European Commission

Requirements for in situ radiometric measurements supporting ocean color System Vicarious Calibration (SVC)

G. Zibordi
Joint Research Centre, Ispra, Italy

All elements taken from:
"*Requirements and Strategies for In Situ Radiometry in Support of Satellite Ocean Color*" by G. Zibordi and Voss, in "*Optical Radiometry for Oceans Climate Measurements*", Academic Press, 2014;
"*System Vicarious Calibration for Ocean Color Climate Change Applications: Requirements for In Situ Data*" by G. Zibordi et al., *Remote Sensing of Environment*, 2015.

Joint Research Centre

System Vicarious Calibration

Accuracy tied to applications

Sample applications

1. Environmental (regional): e.g. *Chla* from band-ratio algorithms with uncertainty lower than 50% in regional seas . Radiometric uncertainty of L_{WN} can be of the order 10% or even more depending on water type, in the blue-green or green/red spectral intervals. This requirement can be achieved without vicarious calibration or alternatively with regional vicarious calibration coefficients optimizing data products for regions exhibiting specific atmospheric and marine optical properties, or unique observation and illumination geometries.

2. Bio-geo-chemical (global): e.g. *Chla* from band-ratio algorithms with uncertainty lower than 30% in oligotrophic and mesotrophic world sea regions. Radiometric uncertainty of L_{WN} need to be lower than ~5% in the blue spectral bands. This requirement can be achieved with vicarious calibration coefficients optimizing accuracy of data products for mesotrophic and oligotrophic regions.

3. Climate Change: Radiometric uncertainty of L_{WN} needs to be lower than 5% at the blue to green wavelengths, and inter-channel uncertainty needs to be lower than 1%, with decadal stability better 1% (here is the real challenge).

Joint Research Centre

System Vicarious Calibration

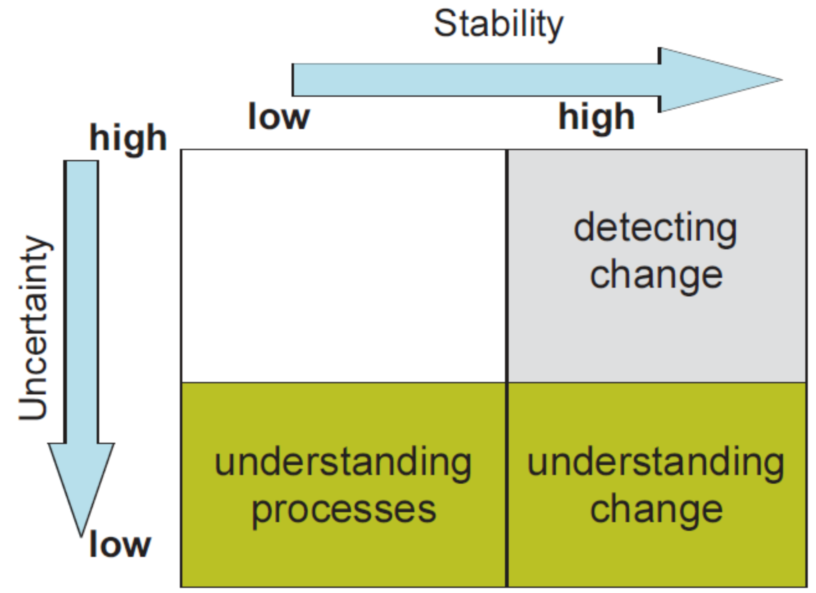
Uncertainty and Stability

Requirements for satellite ocean color missions supporting climate change investigations (Ohring et al. 2004):

Radiometric uncertainty lower than 5% at all λs
(in the blue & green spectral bands according to WMO (2011))

Inter-band uncertainty lower than 1%

Stability higher than 1% per decade
(0.5% according to WMO (2011))



Uncertainty and stability requirements for a climate observing system (Ohring et al. 2004)

Low uncertainties in the measurement of climate variables are essential for understanding climate processes and changes. However, it is not as necessary for determining long-term changes or trends as long as long as the data set has the required stability (Ohring et al. 2004).

Ohring, G. et al. "Satellite instrument calibration for measuring global climate change." B. Am. Meteorol. Soc. 86, 1303-1313 (2004).
WMO, "Systematic Observation Requirements for Satellite-Based Data Products for Climate-2011 Update", GCOS 154 (2011)

Joint Research Centre

Measurement Equation
Uncertainties

In the absence of atmospheric gaseous absorption, sun glint and foam perturbations, the top-of-atmosphere radiance L_T can be related to L_w through the following simplified equation

$$L_T = L_R + L_A + L_w t_d$$

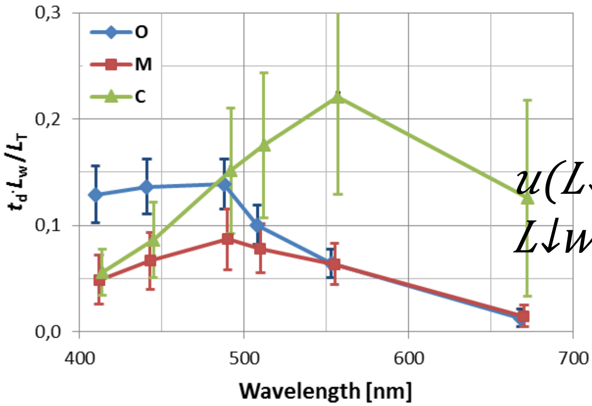
By assuming the values of L_R, L_A and t_d are exactly determined for any given observation condition (i.e., a very good job can be done with the atmospheric correction), then

$$u(L_T)/L_T = u(L_w)/L_w \; t_d L_w / L_T$$

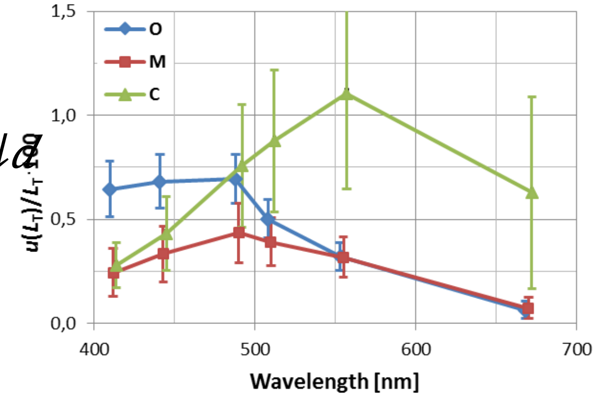
This indicates that $u(L_w)/L_w$ may largely vary with a change of L_w or L_T.

System Vicarious Calibration

Need



$$u(L_T)/L_T = u(L_w)/L_w \; t_d \; L_w/L_T$$



Spectral mean values and standard deviations σ of $t_d \cdot L_w/L_T$ for oligotrophic (O), mesotrophic (M) and coastal (C) waters determined with SeaWiFS data.

Relative uncertainties $u(L_T)/L_T$ determined assuming a spectrally independent 5% uncertainty value for L_w with the mean values of $t_d \cdot L_w/L_T$ from oligotrophic, mesotrophic and coastal waters.

Assuming a spectrally independent uncertainty of 5% for L_w and t_d=1, the values of $u(L_T)/L_T$ for L_w/L_T equal to 0.10, 0.05 and 0.01 are as low as 0.5%, 0.25% and 0.05%, respectively. These values provide an estimate for the required spectral uncertainties of absolute radiometric calibrations for satellite ocean color sensors

These values further confirm:

i. that even assuming that the uncertainties in $u(L_w)/L_w$ due to atmospheric correction are negligible, the sole uncertainties currently affecting in-flight absolute radiometric calibration are an impediment to meet ocean color science requirements for CDRs; and

ii. that system vicarious calibration[1] is the only viable alternative to overcome limitations due to uncertainties in absolute radiometric calibration and likely atmospheric correction.

[1] *System Vicarious Calibration minimizes differences between target observations (assumed known with a given uncertainty) and, the combined effects of inaccurate atmospheric correction and error in sensor calibration ("system vicarious calibration" is not absolute).*

System Vicarious Calibration

Lessons

Data source	L_w method	Spectral features	Site
MOBY	In-water, fixed depths	Hyper-spectral	Pacific Ocean (Hawaii)
MOBY-MS	In-water, fixed depths	Reduced resolution	Pacific Ocean (Hawaii)
BOUSSOLE	In-water, fixed depths	Multi-spectral	Ligurian Sea
NOMAD	Various	Various	Various
AAOT	Above-water	Multi spectral	Adriatic Sea
HOT-ORM	Modeled	User definable	Pacific Ocean (Hawaii)
BATS-ORM	Modeled	User Definable	Atlantic Ocean (Bermuda)

Elements on the various data sources utilized for SVC of SeaWiFS data by applying the same version of the processing code (i.e. same algorithms and atmospheric correction scheme).

By assuming the *g*-factors from MOBY as the reference because of the ideal location (exhibiting oligotrophic waters and maritime aerosol, in addition to annual cycles of small amplitude) and extensive characterization of field radiometers and careful examination of radiometric uncertainties

$$\Delta g = 100\; g - g^{MOBY} / g^{MOBY}$$

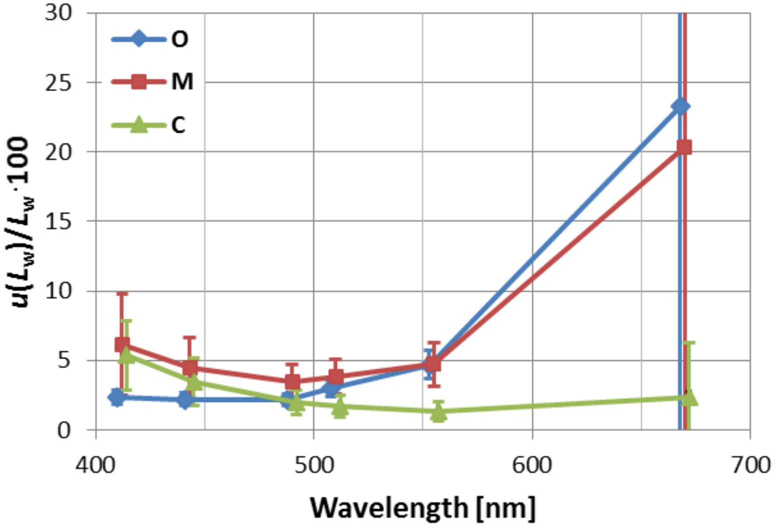
Data source	Δg (412)	Δg (443)	Δg (490)	Δg (510)	Δg (555)	Δg (670)
MOBY-MS	**+0.32**	+0.04	**+0.31**	**−0.45**	**−0.35**	**−0.39**
BOUSSOLE	**+0.33**	−0.03	**+0.43**	**+0.33**	+0.14	**−0.59**
NOMAD	+0.26	+0.03	**+0.49**	−0.20	−0.04	**−0.37**
AAOT	**+0.55**	+0.11	**+0.51**	−0.05	**+0.41**	**+0.93**
HOT-ORM	**−0.66**	**−0.45**	**−0.39**	−0.03	**+0.53**	**−0.11**
BATS-ORM	−0.22	**−1.11**	**−1.05**	**−0.41**	+0.23	+0.02

Relative percent differences Δ*g* between SeaWiFS *g*-factors (the values in bold indicate Δ*g* exceeding ±0.3% in the blue-green spectral regions and ±0.1% in the red).

Joint Research Centre

Uncertainties in retrieved L_w

Actual values



$$u(L_T)/L_T = u(L_w)/L_w \; t_d \; L_w/L_T$$

Relative uncertainties $u(L_w)/L_w$ determined assuming a spectrally independent 0.3% uncertainty value for L_T and mean values of $t_d \cdot L_w/L_T$ for different water types: oligotrophic (O), mesotrophic (M) and coastal (C). The vertical bars refer to values determined with $t_d \cdot L_w/L_T \pm \sigma$.

The 5% uncertainty requirement in satellite-derived L_w cannot be generally met in the red for oligotrophic and mesotrophic waters, and is challenging in the blue at 412 nm for mesotrophic and coastal waters. Thus:

i. the 0.3% value assigned to $u(L_T)/L_T$, could be considered a rough upper threshold for the uncertainties of *g*-factors allowing to meet the 5% science requirement for $u(L_w)/L_w$ in the blue-green spectral regions;

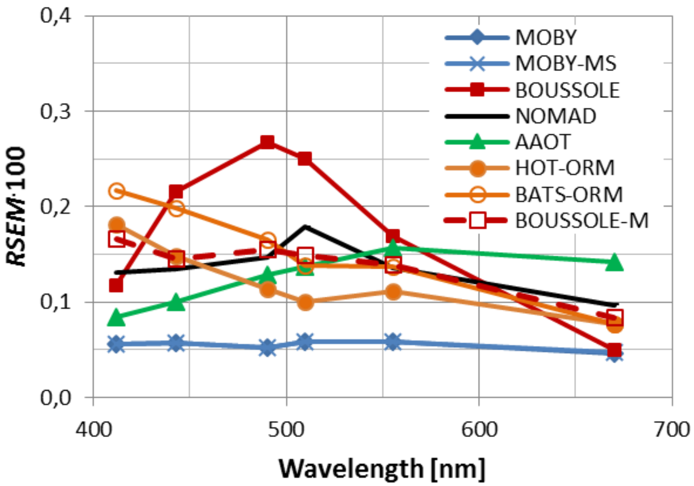
ii. the application to different missions of *g*-factors determined with independent *in situ* data sources and exhibiting typical differences of 0.3% in the blue-green spectral regions with respect to the values obtained with an identical *in situ* data source, may introduce mission dependent biases of several percent in multi-mission CDRs (thus hindering stability requirements in satellite-derived products even when applying the same atmospheric correction code to the processing of data from different missions).

Joint Research Centre

Stability Requirements

The challenge

The 0.5% stability requirement over a decade (WMO 2011) entails maximum uncertainties of approximately 0.05, 0.025 and 0.005% in *g*-factors, assuming generic values of 0.10, 0.05 and 0.01 for the term $t_d \cdot L_w / L_T$.



The relative standard error of the mean (*RSEM*) of *g*-factors *g* determined from

$$RSEM = (\sigma_g / g) / \sqrt{N_y}$$

with σ_g standard deviation of *g* assumed invariant with time for each considered data source, and N_y

The relative standard error of the mean (*RSEM*) of *g*-factors *g* determined from $RSEM = (\sigma_g / g) / \sqrt{N_y}$ with σ_g standard deviation of *g* assumed invariant with time for each considered data source, and N_y

Maximum acceptable uncertainties ensuring the required decadal stability are comparable to the *RSEM* values only determined for MOBY in the blue-green spectral regions.
This result further indicates:

i. the need for long-term highly consistent *in situ* data applicable to SVC in view of minimizing any appreciable perturbation that may affect the determination of *g*-factors over time for different or successive satellite missions;

ii. caution in using data from sole or multiple sources, which may refer to measurement conditions difficult to reproduce for different missions; and

iii. the need for applying mission-independent atmospheric models and algorithms for the atmospheric correction process.

SVC Calibration System

Future strategy

Findings indicate that the creation of ocean color CDRs should ideally rely on:

i. one main long-term *in situ* calibration system (site and radiometry) established and sustained with the objective to maximize accuracy and precision over time of *g*-factors and thus minimize possible biases among satellite data products from different missions; and

ii. unique (i.e., standardized) atmospheric models and algorithms for atmospheric corrections to maximize cross-mission consistency of data products at locations different from that supporting SVC.

It is reminded that strategies for the construction of CDRs also suggest establishing and maintaining secondary *in situ* long-term systems with performance equivalent to the main one in terms of data accuracy, precision and measurement conditions. This recommendation is enforced by the fundamental need to allow for redundancy ensuring fault-tolerance to SVC and additionally to provide optimal means for continuous verification and validation of satellite primary data products including the capability to accurately investigate systematic effects induced by different observation conditions (i.e., viewing and illumination geometry, atmosphere and water types).

calibration of any satellite ocean color sensor regardless of its center-wavelengths and spectral responses;

ii. State-of-the-art absolute calibration traceable to National Metrology Institutes (i.e., tentatively with target standard calibration uncertainty lower than 2% for radiance with stability better than 0.5% per deployment) and comprehensive characterizations of radiometers in terms of linearity, temperature dependence, polarization sensitivity and stray light effects, in view of minimizing measurement uncertainties and allowing for accurate determinations of uncertainty budgets;

iii. Application of quality assurance/control schemes minimizing effects of measurement perturbations like those (when applicable) due to infrastructure shading, radiometer self-shading, wave perturbations, bio-fouling, and additionally scheduling regular checks of *in situ* systems and frequent swap of radiometers, as best practice to maximize long-term accuracy and precision of *in situ* reference radiometric data;

iv. Data rate ensuring generation of matchups for any satellite ocean color mission with time differences appropriate to minimize variations in bi-directional effects due to changes in sun zenith and daily fluctuations in the vertical distribution of phytoplankton.