FRM4SOC-2 existing resources and lessons learned

Riho Vendt, Agnieszka Bialek, Carsten Brockmann, Christophe Lerebourg, Kevin Ruddick, Gavin Tilstone, Juan Ignacio Gossn, Ewa Kwiatkowska

Funded by the European Union

FRM4SOC (Phase 1) 2016 – 2019

- Initiated, funded and coordinated by ESA
- In a series of several other FRM projects
- *https://frm4soc.org*

FRM4SOC Phase 2

- Project kick-off 8 April 2021
- Funded by the EU and coordinated by EUMETSAT
- Project end March 2023 (24 months)
- Two optional 12 month extensions may be granted
- *https://frm4soc2.eumetsat.int/*

Funded by the European Union

The Fiducial Reference Measurements (FRM)

fi·du·cial *(adj)* *Regarded or employed as a standard of reference, as in surveying.*

[Latin *fīdūciālis*, *fīdūcia* – trust,confidence.]

In Earth Observation – a best estimate for the „ground truth“

The FRM must:

- have documented **traceability to SI units** (via an unbroken chain of calibrations and comparisons);
- be independent from the satellite retrieval process;
- be accompanied by a complete **estimate of uncertainty**, including contributions from all FRM instruments and all data acquisition and processing steps;
- follow **well-defined procedures**/community-wide management practices and;
- be openly available for independent scrutiny.

- ✓ Donlon, C.; Goryl, P. Fiducial Reference Measurements (FRM) for Sentinel-3. In Proceedings of the Sentinel-3 Validation Team (**S3VT) Meeting**, ESA/ESRIN, Frascati, Italy, 26–29 November **2013**.
- ✓ Donlon, C.J.; Wimmer, W.; Robinson, I.; Fisher, G.; Ferlet, M.; Nightingale, T.; Bras, B. A., Second-Generation Blackbody System for the Calibration and Verification of Seagoing Infrared Radiometers. **J. Atmospheric Ocean. Technol. 2014**, 31, 1104–1127.
- ✓ G. Zibordi and C. J. Donlon, Chapters 3 and 5, vol. 47, G. Zibordi, C. J. Donlon, and A. C. Parr, Eds. **Academic Press, 2014**.

SeaWiFS Project Technical Report Series

This page provides access to the SeaWiFS Project Technical Report Series and SeaWIFS-related articles. All titles including those already published, those in press and those under preparation will be made available through this page.

Currently, only the full citations and abstracts are online. We hope to be able to provide the full text and figures sometime in the near future. Until then, copies of the SeaWiFS Project Technical Reports can be obtained from:

Elaine R. Firestone
Technical Editor
SeaWiFS Technical Report Series
Code 970.2
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
(301) 286-4553
gsfcmail: efirestone
internet: elaine@seawifs.gsfc.nasa.gov

VOL. 1: An Overview of SeaWiFS and Ocean Color.

VOL. 2: Ascending vs. Descending Node.

VOL. 3: Calibration and Validation Plan for SeaWiFS.

SOOP
SIRREX
SeaBass
SXR

NASA/TM-2003-21621/Rev-Vol I

James L. Mueller, Giulietta S. Fargion and Charles R. McClain, Editors
J. L. Mueller, R.W. Austin, A. Morel, G.S. Fargion, and C.R. McClain, Authors.

Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4, Volume I:

Introduction, Background and Conventions

National Aeronautical and Space administration

Goddard Space Flight Space Center
Greenbelt, Maryland 20771

January 2003

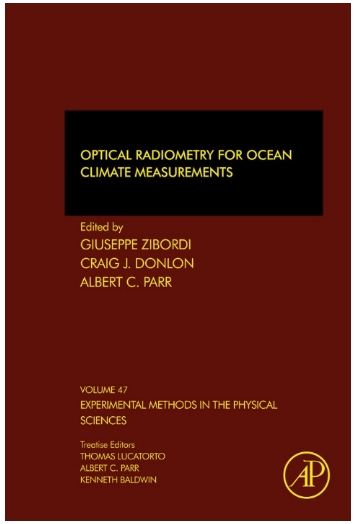
IOCCG

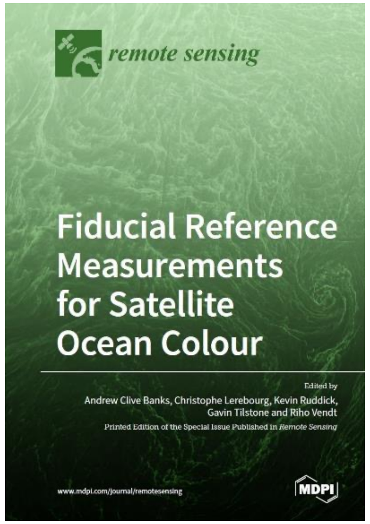
IOCCG Protocol Series

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





Pergamon

Progress in Oceanography 45 (2000) 427–465

Progress in Oceanography

The calibration and validation of SeaWiFS data

S.B. Hooker *, C.R. McClain

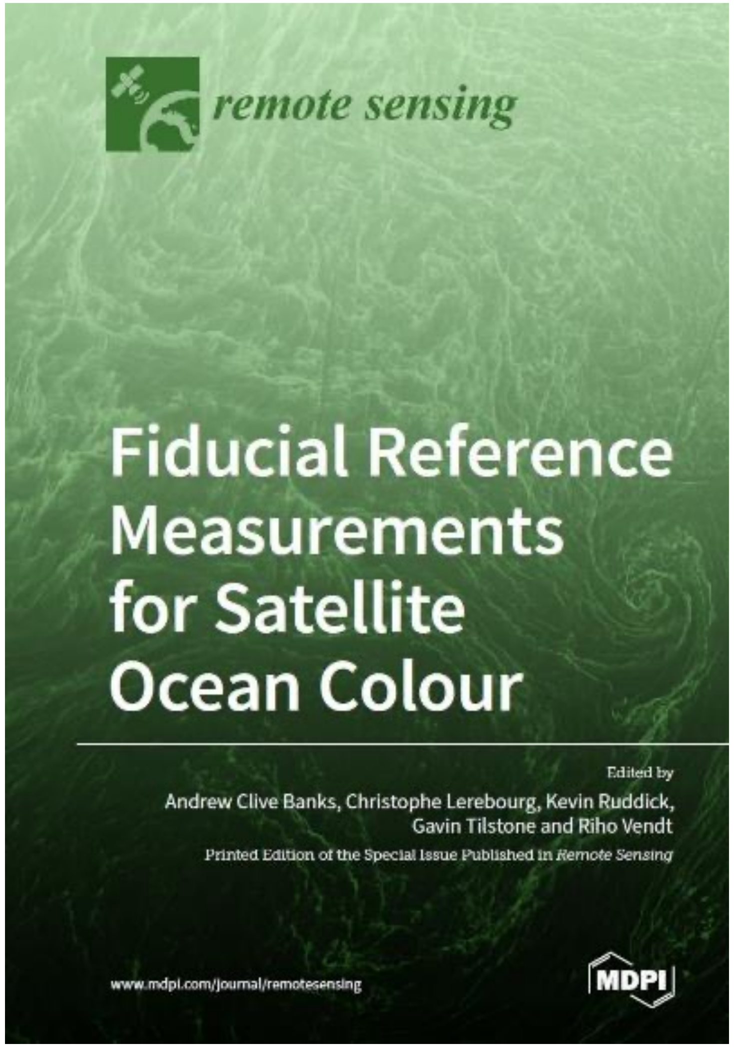
NASA Goddard Space Flight Center, Laboratory for Hydrospheric Processes, SeaWiFS Project Code 970.2, Greenbelt, MD 20771, USA

GROUP ON EARTH OBSERVATIONS

QA4EO A QUALITY ASSURANCE FRAMEWORK FOR EARTH OBSERVATION

A Quality Assurance Framework for Earth Observation: Principles

Author:	QA4EO task team
E-mail:	sec@qa4eo.org
Issued under Authority of:	QA4EO
Issue no:	Version 4.0
Date of issue:	14 January 2010



Fiducial Reference Measurements for Satellite Ocean Colour

Andrew Clive Banks, Christophe Lerebourg, Kevin Ruddick, Gavin Tilstone and Riho Vendt (Eds.)

The results of the FRM4SOC project are published as a special issue of the MDPI journal Remote Sensing.

Open Access

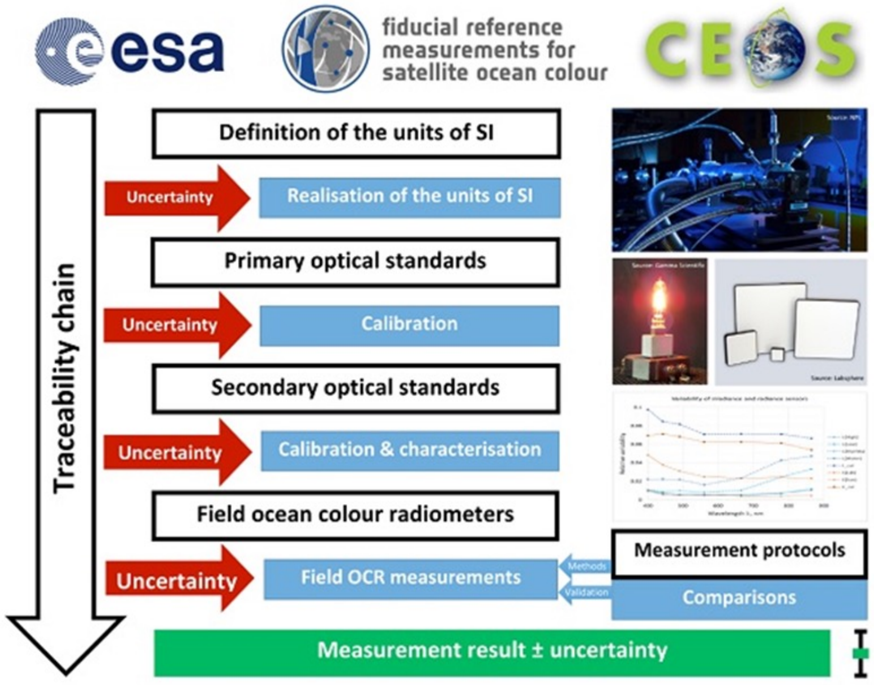
Book (Hard Cover): ISBN 978-3-03943-064-2 (Hbk)
PDF: ISBN 978-3-03943-065-9 (PDF)
https://doi.org/10.3390/books978-3-03943-065-9
Individual papers (web page of the special issue)

fiducial reference measurements for satellite ocean colour
FRM4SOC Phase-1
esa

Implementing the FRM principles

We need to define:

1. measured quantities and measurement models (equations)
2. how to measure (protocols/procedures)
3. choice of adequate instruments
4. establish traceability to SI
5. build measurement uncertainty budgets
6. Implement p1 – p5 adequately
   (competent personnel, training, common understanding)
7. validate traceability and uncertainty budgets in intercomparisons



Remote Sens. **2020**, *12*, 1322; doi:10.3390/rs12081322

Conclusions / Lessons learned from FRM4SOC-1

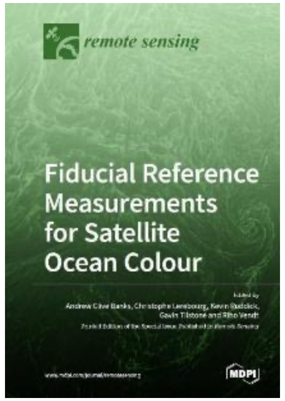
- **Traceability to SI with related uncertainty budget is essential for collecting high quality EO data.**
- **Carefully planned FRM4SOC comparisons have revealed errors, that (would) have not been discovered in regular measurement campaigns.**
- **Laboratory as well as in situ comparison exercises must continue and include even more global cooperation on all levels.**
- **Measurement protocols shall be globally harmonised as well as understood and followed uniformly on all levels.**
- **Improved and harmonised understanding of uncertainty evaluation is needed – best practice, examples, training.**
- **Specifications for new generation (e.g. hyperspectral) instruments shall be identified and required metrology infrastructure shall be developed accordingly.**
- **The FRM activities shall be continued and ensured with appropriate funding.**

Banks A. C., et al., Remote Sens. 2020, 12, 1322; doi:10.3390/rs12081322

Goals of the FRM4SOC Phase 2

Ensure the adoption of FRM principles across the Ocean Colour community.

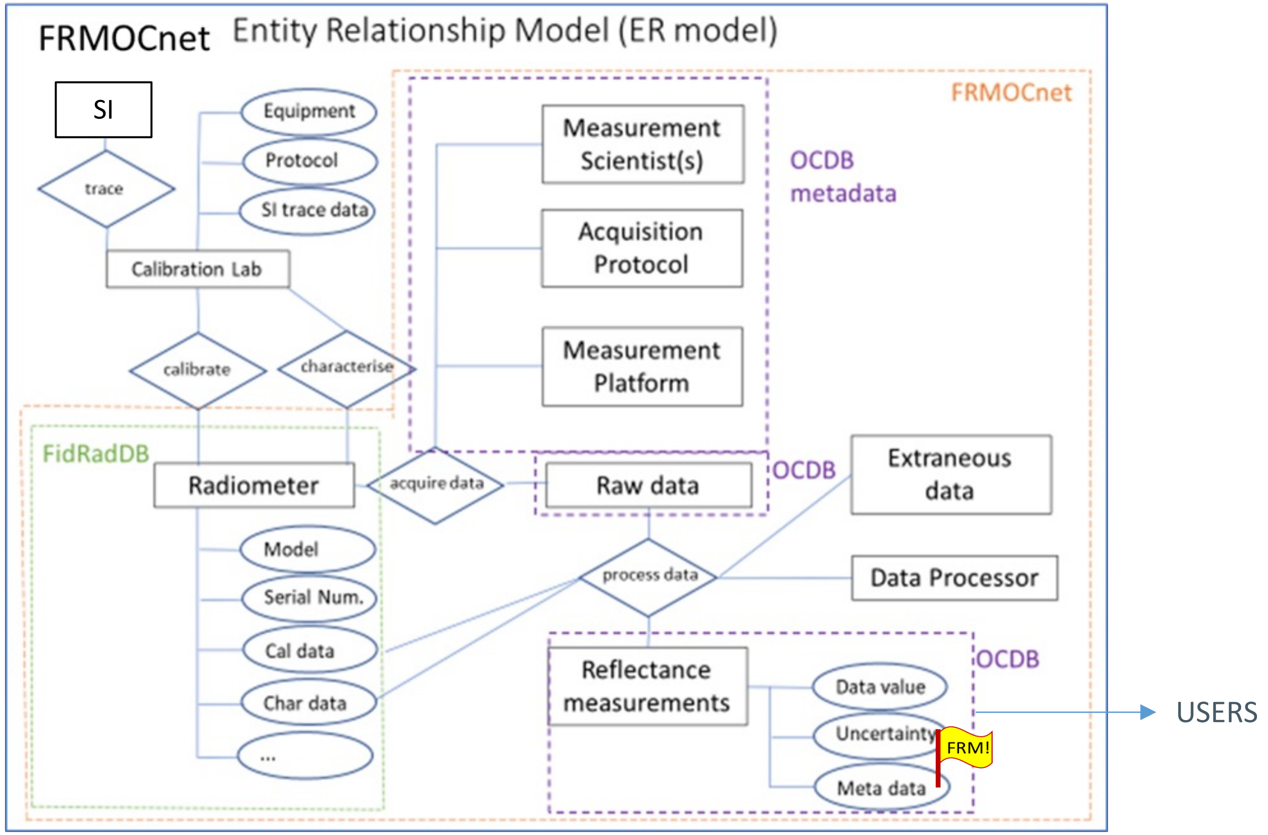
- FRM4SOC-2 builds on the outcomes from earlier studies in the field and the first FRM4SOC study managed by ESA
- We are developing a network of radiometric measurements with the FRM certification.

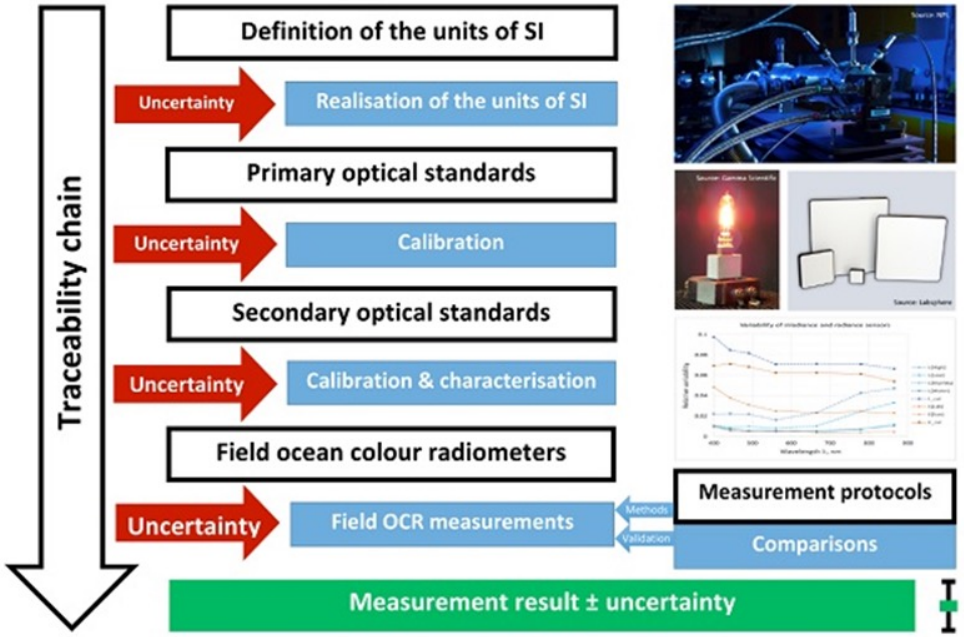


FRM4SOC		**FRM4SOC-2**
Identification of gaps in • **traceability,** • **calibration,** • **characterisation,** • **uncertainty estimation**	→	Consolidate **FRM4SOC-1** focusing on • **Operational** OCR cal/char guidelines. • **Operational** (prescriptive) FRM procedures/protocols. • in discussion wit the **global** community.

The guidelines to obtain FRMs must be clear and as straightforward as possible.

FRMOCnet (network of radiometric measurements with FRM certification)

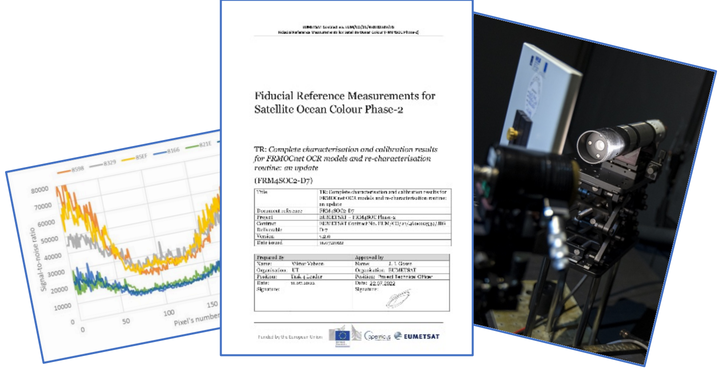




Remote Sens. **2020**, *12*, 1322; doi:10.3390/rs12081322

9. Review and test the developed procedures, guidelines and tools: a field experiment, an international workshop, Expert Review Board

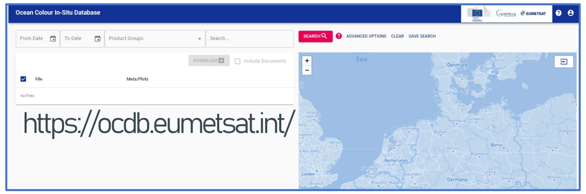
1. Initially focus on the two most common Ocean Colour hyperspectral radiometer classes



2. Fully characterise the two Ocean Colour radiometer classes

(issue recommendations to instrument manufacturers)

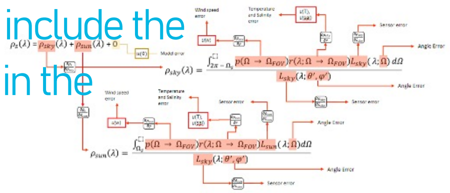
8. Adapt and maintain Ocean Colour In-Situ Database OCDB



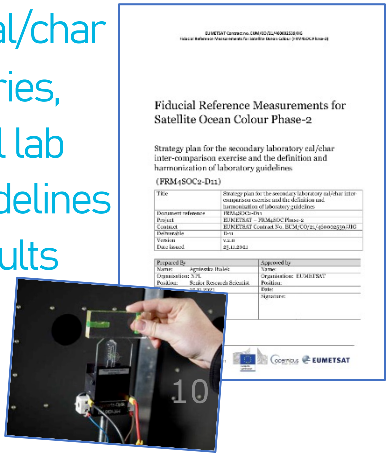
Parameter	Scope	Before initial use	Re-cal/char	D-2 requirement
1. Absolute calibration for radiometric responsivity	individual	required	1 year	IR1
2. Long term stability	individual	required	after every calibration	IR1
3. Stray light and out of band response	individual	required	3 – 5 years	IR2
4. Immersion factor (irradiance)	individual	required for under-water	after fore-optics modification	-
4b.Immersion factor (radiance)	individual/class-specific	required for under-water	after fore-optics modification	-
5. Angular response of irradiance sensors in air	individual	required	after fore-optics modification	IR3
6. Response angle (FOV) of radiance sensors in air	class-specific	recommended	after fore-optics modification	-
7. Non-linearity	class-specific	recommended	after repair in workshop	IR4
8. Accuracy of integration times	class-specific	recommended	after repair in workshop	IR4
9. Dark signal	individual	required	1 year	IR7
10. Thermal responsivity	class-specific	recommended	after repair in workshop	IR5
11. Polarisation sensitivity	class-specific	recommended	after repair in workshop	IR6
12. Temporal response	TBD	TBD	TBD	IR8
13. Wavelength scale	class-specific	recommended	after fore-optics modification	IR9
14. Signal-to-noise ratio	individual	recommended	1 year	-
15. Pressure effects	TBD	TBD	TBD	-

3. Provide community guidelines on radiometer cal/char schedules

7. Develop a complete end-to-end uncertainty budget for the instruments and the measurements, include the uncertainty calculations in the community processor

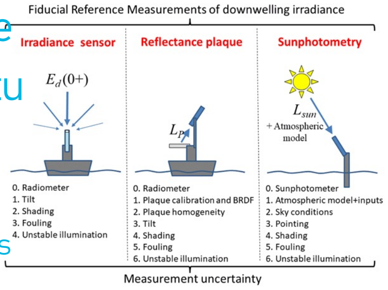


4. Develop radiometer cal/char guidelines for laboratories, include an international lab exercise to test the guidelines and inter-compare results



6. Develop a community processor for in situ radiometric measurements (cooperating with NASA on HyperInSPACE)

5. Provide prescriptive and detailed FRM in situ measurement procedures (following from the IOCCG protocols and FRM4SOC-1 experience)



OCR Calibration and characterisation

1. Absolute calibration for radiometric responsivity
2. Long term stability
3. Stray light and out of band response
4. Immersion factor (irradiance)
4b.Immersion factor (radiance)
5. Angular response of irradiance sensors in air
6. Response angle (FOV) of radiance sensors in air
7. Non-linearity
8. Accuracy of integration times
9. Dark signal
10. Thermal sensitivity
11. Polarisation sensitivity
12. Temporal response
13. Wavelength scale
14. Signal-to-noise ratio
15. Pressure effects

- Characterisation of instruments
- Guidelines for laboratories
- Laboratory comparison

NASA/TM-2003-

Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4, Volume II:

Instrument Specifications, Characterization and Calibration

James L. Mueller, CHORS, San Diego State University, San Diego, California
Giulietta S. Fargion, Science Applications International Corporation, Beltsville, Maryland
Charles R. McClain, Goddard Space Flight Center, Greenbelt, Maryland

J. L. Mueller, and R.W. Austin
CHORS, San Diego State University, San Diego, California
Christophe Pietras
Science Applications International Corporation, Beltsville, Maryland
Stanford B. Hooker and Brent Holben
NASA Goddard Space Flight Center, Greenbelt, Maryland
Mark Miller
Department of Applied Science, Brookhaven National Laboratory, Upton, New York
Kirk D. Knobelspiesse
Science Systems and Applications, Inc., Greenbelt, Maryland
Robert Frouin
Scripps Institution of Oceanography, University of California, San Diego, California
Ken Voss
Physics Department, University of Miami, Florida

National Aeronautical and Space administration

Goddard Space Flight Space Center
Greenbelt, Maryland 20771

January 2003

Chapter 1.2

Principles of Optical Radiometry and Measurement Uncertainty

B. Carol Johnson,[1,*] Howard Yoon,[1] Joseph P. Rice,[1] Albert C. Parr[1,2]
[1] Sensor Science Division, National Institute of Standards and Technology, Gaithersburg, MD, USA; [2] Space Dynamics Laboratory, Utah State University, Logan, UT, USA
*Corresponding author: Email: carol.johnson@nist.gov

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

NASA/TM–2002–206892, Vol. 17

SeaWiFS Postlaunch Technical Report Series

Stanford B. Hooker, Editor
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Elaine R. Firestone, Senior Scientific Technical Editor
Science Applications International Corporation, Beltsville, Maryland

Volume 17, The Seventh SeaWiFS Intercalibration Round-Robin Experiment (SIRREX-7), March 1999

Stanford B. Hooker
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Scott McLean, Jennifer Sherman, Mark Small, and Gordana Lazin
Satlantic, Inc., Halifax, Canada

Giuseppe Zibordi
JRC/SAI/Marine Environment Unit, Ispra, Italy

James W. Brown
RSMAS/University of Miami, Miami, Florida

remote sensing MDPI

Article
Laboratory Intercomparison of Radiometers Used for Satellite Validation in the 400–900 nm Range

Viktor Vabson [1,*], Joel Kuusk [1], Ilmar Ansko [1], Riho Vendt [1], Krista Alikas [1], Kevin Ruddick [2], Ave Ansper [1], Mariano Bresciani [3], Henning Burmester [4], Maycira Costa [5], Davide D'Alimonte [6],

OPEN ACCESS IOP Publishing | Bureau International des Poids et Mesures Metrologia
Metrologia 55 (2018) 747–758 https://doi.org/10.1088/1681-7575/aadd7f

Non-linear response of a class of hyper-spectral radiometers

Marco Talone and Giuseppe Zibordi

OPEN ACCESS IOP Publishing Metrologia
Metrologia 57 (2020) 025008 (7pp) https://doi.org/10.1088/1681-7575/ab6277

Reduction of non-linearity effects for a class of hyper-spectral radiometers

Marco Talone[1], Giuseppe Zibordi[1] and Agnieszka Białek[2]

Volume 122, Article No. 31 (2017) https://doi.org/10.6028/jres.122.031
Journal of Research of the National Institute of Standards and Technology

Immersion Coefficient for the Marine Optical Buoy (MOBY) Radiance Collectors

Michael Feinholz[1], B. Carol Johnson[2], Kenneth Voss[1], Mark Yarbrough[1], and Stephanie Flora[1]

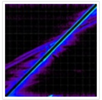
Response to Temperature of a Class of In Situ Hyperspectral Radiometers

Giuseppe Zibordi, Marco Talone, and Lukasz Jankowski

Joint Research Centre, European Commission, Ispra, Italy

(Manuscript received 14 March 2017, in final form 4 May 2017)

Applied Optics Vol. 55, Issue 15, pp. 3966-3977 (2016) • https://doi.org/10.1364/AO.55.003966



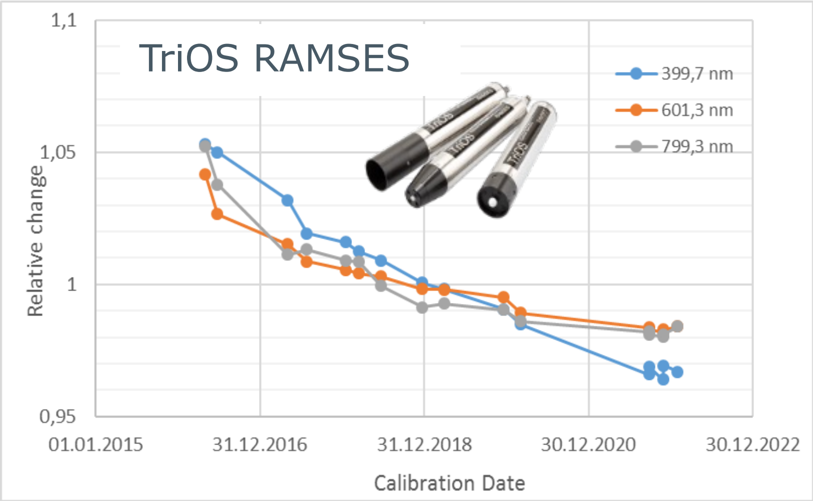
Stray light effects in above-water remote-sensing reflectance from hyperspectral radiometers

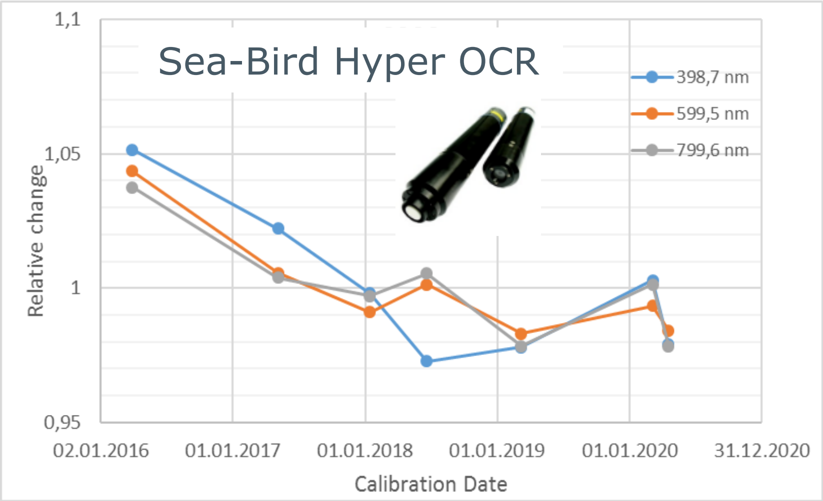
Marco Talone, Giuseppe Zibordi, Ilmar Ansko, Andrew Clive Banks, and Joel Kuusk

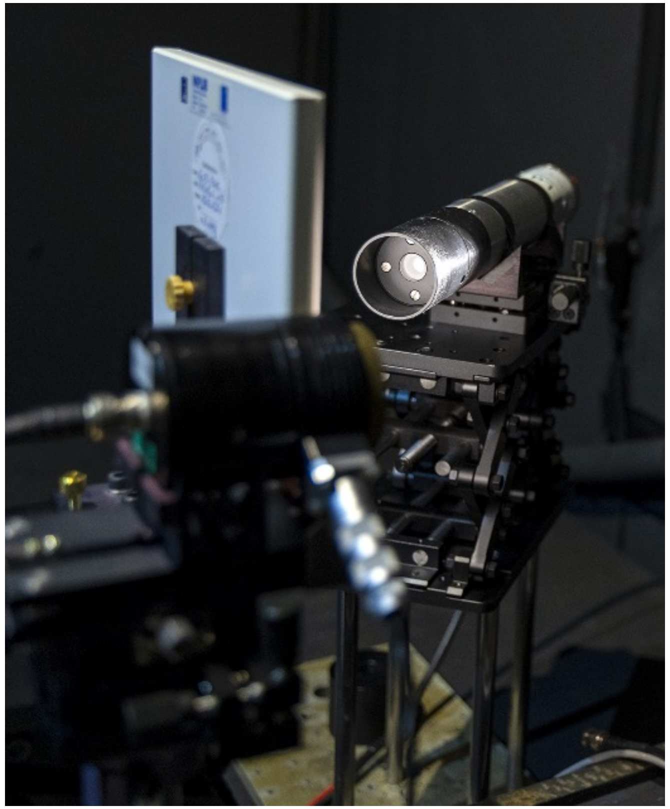
Author Information • Find other works by these authors •

OCR Calibration and characterisation

Example of the calibration history







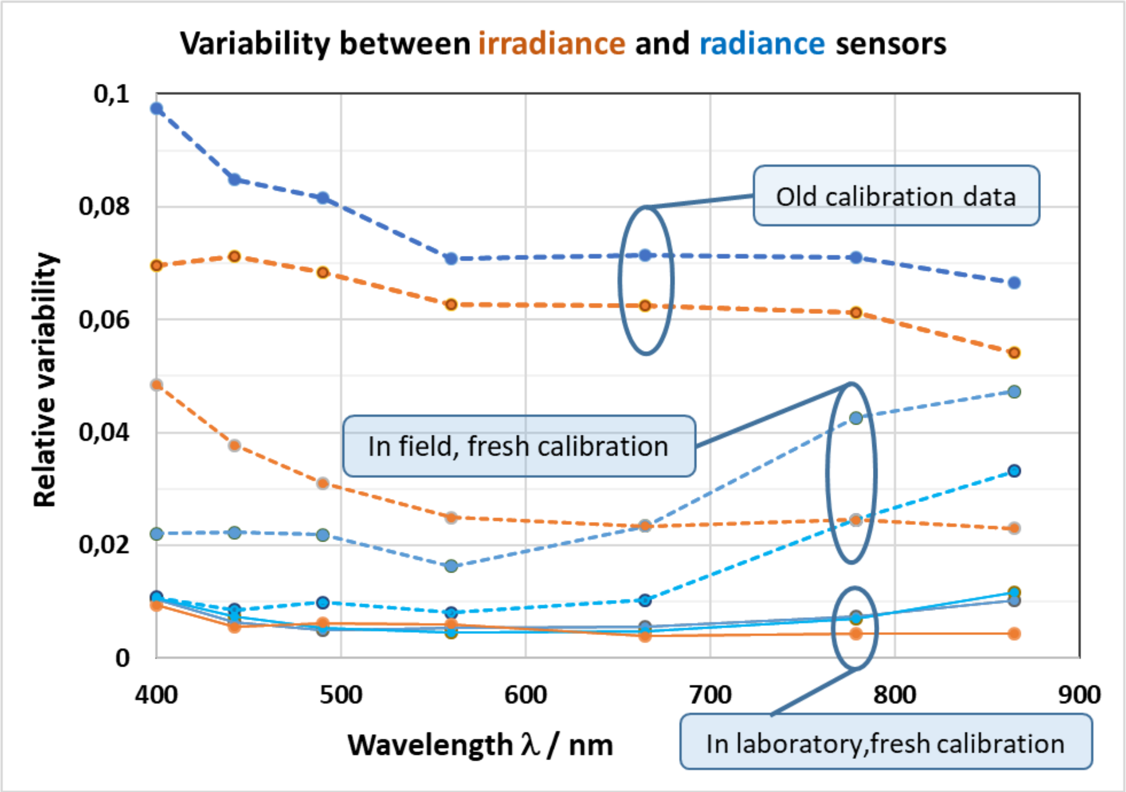
Overview of past comparison exercises performed in support of various OC missions.

Name		Date	Irradiance	Radiance	Comments	Ancillary instrumentation
SIRREX	1	July 1992	Transfer of irradiance scale from a reference lamp to 17 FEL lamps	Integrating spheres (various sizes), lamps + plaques	Based in one lab – aim to transfer a common spectral irradiance and radiance scale from GSFC to participating labs, plaque BRDF issues reported, require improvement of instrumentation to meet the mission goals.	Shunt resistors, voltmeters
	2	June 1993	Transfer of irradiance scale from a reference lamp to 26 FEL and 1 DWX lamp	Integrating spheres (various sizes), lamps + plaques	Based in one lab – aim to transfer the scale. Irradiance results satisfactory, radiance results unsatisfactory	Shunt resistors, voltmeters
	3	Sep 1994	FEL lamps comparison	Integrating spheres (various sizes), lamps + plaques	Based in one lab – irradiance results satisfactory radiance results improved, plaque still require further investigation.	Shunt resistors, voltmeters
	4	May 1995	N/A	N/A	Based at NIST training in a common protocol for calibration of radiometers, Conversion between R (8°/h) to R (0°/45°) geometry for applied,	
	5	July 1996	NIST calibrated participants irradiance radiometers	NIST calibrated participants radiance radiometers	Based at NIST focusing on training and standard measurements protocols implementations	Instruments intercomparison in field
	6	Aug-Sep 1997	2 transfer radiometers measured irradiance at each lab	2 transfer radiometers measured irradiance at each lab	Measurements conducted by NASA personnel traveling to each participating lab.	
	7	March 1999	FEL comparison	lamp + plaques	Based in one lab focused on uncertainty in a single lab, plus rotation and polarisation sensitivity	
	8	Sep-Dec 2001	N/A	N/A	Based in 3 labs, focused on immersion factors and cosine response	
SIMRIC	1	2001	N/A	Lamp plaque, integrating sphere	7 labs measure in-house radiance source with a reference radiometer,	
	2	2002	N/A	Lamp plaque, integrating sphere	10 labs measure in-house radiance source with a reference radiometer,	
FRM4SOC	1	2017-2018	FEL comparison 14 lamps	Radiance comparison in participant laboratories using lamp + plaque	Lamp comparison and training based at NPL; radiance comparison based at each participant own lab. Irradiance results within uncertainty. Radiance saw two distinctive groups of results.	

FRM4SOC-1 Comparison of radiometers

13 participants

2017 at UT, Tõravere, Estonia



Vabson, V., et al. Remote Sens. 2019, 11, 1129; doi:10.3390/rs11091129

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Copernicus Europe's eyes on Earth

EUMETSAT

Comparison of radiometer calibration 2022

- 2 TriOS Ramses
    - 1 radiance
    - 1 irradiance
- 2 SeaBird HyperOCR
    - 1 radiance
    - 1 irradiance

NASA/TM-2003-21621/Rev-Vol III

James L. Mueller, Giulietta S. Fargion and Charles R. McClain, Editors
J. L. Mueller, Andre Morel, Robert Frouin, Curtiss Davis, Robert Arnone, Kendall Carder, Z.P. Lee, R.G. Steward, Stanford Hooker, Curtis D. Mobley, Scott McLean, Brent Holben, Mark Miller, Christophe Pietras, Kirk D. Knobelspiesse, Giulietta S. Fargion, John Porter and Ken Voss, Authors.

Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4, Volume III:

Radiometric Measurements and Data Analysis Protocols

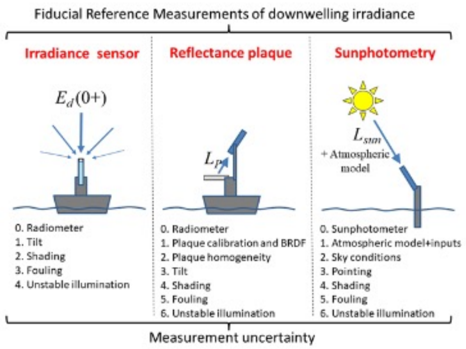
National Aeronautical and Space administration

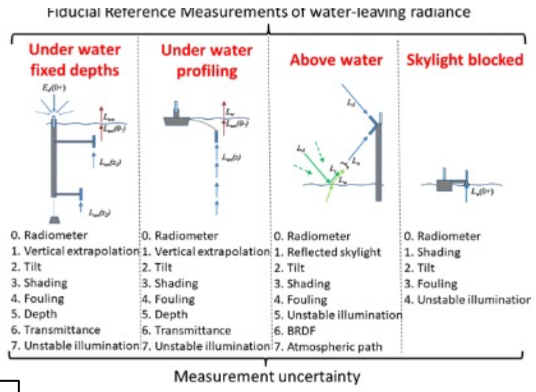
Goddard Space Flight Space Center
Greenbelt, Maryland 20771

January 2003

A Measurement Procedure for shipborne operation of the TriOS RAMSES and SeaBird/Satlantic HyperOCR radiometers to obtain Fiducial Reference Measurements (MPROC)

- Elaboration of the IOCCG and FRM4SOC-1 protocols
- In form of clear and prescriptive guidelines
- Examples of complete uncertainty analysis following FRM principles





IOCCG

IOCCG Protocol Series

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

remote sensing — MDPI

Review

A Review of Protocols for Fiducial Reference Measurements of Water-Leaving Radiance for Validation of Satellite Remote-Sensing Data over Water

Kevin G. Ruddick [1,*], Kenneth Voss [2], Emmanuel Boss [3], Alexandre Castagna [4], Robert Frouin [5], Alex Gilerson [6], Martin Hieronymi [7], B. Carol Johnson [8], Joel Kuusk [9], Zhongping Lee [10], Michael Ondrusek [11], Viktor Vabson [9] and Riho Vendt [9]

remote sensing — MDPI

Review

A Review of Protocols for Fiducial Reference Measurements of Downwelling Irradiance for the Validation of Satellite Remote Sensing Data over Water

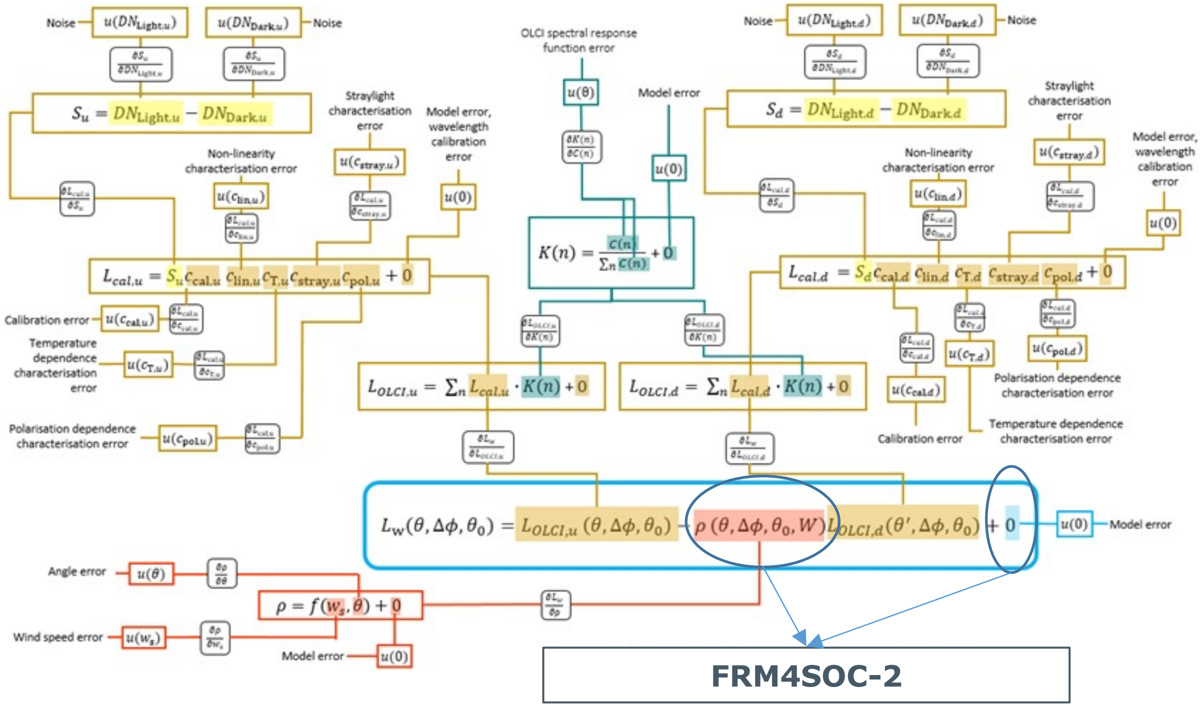
Kevin G. Ruddick [1,*], Kenneth Voss [2], Andrew C. Banks [3], Emmanuel Boss [4], Alexandre Castagna [5], Robert Frouin [6], Martin Hieronymi [7], Cedric Jamet [8], B. Carol Johnson [9], Joel Kuusk [10], Zhongping Lee [11], Michael Ondrusek [12], Viktor Vabson [10] and Riho Vendt [10]

museum
Royal Belgian Institute of Natural Sciences

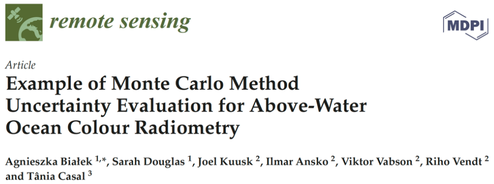
Uncertainty budgets

Elaboration of the FRM4SOC Phase 1 uncertainty budgets

- Developing end-to-end uncertainty budgets for
  - remote sensing reflectance,
  - fully normalised water-leaving radiance.
- Implementing uncertainty calculations in the CP processing chain.
- Providing easy and practical guidelines for uncertainty calculation.



Water leaving radiance uncertainty tree diagramm.
Bialek, A., et al., Remote Sens. 2020, 12, 780; doi:10.3390/rs12050780


remote sensing

MDPI

Article

Example of Monte Carlo Method Uncertainty Evaluation for Above-Water Ocean Colour Radiometry

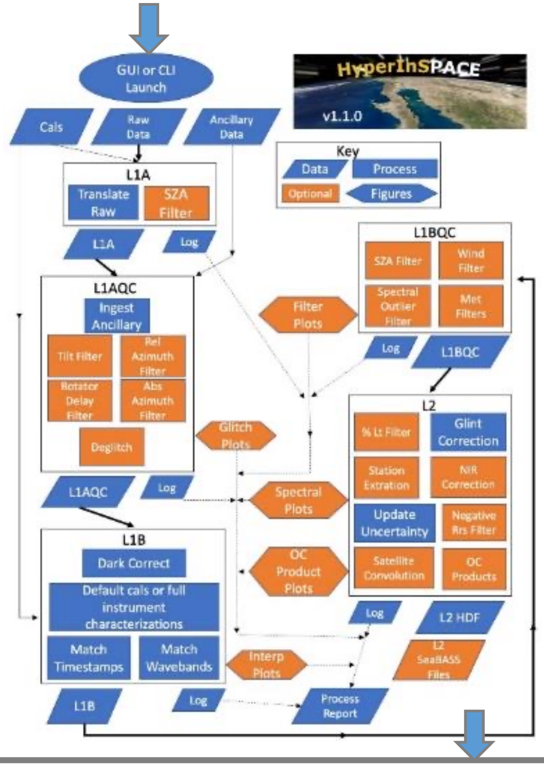
Agnieszka Białek [1,*], Sarah Douglas [1], Joel Kuusk [2], Ilmar Ansko [2], Viktor Vabson [2], Riho Vendt [2] and Tânia Casal [3]

HyperInSPACE Community Processor (HCP) for in situ data processing and uncertainty budget calculation

https://github.com/nasa/HyperInSPACE

N. Vandenberg, M. Costa, Y. Coady and T. Agbaje, "PySciDON: A python scientific framework for development of ocean network applications," *2017 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing (PACRIM)*, 2017, pp. 1-6,

SI traceable measurement data from calibrated and characterised radiometers



SI traceable remote sensing reflectance R_{rs} with related measurement uncertainty

Ocean Colour In-Situ Database (OCDB)

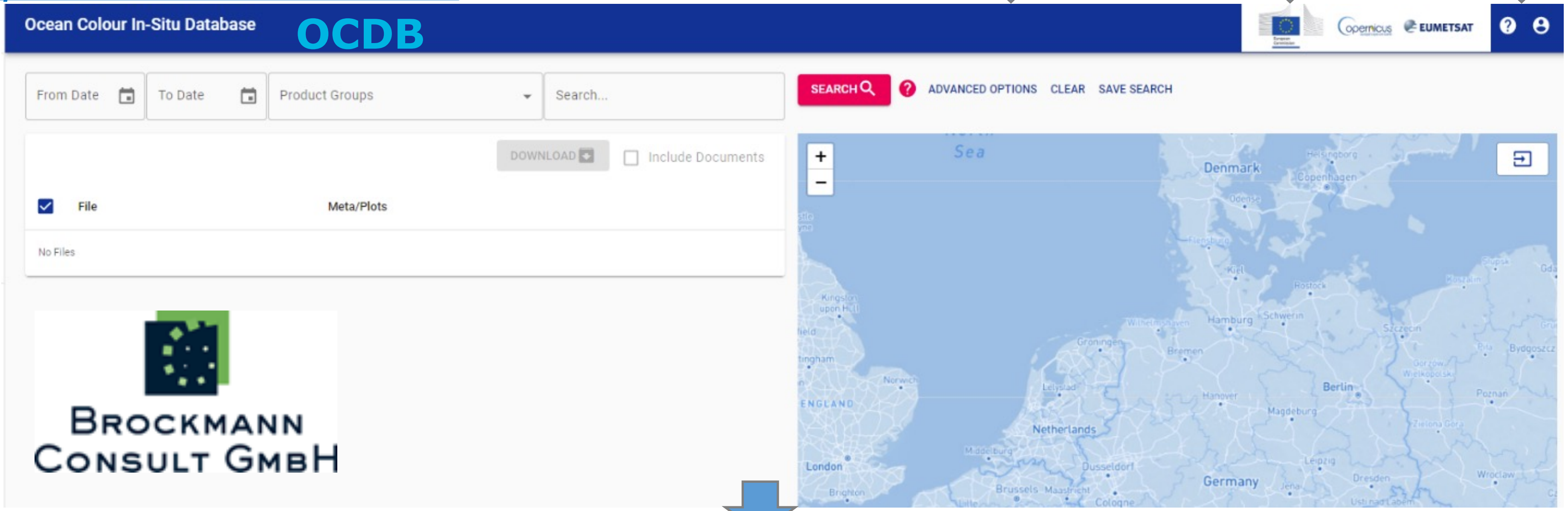
Community Processor

AERONET-OC

MOBY

BGC Argo

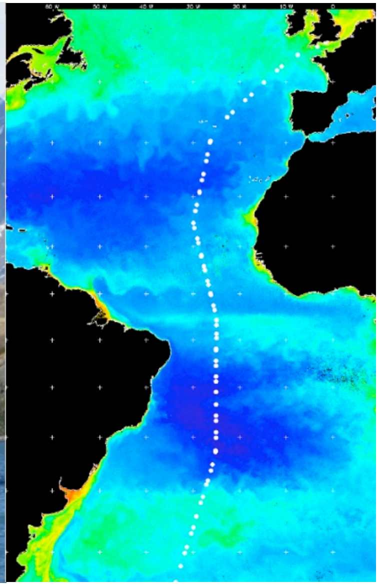
https://ocdb.eumetsat.in



Brockmann Consult GmbH

Data users

AMT



- Provided vital data for the duration of the SeaWiFS mission.
- Served as a developmental and inter-comparison platform for selecting the most accurate ocean colour algorithm for SeaWiFS.
- AMT-1 (1995) … AMT-30 (2023)

AAOT

- Long history of use for satellite ocean colour validation and development. NASA and ESA missions
- It was used throughout the ESA MERIS mission to characterise measurement uncertainties in radiometers for the validation of ocean colour products
- In situ determination of the remote sensing reflectance: an inter-comparison.
- FRM4SOC-1 FICE
- Hosts permanently several OC stations.

Zibordi et al. 2002, 2004, 2006, 2012, …

Field InterComparison Exercise (FICE)

11-20 July 2022,

at Acqua Alta Oceanographic Tower (AAOT), Venice, Italy.

Comparison of L_i, L_t, L_w, E_d, R_{rs}, L_{wn}

Critical review, testing, and feedback on

- Measurement protocols/procedures
- Community processor
- FRMOCnet
- Application of instrument characterisation

Validation of

- SI traceability;
- Uncertainty budgets;
- Aimed uncertainty levels.

Participants: CNR-ISAC, Helmholtz Center Hereon, NASA, NOAA, PML, RBINS, UT

Instruments:

Above water (7): TRIOS RAMSES, TriOS RAMSES G2 sun tracker (SoRAD), Seabird HyperOCR HyperSAS with PySAS robot, HYPSTAR, PANTHYR.

In-water (2): Sea-Bird HyperPro II, TriOS RAMSES floating buoy.