PROGRAMME OF THE EUROPEAN UNION

IMPLEMENTED BY EUMETSAT

fiducial reference measurements for satellite ocean colour

Rationale and requirements for the calibration and characterisation of ocean color radiometers

Giuseppe Zibordi

giuseppe.zibordi@eoscience.eu

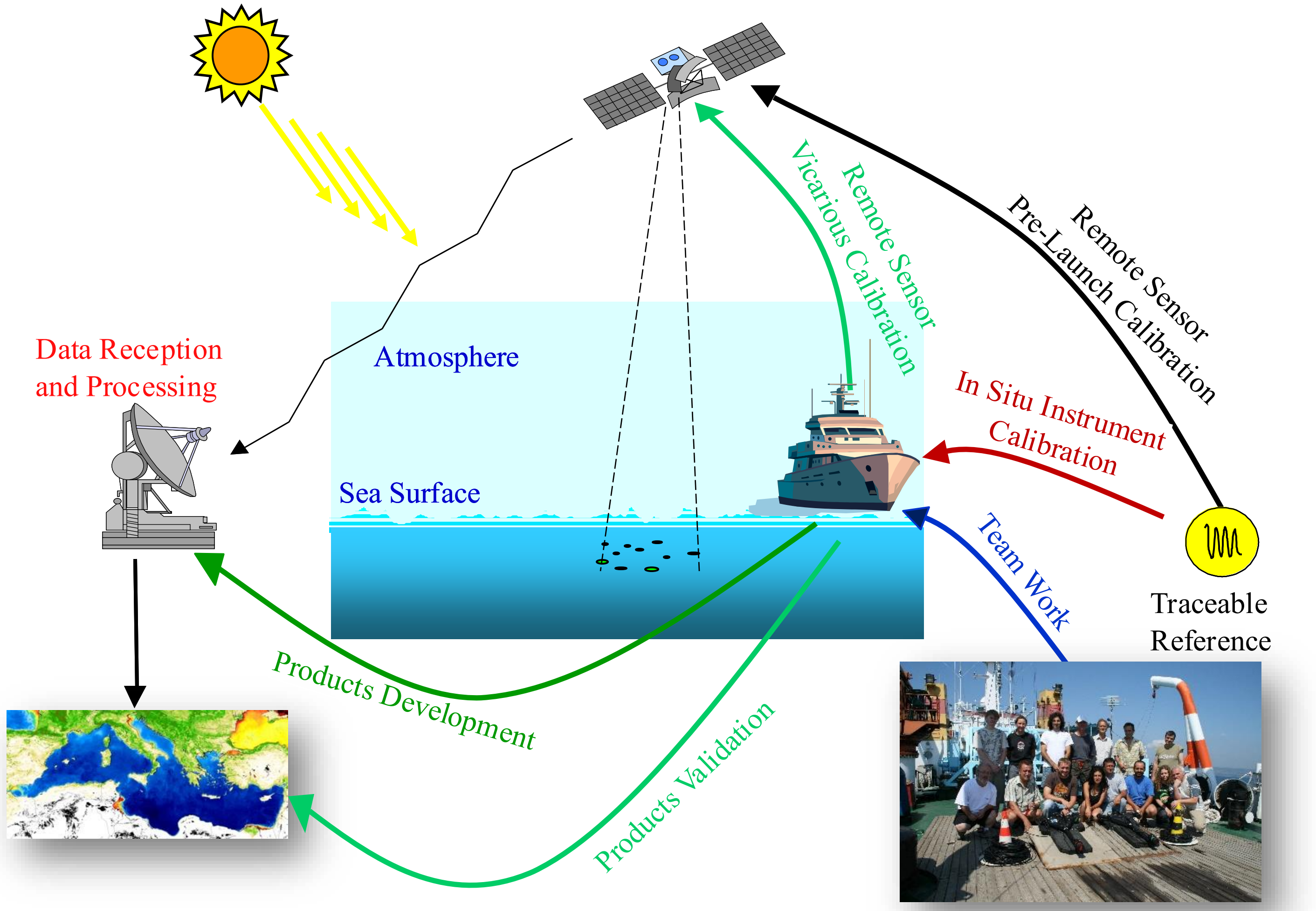
Prologue

“Good (practically useful) data do not collect themselves. Neither do they magically appear on one’s desk, ready for analysis and lending insight into how to improve processes” (S.B. Vardemann and J.M. Jobe 2016)

“… adequately sampled, carefully calibrated, quality controlled, and archived data for key elements of the climate system will be useful indefinitely” (Wunsch, R.W. Schmitt, and D.J. Baker 2013)

The Ocean Color Paradigm

In situ reference measurements are central to system vicarious calibration, data products development and validation

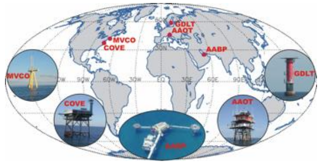


Field measurement programs should rely on:

- ❑ *Protocols*
- ❑ *Best practices*
- ❑ *Quality assurance and control*
- ❑ *Uncertainties*

Uncertainties require comprehensive understanding of instrument responsivity and non-ideal performance

Performance Matrix for in situ validation data



Ranking (0-10) ***(0=lowest and 10 =highest)***	***AERONET-OC (AAOT)***	***BiOMaP (ships)***
Measured Quantities	1	10
Matchups versus Deployment-Time	10	10
Accuracy	8	8
Temporal Representativity	10	1
Bio-optical Representativity	5	10
Matchups versus Funding	10	1
Overall mean	**6.8**	**6.7**

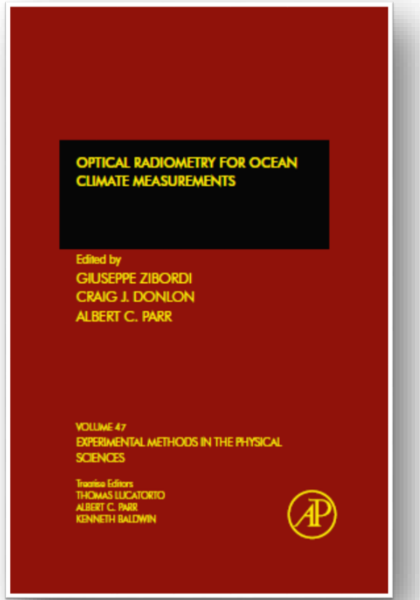
The cost per matchup:

less than 0.5 US K$

more than 25-50 US K$

fiducial reference measurements for satellite ocean colour

The way forward for ocean color Cal/Val



- *Lessons learnt indicate* ***the need for at least one long-term reference site providing in situ optical radiometry data*** *of exceptional quality for system vicarious calibration across successive missions.*
- *The assessment of satellite data products and the development of bio-optical algorithms should be supported by* ***geographically distributed radiometric measurements from regions representative of the world seas****. In all cases, data quality should be assured through* ***the application of state of the art measurement protocols, fully characterized and well-calibrated field radiometers, and finally validated processing schemes*** *(ideally benefitting of measurement networks).*
- ***Data, complemented by uncertainty values,*** *should be* ***stored in dedicated and accessible repositories.***
- ***Inter-comparisons of extended field methods, instruments, and data reduction schemes*** *are the way to secure accuracy.*
- ***Standardization of measurements and data reduction****, is an invaluable component of the overall strategy to assure high consistency to field data regardless of source and region.*
- *The development of new methods and instruments need high consideration. However,* ***the use of newly developed methods or instruments in operational programs needs to be carefully done*** *to avoid introducing significant discontinuities or inconsistencies in time series or in globally distributed data.*
- *Finally, it is important to highlight that* ***international collaboration*** *on each element of the proposed strategies is essential both in benefiting from transnational experience and optimizing the use of resources.*

*G. Zibordi and K.J.Voss, Requirements and Strategies for In Situ radiometry in Support of Satellite Ocean Color. In Optical Radiometry for Oceans Climate Measurements, Experimental Methods in the Physical Sciences volume 47, G. Zibordi, C.Donlon and A. Parr Ed.s, Elsevier - Academic Press, Amsterdam (**December 2014**).*

FRM: origin, name and definition

Origin

The *Fiducial Reference Measurement (FRM)* concept was established to highlight the need for highly accurate *in situ* measurements supporting post-launch satellite activities such as the indirect calibration of the sensor in space or the validation of satellite-derived data products (commonly referred as *Cal/Val activities*).

Name

Fiducial Reference Measurement (FRM), however, from the etymological perspective it is equivalent to:

Fiducial Fiducial Measurements (F^2M)
Reference Reference Measurements (R^2M)

Definition

"A suite of independent, fully characterized, and traceable (to a community agreed reference, ideally SI) measurements of satellite relevant measurand, tailored specifically to address the calibration/validation needs of a class of satellite borne sensor that follow the guidelines outlined by the GEO/CEOS Quality Assurance framework for Erath Observation (QA4EO) (https://qa4eo.org)".

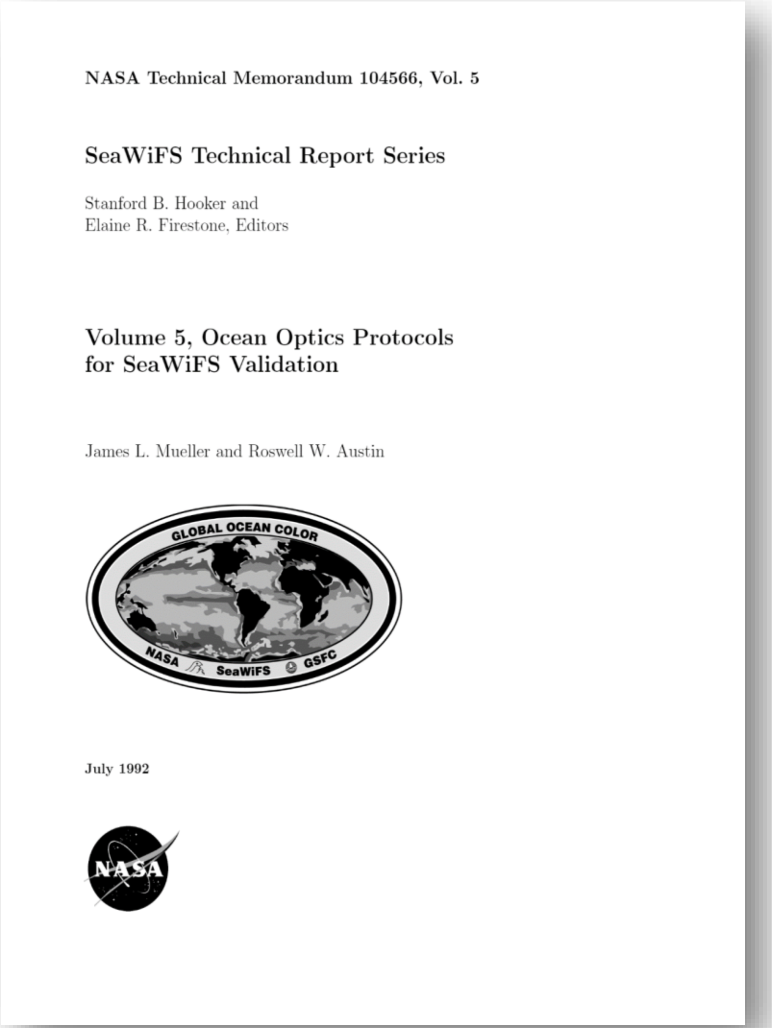
An (attempted) comprehensive definition of FRM

In situ radiometric measurements should be considered adhering to FRM requirements when:

- *Performed following*
  - *i.* published and verified, ideally community shared, measurement protocols and
  - *ii.* detailed quality assurance (QA) procedures.
- *Executed with instruments exhibiting*
  - *i.* features allowing to satisfy application needs and
  - *ii.* documented radiometric performance (*i.e.*, supported by absolute calibrations traceable to SI and characterizations determined for each potential instrument non-ideal performance).
- *Reduced and processed in agreement with community shared protocols supported by documented details on*
  - *i.* the flow leading to the determination of data products including the application of radiometric calibrations and corrections for the instrument non-ideal performance,
  - *ii.* the quality control procedures (QC), and
  - *iii.* the metrology principles applied for the determination of the uncertainty budget.
- *Accessible through consolidated data-bases supported by*
  - *i.* details on units and data formats, and
  - *ii.* ideally, community shared indices identifying the measurement method and the application fitness.

fiducial reference
measurements for
satellite ocean colour

Protocols


NASA Technical Memorandum 104566, Vol. 5

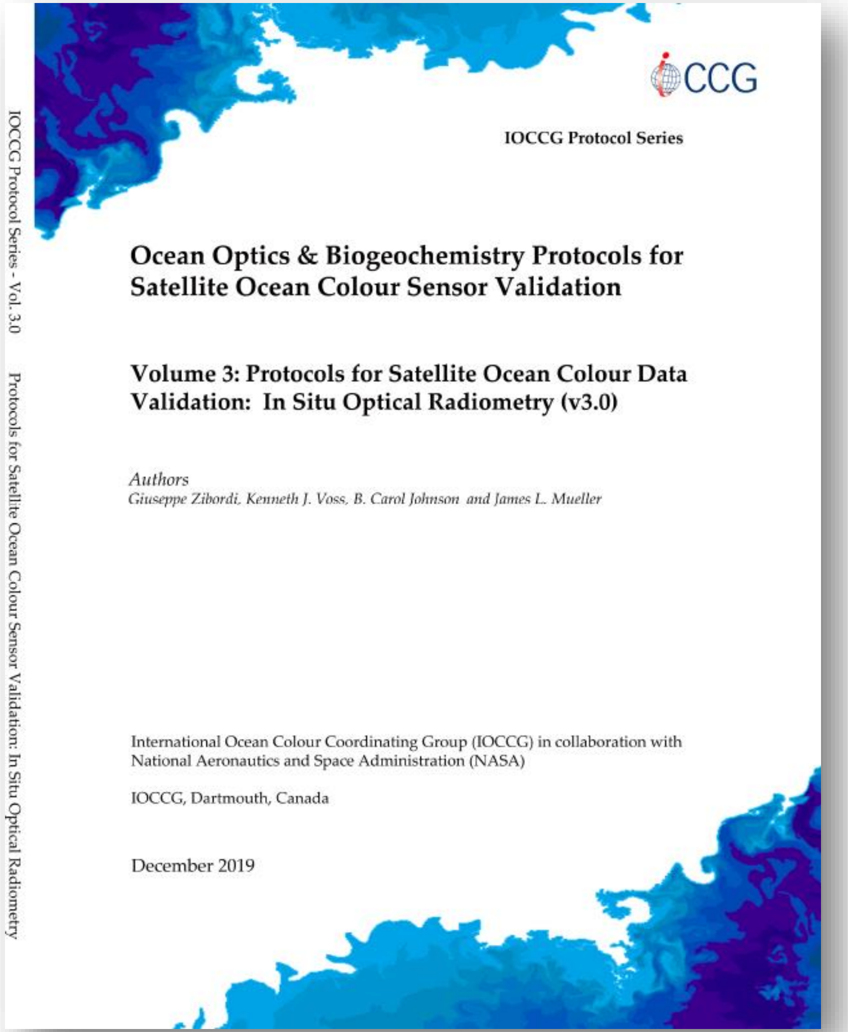
SeaWiFS Technical Report Series

Stanford B. Hooker and
Elaine R. Firestone, Editors

Volume 5, Ocean Optics Protocols
for SeaWiFS Validation

James L. Mueller and Roswell W. Austin

July 1992


IOCCG Protocol Series - Vol. 3.0   Protocols for Satellite Ocean Colour Sensor Validation: In Situ Optical Radiometry

IOCCG

IOCCG Protocol Series

Ocean Optics & Biogeochemistry Protocols for
Satellite Ocean Colour Sensor Validation

Volume 3: Protocols for Satellite Ocean Colour Data
Validation: In Situ Optical Radiometry (v3.0)

Authors
Giuseppe Zibordi, Kenneth J. Voss, B. Carol Johnson and James L. Mueller

International Ocean Colour Coordinating Group (IOCCG) in collaboration with
National Aeronautics and Space Administration (NASA)

IOCCG, Dartmouth, Canada

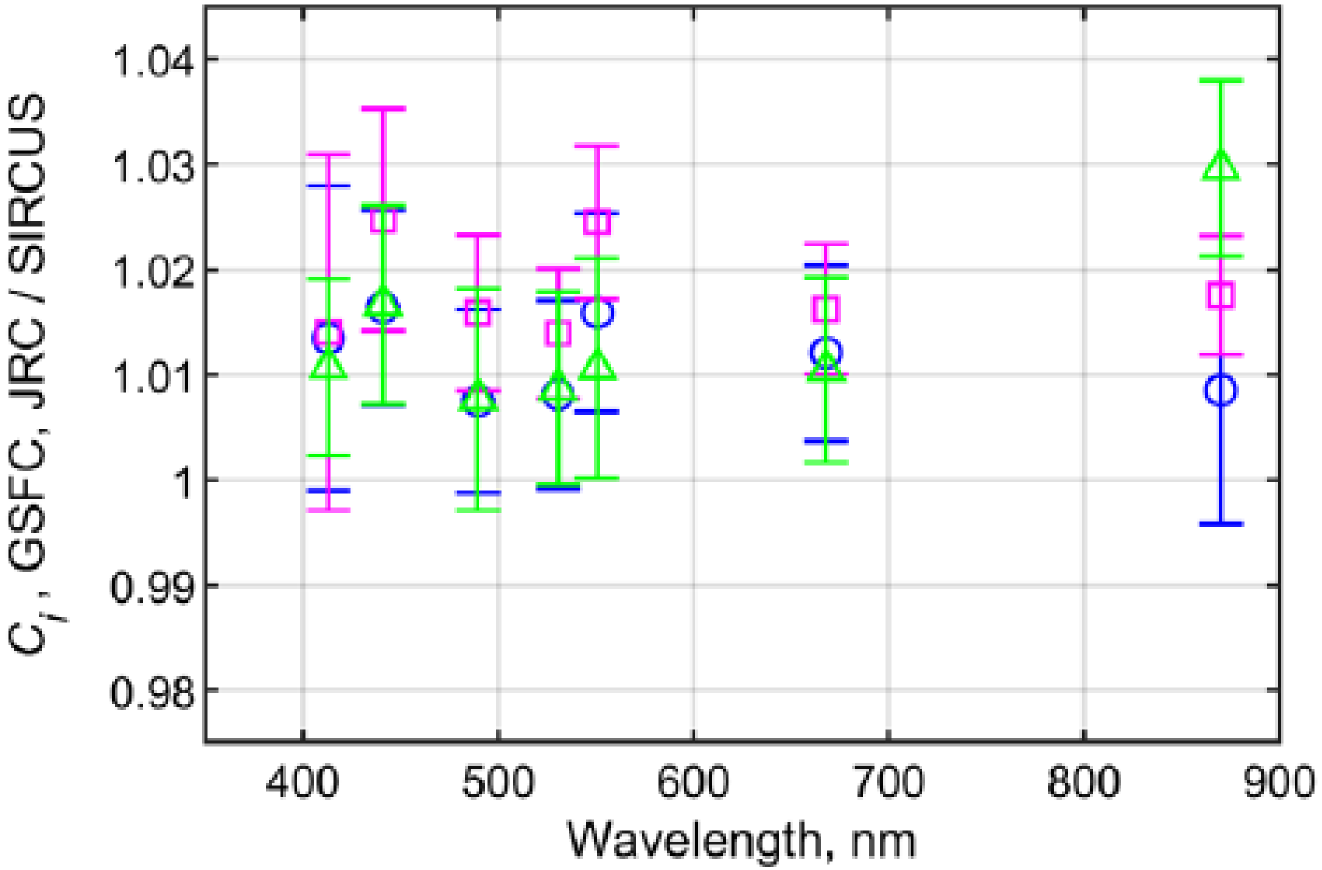
December 2019

Calibration and characterization needs

	Regular	Occasional	Initial	Class-based
Radiometric responsivity	X			
Spectral response		X		
Out-of-band & stray-light		X		
Immersion factor (irradiance)			X	
Immersion factor (radiance)				X
Angular response			X	
Linearity				X
Integration time				X
Temperature response				X
Polarization sensitivity				X
Dark signal	X			
Temporal response				X
Pressure effects				X

IOCCG Protocol Series (2019). Protocols for Satellite Ocean Colour Data Validation: In Situ Optical Radiometry. Zibordi, G., Voss, K. J., Johnson, B. C. and Mueller, J. L. IOCCG Ocean Optics and Biogeochemistry Protocols for Satellite Ocean Colour Sensor Validation, Volume 3.0, IOCCG, Dartmouth, NS, Canada.

NIST, NASA and JRC radiance calibrations



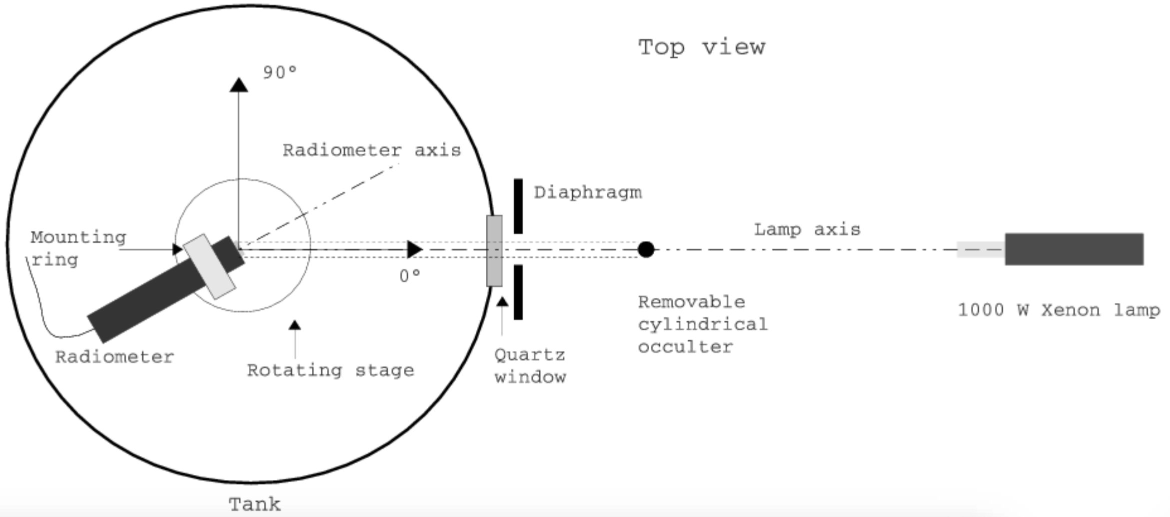
Ratio of NASA-GSFC ○, □ and JRC △ to NIST radiance calibrations (note the use of error-bars and the adoption of NIST values a the reference.

Inter-calibrations among laboratories are essential to identify issues in calibration set-ups, sources, or even protocols implementation.

Best laboratory radiance inter-calibration exercises exhibit values within 2% for radiance (k=1)

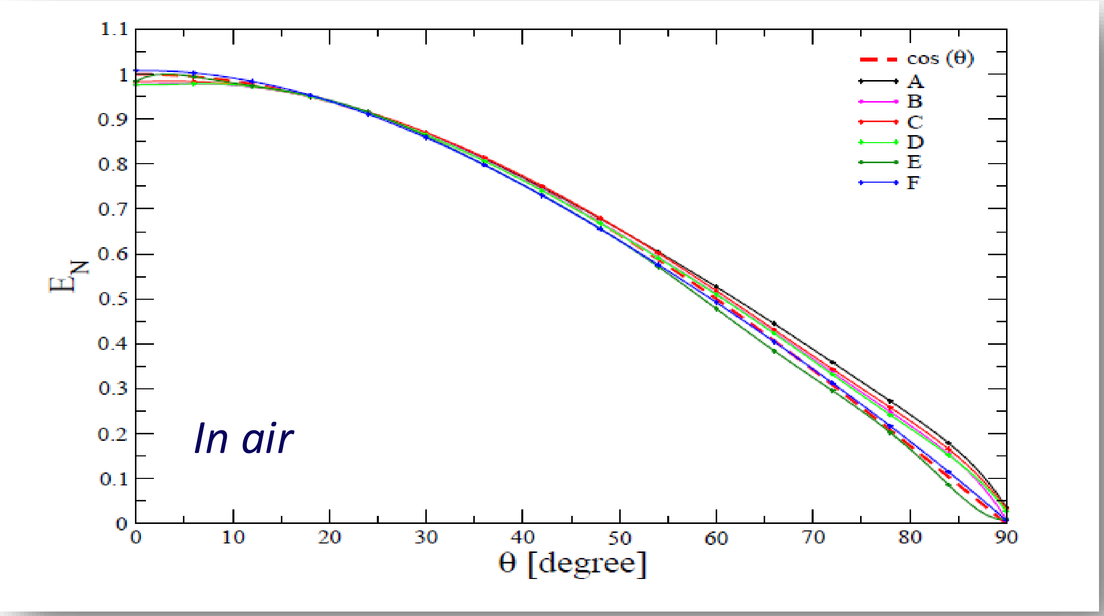
Johnson, B. C., Zibordi, G., Brown, S. W., Feinholz, M. E., Sorokin, M. G., Slutsker, I., ... & Yoon, H. W. (2021). Characterization and absolute calibration of an AERONET-OC radiometer. *Applied Optics*, *60*(12), 3380-3392.

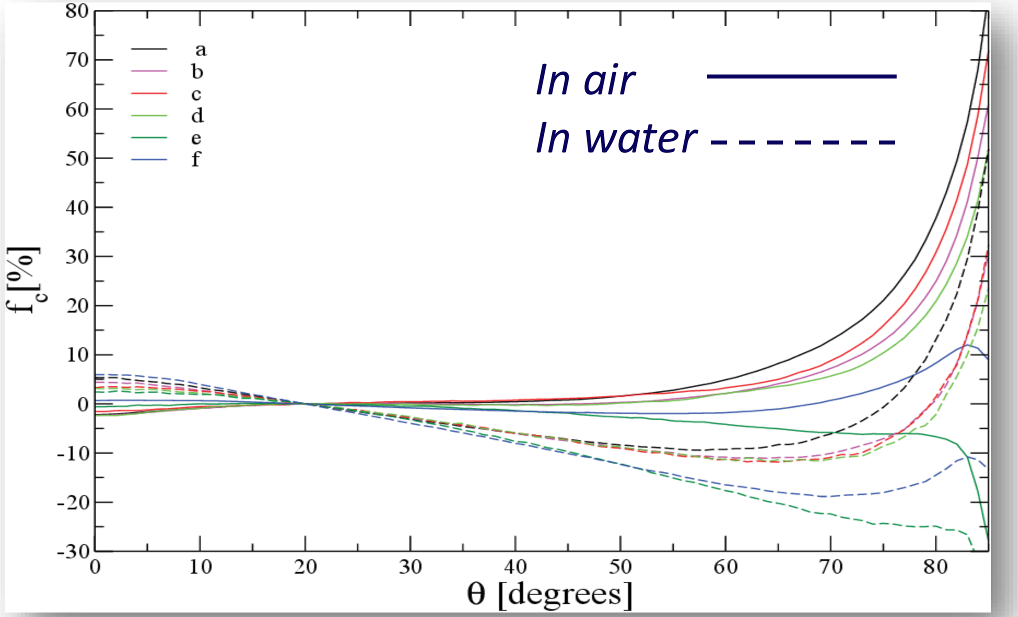
Cosine Response for Irradiance Sensors



$$f_c(\lambda,\theta,\varphi) = 100\left[\frac{E(\theta,\varphi,\lambda)}{E(0,\varphi,\lambda)cos\theta} - 1\right]$$

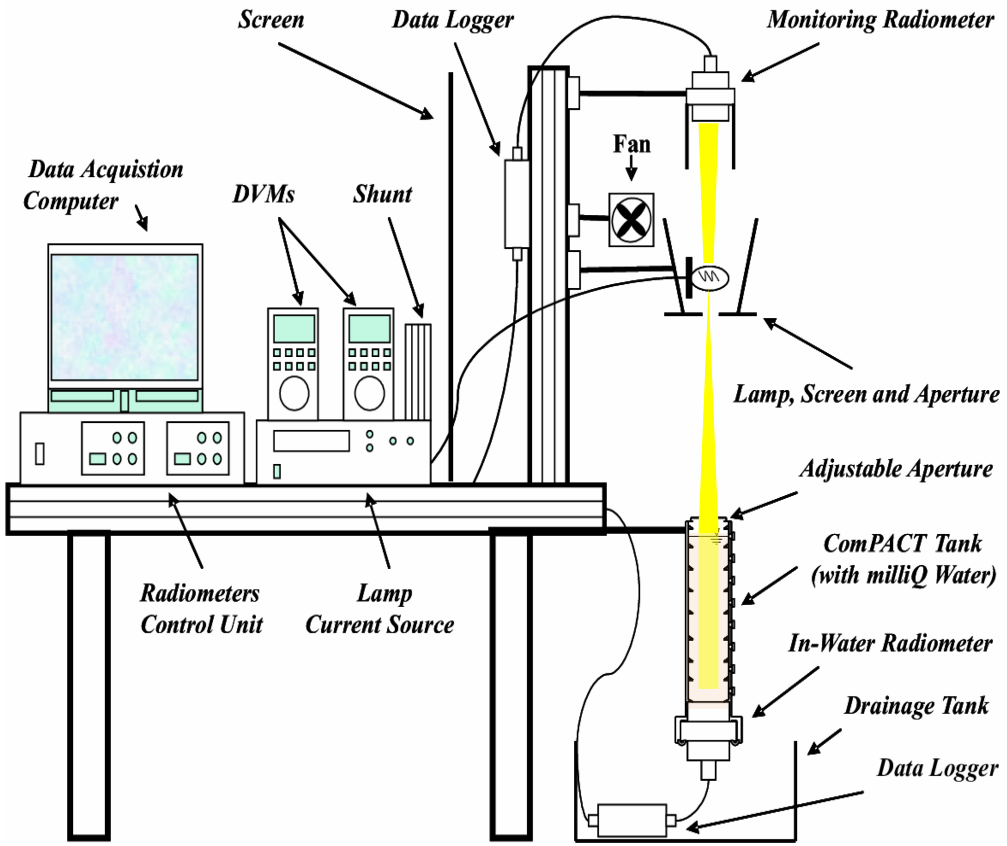
The cosine response of irradiance sensors should be characterized for each unit because simple geometric differences of the collector may lead to appreciable differences.

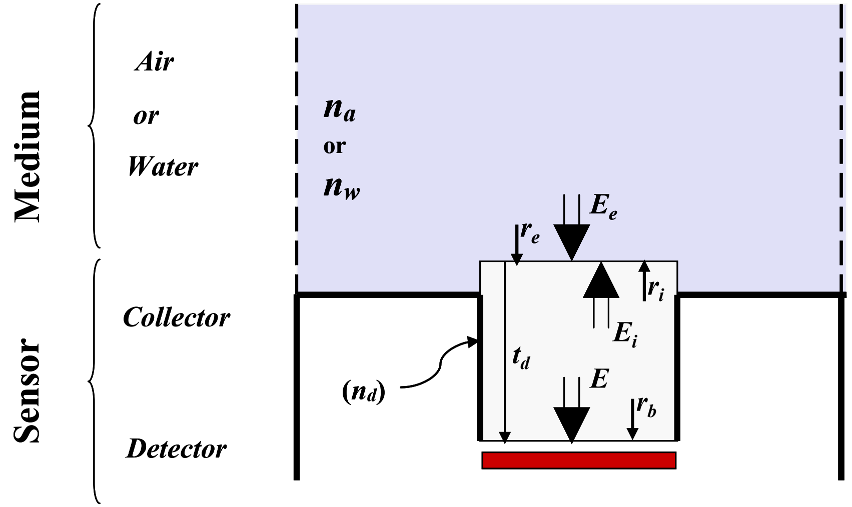


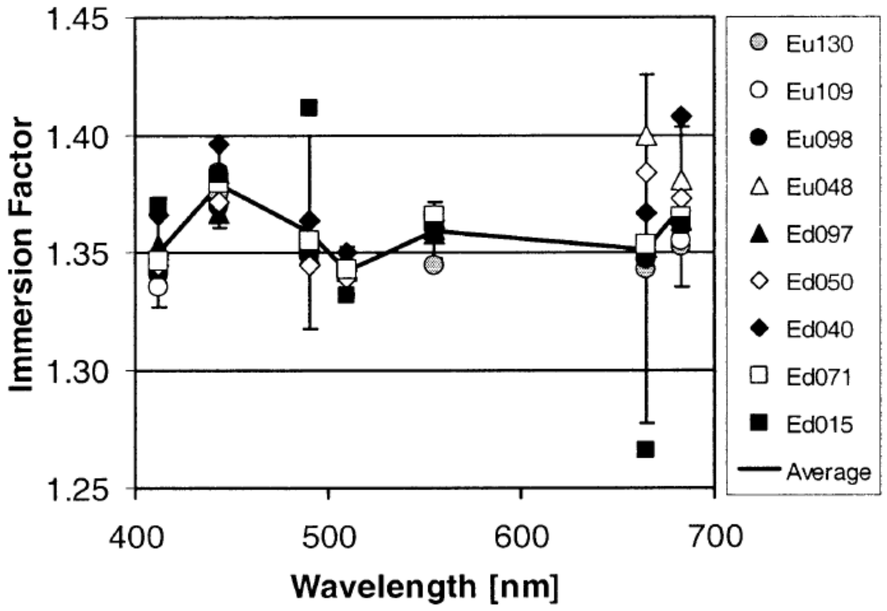


S. Mekaoui and G. Zibordi. Cosine error for a class of hyperspectral irradiance sensors, *Metrologia 50 (2013).*

Immersion Factor I_f (irradiance)







The immersion factor of irradiance sensors must be experimentally determined. It can vary by several percent from unit to unit because of mechanical/optical differences affecting collectors.

G.Zibordi et al. Characterization of the immersion factor … . Journal of Atmospheric and Oceanic Technology, 21:501-514, 2004.

Joint Inter Agency Request to Manufacturers

- This is a brief (1 ½ page) document defining a set of basic requirements targeted to field OCR manufacturers.
  - Initiated by the FRM4SOC-2 team, EUMETSAT, and NASA
  - Issued by the IOCCG as an addendum to Protocol Chapter 3

- **Juan Gossn** (EUMETSAT) will talk in more detail tomorrow about its content.
- We encourage everyone here and especially those representing manufacturing companies to read through it in preparation for Juan's talk.

Available at *IOCCG.org*
→ What we do?
→ IOCCG Publications
→ IOCCG Protocol
→ Protocol 3 Addendum

IOCCG
International Ocean Colour Coordinating Group

Request to manufacturers of in situ and above-water spectral imaging radiometers in the UV, VIS and NIR range

The quality of the satellite Ocean Colour data products and user services relies on the quality of in situ radiometric measurements used in algorithm development and product validations (see list of current and scheduled Ocean Colour space missions on the IOCCG website). Exhaustive collections of in situ radiometric measurements, such as SeaBASS, OC-CCI and GLORIA, demonstrate the importance of the instruments that manufacturers provide to the Ocean Colour community. Satellite Ocean Colour observations are a vital means for understanding the ecology and biogeochemistry of our oceans as well as the threats they face in a changing climate. Ocean Colour is an Essential Climate Variable. The data are critical for managing aquatic resources and water quality to sustain a habitable planet, and safeguard human health and the health and biodiversity of aquatic ecosystems. Ocean Colour observations are, however, as priceless as they are difficult. The satellite signal coming from natural water bodies is low in the visible range of the spectrum due to a large contribution from the atmosphere, and is confounded with artefacts (for example, sea surface glitter). Space-borne instruments must be accurately calibrated and characterised before launch, monitored while in space, and additionally vicarious calibrated.

Similar calibration and characterisation activities are also performed on field radiometers, so that the community can depend on the validation and the algorithms that define the performance of satellite missions. However, these calibration/characterization activities are often hindered because of a lack of manufacturers' statements about field radiometer calibration uncertainties, and a lack of characterisation of critical effects such as non-linearity, internal spectral stray light, and variability of angular response. In this context, ESA (2016-2019) and EUMETSAT (2021-present) conducted a series of FRM4SOC (Fiducial Reference Measurements for Satellite Ocean Colour) projects with the overarching goal to promote the adoption of the Fiducial Reference Measurement (FRM) standards in Ocean Colour. These FRM standards include a series of requirements on radiometers to ensure documented traceability to SI units via an unbroken chain of calibrations, and the assessment of instrument-related uncertainties and a series of recommended characterisations. Among several documents issued in the frame of this project, one (D-27) is intended to inform radiometer manufacturers about a list of requirements to meet the FRM standard, as well as to provide recommendations from the user experience to improve the performance of the instruments (D-27, section 4).

Agencies and institutions work together to teach the Ocean Colour community the importance of calibration/characterization of their radiometers. They also provide guidelines, measurement procedures, support for calibrations, and tools (e.g. HyperCP). However, it is impossible to maintain the required FRM standard and assign uncertainties if **absolute radiometric response coefficients provided by the manufacturers do not have any measures of uncertainty assigned to them.**

IOCCG requests to Manufacturers

Requests to Manufactures :

i. *Provide absolute calibration coefficients with associated uncertainties.*
This is most pressing. The calibration uncertainty associated with the radiometer absolute response is essential. It is required to provide traceability to *SI*. Without these, users may not be able to achieve the FRM standard.

ii. *Participate in comparison experiments with national metrology institutes and/or secondary cal-labs.*
Such experiments can provide metrology support on laboratory standards, laboratory set up, and ensure metrological compatibility of the absolute calibration coefficients.

iii. *Help to propagate FRM guidelines, procedures and tools.*
Information can be provided in radiometer manuals and in direct communication with customers about existing FRM resources, such as additional characterisations and enhanced calibrations needed to achieve the FRM standards, and guidance to the IOCCG and FRM4SOC documentation to ensure that manufacturers, calibration labs, and users have an unambiguous understanding.


… are there any questions ?