncertainty components will be applicable to each measurement and in some cases it may be appropriate to further sub-divide e.g. Model uncertainty relates to the Atmospheric transmittance and will of course include a number of parameters. However, it should be noted that since the wavelength uncertainty in particular has a strong dependency on wavelength this table could only present a range for that parameter. It would therefore be helpful for the participants to provide an appropriate breakdown for such uncertainties to match this sensitivity. The summary table associated with the results (Appendix C) will of course need to take full account of this wavelength dependent parameter for each wavelength point.

The RMS total refers to the usual expression i.e. square root of the sum of the squares of all the individual uncertainty terms as shown in the example for Type A uncertainties.

Laboratory: ……

Date: …… Signature: ……..

11 Appendix D Data receipt confirmation

All data should be sent to NPL. The details of the person of contact can be found below:

To: (Participating laboratory please complete)

From: **Irina Behnert**
National Physical Laboratory
Hampton Road
Teddington
Middlesex
United Kingdom
TW11 0LW

Tel: ++44 20 8943 6780
e-mail: irina.behnert@npl.co.uk

We confirm having received the data of the CEOS key comparison August 2009, Tuz Golu on .....(date).

.....
.....
.....
Date:……Signature:…….