Brief Summary Report from the IOCCG Workshop on
Ocean Colour System Vicarious Calibration for Science and Operational Missions

Background
System vicarious calibration (SVC) is an integral part of Earth Observation programs that have ocean color objectives; including climate, environmental and operational applications. SVC of satellite sensors is essential to meet the accuracy requirements of ocean color missions (IOCCG, 2012).

Ocean color product requirements call for a level of uncertainties which cannot be solely achieved by prelaunch and on-orbit sensor characterizations and calibrations. The required performance has to be fulfilled with a system that is composed of the satellite sensor and algorithms. SVC works by minimizing the total system uncertainties of the sensor calibration and algorithms. Sensor near-infrared (NIR) and visible (VIS) bands are typically independently calibrated. Their vicarious gains can also be consistently derived using the shortwave infrared (SWIR) wavelengths. VIS band calibration involves highly accurate in situ measurements from a field source with uncertainties well below the ocean color measurement requirements. Direct traceability of field source calibration to the international system of units allows linking ocean color uncertainties to standards. The SVC geographic reference locations are characterized by maritime atmosphere and clear low-chlorophyll waters which for the algorithms are the simplest to model. Spatial homogeneity and temporal stability of the atmosphere and ocean surface are also required to reduce the uncertainties from matching point in situ measurements with much larger satellite foot-prints.

To meet the ocean color product requirements, the target uncertainty of Top-Of-the-Atmosphere (TOA) radiances, after SVC, is lower than 0.3% with inter-band differences of about 0.1%. For comparison, ocean color sensors are characterized to 2% uncertainty in terms of reflectance and 5% in terms of radiance. In initial circumstances, the SVC approach may provide vital feedback as to the quality of TOA radiance products to the instrument calibration teams. Fundamentally, the prerequisite to meeting the SVC uncertainty goal is that relative sensor uncertainties associated with individual component characterizations and temporal degradation are approximately 0.1%. Consequently, the science and user needs dictate that SVC is a fundamental part of each satellite ocean color mission.

Objectives of the Workshop
The IOCCG Workshop on SVC gathered experts actively working in the field to discuss SVC criticality, requirements and methodologies. The workshop focused on sharing an understanding of SVC strategies across missions along with goals for standardization and international cooperation. The discussions covered upcoming ocean color science missions and long-term operational programs that will require SVC support for decades to come. The workshop thus aimed to gain consensus on requirements for SVC in situ data and infrastructure so as to build a scientifically sound, strategic and sustainable vision of SVC in support of science and operations.

A tangible outcome from the workshop will be a paper describing the shared position on SVC with detailed requirements and recommendations. Five sessions of the workshop were supported by key talks and addressed the following topics:

1. SVC current status
   - In situ SVC sites with emphasis on in situ radiometer system calibration and characterization, and estimates of measurement uncertainties
   - SVC methods implemented by individual Space Agencies- both NIR and VIS
   - Quantification of systematic biases in current satellite ocean color data products from different missions and potential residual vicarious gain dependencies
   - Impact on SVC of satellite sensor pre-launch and on-orbit characterization and relative degradation
   - Results from other statistical techniques
2. NIR methodologies and recommendations for standardization
   - Review of NIR methods, methods based on SWIR bands, SVC site requirements, and SVC implementation
3. VIS methodologies and recommendations for standardization
   - Review of VIS methods with emphasis on in situ data sources; site requirements; data quality and screening protocols; SVC implementation; and OCR-VC requirements
4. Operational mission needs
   - Need for SVC infrastructure that can meet the requirements of operational marine services for decades to come (fiducial reference)
   - Supplemental SVC methods to achieve operational status early in the mission- both NIR and VIS
5. Advancement as a community
   - Future of SVC including funding for SVC infrastructure, availability of improved and new technologies and instrumentation
   - International cooperation, increased coordination, and data sharing.

Outcome

The IOCCG workshop on *Ocean Colour System Vicarious Calibration for Science and Operational Missions* resulted from a specific recommendation from a splinter session on SVC during the International Ocean Color Science (IOCS) meeting, which was held in Darmstadt in May 2013. The splinter recommended further and more detailed discussions on a number of topics addressed during the session (see list of recommendations in Annex 1). This SVC workshop was also directly associated with recommendations included in the INSITU-OCR White Paper and IOCCG Report number 13 (IOCCG, 2012). The White Paper was produced in the context of the Satellite Ocean Color Radiometry Virtual Constellation (OCR-VC) within the framework of joint actions between the Committee on Earth Observation Satellites (CEOS) and IOCCG (see specific recommendation on SVC included in Annex 2). INSITU-OCR is an acronym for International Network for Sensor InTercomparison and Uncertainty assessment for Ocean Colour Radiometry.

The main recommendations and actions resulting from the discussions that occurred during the SVC workshop and that were fully shared among participants are presented below.

- **R1: Need for multiple in situ measurement sites supporting SVC**

A single, well-defined site delivering long-term, continuous, sustained, highly accurate, stable and hyperspectral in situ measurements that meet SVC requirements is sufficient to support most SVC applications of global missions including climate research, ecosystem monitoring, and marine resource services. At the same time, it is recognized that a continuous satellite ocean color time-series requires continuous in situ SVC measurements over long time-scales. The criticality of in situ SVC measurements to the support of these missions and applications therefore suggests the need for redundancy in SVC measurements to ensure against failure or dismissal of any single SVC source and to allow for characterization of performance biases between sources. The need for multiple in situ measurement sites supporting SVC is thus restated with an emphasis on ensuring access, continuity and consistency of SVC-qualified measurements as a direct complement to the long-term, multi-mission satellite data record.

Recommendation

It is recommended that at least two in situ high quality radiometer systems that meet SVC requirements be maintained in order to provide a primary source as well as redundant secondary sources for these critical measurements. It is recommended that biases between SVC-qualified sources be well characterized to enable transition if the primary site is lost or decommissioned.

The requirement of geostationary missions to host an SVC source within their specific Earth disk coverage is also recognized.

- **R2: Standardization of uncertainty estimates for in situ measurements supporting SVC**

The determination of uncertainties affecting field data applied to SVC is an essential component of the overall measurement process and should be supported by rigorous metrology to ensure traceability of measurements. Direct traceability of field source calibration to the international system of units can support linking ocean color uncertainties to standards, which is an important goal of the cal/val process. Environmental conditions at the site and diurnal variability, both atmospheric and marine, require the same rigorous evaluation.

Recommendation

In view of fulfilling measurement traceability requirements and ensuring full comparability of uncertainty estimates from different measurement systems and sites, it is recommended that uncertainties of in situ measurements performed for SVC be determined by consistently following the same metrology principles. It is then recommended that basic guidelines be produced and strictly applied by the various in situ data producers to support this specific action.

- **R3: Inventory and data sharing of in situ measurements for SVC**

International space agencies rely on different in situ field data sources to support SVC. The different sources are a necessity for the geostationary missions and are commonly implemented by missions with a regional focus. In the case of global missions, the accessibility of multiple sources of field data provides critical redundancy to the in situ measurements that are potentially applicable for SVC. Independent, highest-quality in situ measurements also support validation and monitoring of satellite system performance.

Recommendation

It is recommended to create an inventory of in situ data sources available from international space agencies that provide reference measurements applicable to SVC. It is also recommended to create conditions for open access and free sharing of the full in situ measurement data records.

In particular, access to Kavaratti buoy data administered by ISRO is requested for IOCCG and global data users. The KIOST/KOSC open policy on in situ data for international cal/val cooperation is sincerely welcomed. Both, MOBY and BOUSSOLE data are currently freely and openly available to the community and can be included in the inventory.

- **R4: Field assessment of in situ measurements for SVC**

SVC has very strict requirements in terms of uncertainties, traceability and environmental conditions at the site. Equivalence of measurements from multiple sites is a fundamental aspect in view of supporting their combined or independent use for SVC of ocean color satellite missions. The following actions should be established as a best practice for in situ radiometers considered as SVC measurement sources: inter-comparisons of field radiometer systems, application of equivalent schemes for radiometer calibration and characterization, and use of common methods for the determination and quality assurance of primary radiometric quantities (i.e., R_{rs} or L_{wn}).

Recommendation

It is recommended that a field program be established to perform regular inter-comparisons of the in situ radiometers qualified as SVC sources through a fully characterized, well-understood and transportable system. This recommendation is made in conjunction with the actions to standardize in situ measurement uncertainty reporting.

- **R5: Harmonization of protocols for SVC gain derivation**

Both climate and operational applications require multi-mission satellite data sets which are consistent across different sensors, stable and accurate. The applications rely on availability of long-term uniform ocean color data records and also on dissemination of unbiased products at Near-Real Time (NRT). Differences in methodologies across missions for SVC gain derivation could, however, contribute to product discrepancies even if SVC in situ measurements are standardized. The methodologies encompass detailed protocols for SVC in situ data processing; in situ and satellite data screening and related exclusion criteria; application of relevant satellite data processing, including atmospheric correction and surface BRDF; and procedures for gain calculation. Full correspondence is required between the vicarious gain derivation and the standard processing. Converging on equivalent, accurate and comprehensive modeling of the atmospheric components, including gases, molecules and aerosols, can further improve the multi-mission consistency.

Recommendation

Harmonization of SVC methodologies is an important element towards achieving multi-mission consistency, stability and accuracy. It is recommended that the existing peer-reviewed protocols for SVC gain derivation are followed across missions. Further update and detailing of the protocols is requested.

Inter-comparisons of individual components of the atmospheric correction and convergence on equivalent models are advocated.

- **R6: SVC during the early phases of a mission in the context of operational services**

SVC is critical for operational ocean color data services. Investment in SVC infrastructure and activities is necessary to meet the requirements of marine services for upcoming decades of operations. To enable the distribution of quality NRT data as well as consistent long-term measurement time series that are required by most applications, SVC relies on a prerequisite: continuous sensor calibration and characterization on-orbit. During the first few years of the mission, the number of SVC matchups is insufficient to produce stable vicarious gains. Nevertheless, operational constraints impose the requirement for quality data at the start of operations so as to ensure prompt validation of satellite data products, immediate access to products by users, and timely exploitation of products in services.

Recommendation

To ensure immediate generation of quality satellite ocean color data products during the early phases of the mission, it is recommended that, in addition to in situ data from SVC *facilities, SVC (both in NIR and VIS) be performed over oligotrophic stable target areas using models and climatological data or data acquired from reliable contemporary missions. The use of commonly agreed regions and bio-optical models is recommended to create conditions for consistency between the data products from different missions, as products from multiple missions are required by operational applications to ensure sustainability and robustness of marine services.*

- **R7: Applicability of oceanic regions in the northern hemisphere for SVC in the NIR**

Currently, NIR SVC relies on satellite observations performed at sites located in the southern oceans (e.g., South Pacific Gyre and/or Southern Indian Ocean). These sites exhibit easily modeled conditions of homogeneous very-low-chlorophyll gyres and a stable marine atmosphere, which can be evidenced by time series of marine aerosol properties observed at nearby AERONET stations.

Recommendation

It is recommended for NIR SVC to evaluate the impact of using oceanic regions located in the northern hemisphere in light of exploring more fully the advantages and drawbacks of a variety of sites and assessing new site applicability in meeting the SVC requirements.

IOCCG (2012), Mission Requirements for Future Ocean-Colour Sensors, C. R. McClain and G. Meister (Eds.), *Reports of International Ocean-Colour Coordinating Group*, No. 13, IOCCG, Dartmouth, Canada.

Annex 1. Final Recommendations from the IOCS Splinter Session on SVC (available at http://iocs.ioccg.org/wp-content/uploads/report-iocs-2013-meeting.pdf **)**

1. The current VIS and NIR method for system vicarious calibration of satellite ocean color sensors, which rely on the vicarious calibration of VIS bands with respect to NIR bands with the application of highly accurate in situ VIS data, is considered a robust approach over clear waters and should be considered for the forthcoming missions.

2. The importance of involving National Reference Laboratories in the characterization of field radiometers and SI traceability of measurements is essential. Still, the evaluation of new in situ platforms (i.e., gliders, AWS, …), in addition to existing bio-optical buoys, is recommended.

3. The analysis of legacy constraints for in situ measurements and sites supporting system vicarious calibration suggests that spatial homogeneity of the measurement site(s) is an essential requirement. The constraint on the aerosol optical thickness lower than 0.1 in the visible could likely be "relaxed" as long as the atmospheric conditions are well characterized. It is additionally recommended that the availability of supplementary atmospheric measurements at the vicarious measurement site(s) (e.g., vertical characterizations of the atmospheric components) are of potential aid to system vicarious calibration.

4. The use of commercial systems to support system vicarious calibration imposes the generation of in situ traceable measurements through fully characterized hyperspectral systems. This requires comprehensive characterizations of commercial hyperspectral systems whose performances often need thorough verification.

5. The standardization of system vicarious calibration is a necessary strategy for the generation of CDRs from multiple satellite instruments. Current system vicarious calibration exercises involving NASA and ESA sensors appear to indicate that the lack of standardization between institutions (not only for the system vicarious calibration process) may lead to significant differences in derived satellite data products not compatible with the creation of CDRs from independent missions. However, standardization using current technologies should consider that forthcoming advanced systems like PACE may benefit from additional measurement capabilities (e.g., polarization) with respect to current space sensors.

6. The short time available for the Splinter Session on System Vicarious Calibration has not provided the capability to comprehensively address all specific elements of relevance for the forthcoming satellite ocean color missions. It is then expected that results from the Splinter Session are the start for additional international actions aiming at detailing specific requirements and methods for System Vicarious Calibration of new missions like PACE and Sentinel-3.

Annex 2. Specific recommendation on SVC included in the INSITU-OCR White Paper (available at http://www.ioccg.org/groups/INSITU-OCR_White-Paper.pdf)

Vicarious calibration

Current target for absolute calibration uncertainty of satellite ocean color sensors is 0.5%. This stringent value is justified by the high accuracy requirements established for utilizing satellite ocean color products in climate and operational investigations. Such a level of accuracy can be achieved with vicarious calibration: the adjustment of pre-launch calibration coefficients using top-of-atmosphere (TOA) radiance predicted from in situ measurements through modeling of atmospheric radiative processes. The objective of vicarious calibration is the minimization of combined uncertainties resulting from satellite absolute pre-launch calibration and from the specific models/algorithms applied for determining primary radiometric products (e.g., normalized water-leaving radiance spectra) from TOA radiance. Vicarious calibration should be performed using in situ radiometry ideally performed with dedicated systems (e.g., MOBY- or BOUSSOLE-like) ensuring a high degree of accuracy and with full traceability to SI standards. The vicarious calibration site should be selected in a region where variability and complexity of the atmospheric and oceanic optical properties are low, to minimize additional sources of error due to temporal and spatial sampling differences between the satellite observation and the in situ measurement. Multiple vicarious calibration sites may offer additional information and alternative sources of data, however, these sites should be equivalent in terms of measurement accuracy, traceability and observation conditions (e.g., different complexities of the atmosphere might lead to inaccurate determinations of the aerosol type and consequently to the determination of substantially different adjustment factors for the pre-launch calibration coefficients).

Recommendation

Maintain at least one long-term vicarious calibration site with SI traceable radiometry pursuing the objective of producing and delivering highly accurate measurements collected under ideal measurement condition (e.g., spatial homogeneity, known aerosol and marine optical properties) in a region representative of global ocean observations. Multiple sites are encouraged, but their equivalence in performance is fundamental. It is essential that a rigorous metrology be established at each measurement site in view of assuring measurement traceability. Because of this, inter-comparisons of each relevant component of the vicarious calibration process should be encouraged and differences thoroughly investigated. Within such a context the adoption of a commonly agreed vicarious calibration approach, supported by sharing of processing modules, would enhance inter-mission consistency of radiometric products. Vicarious calibration should be reassessed whenever the instrument calibration or OCR retrieval algorithm is modified, and uncertainties on the derived gains should also be reported to support the determination of OCR uncertainties.

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