Fiducial Reference Measurements for Satellite Ocean Colour Phase 2

FRM4SOC Phase 2 OCR Workshop proceedings

5 - 7 December 2022

EUMETSAT, Darmstadt, Germany / WebEx

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Acronyms and Abbreviations

Acronym	Description
AAOT	Acqua Alta Oceanographic Tower
cal/char	Calibration and Characterisation
CEOS	Committee on Earth Observation Satellites
ECR	Early Career Researcher
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
ERB	(FRM4SOC Phase 2) Expert Review Board
ESA	European Space Agency
FICE	Field Intercomparison Exercise
FidRadDB	Fiducia Reference Measurement Radiometer Database
FRM	Fiducial Reference Measurements
FRMOCnet	Fiducial Reference Measurements Ocean Colour Network
FRM4SOC	Fiducial Reference Measurements for Satellite Ocean Colour
HCMR	Hellenic Centre for Marine Research
ILAC	International Laboratory Accreditation Cooperation
IOCS	International Ocean Colour Science meeting
IOCCG	International Ocean Colour Coordination Group
IOCCG SLS	IOCCG Summer Lecture Series
ISO	International Organization for Standardization
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NPL	National Physical Laboratory
OC	Ocean Colour
OCDB	Ocean Colour in Situ Database
OCR	Ocean Colour Radiometer
PML	Plymouth Marine Laboratory
QA4EO	Quality Assurance Network for Earth Observation
RBINS	Royal Belgian Institute of Natural Sciences
S3VT	Sentinel 3 Validation Team
SANSA	South African National Space Agency
SoW	Statement of Work
UT	University of Tartu
TO	Tartu Observatory, University of Tartu

Contents

1. Scope

This document corresponds to deliverable D-23, "OCR Workshop Proceedings" of the FRM4SOC Phase 2 project as described by the Statement of Work (SoW) [AD-0] and provides the summary of the OCR Workshop held from 5 to 7 December 2022 at EUMETSAT, Darmstadt, Germany and online on WebEx.

2. Introduction

A workshop on ensuring the quality of in-situ measurements for validation of Earth Observation Ocean Colour satellite data was hosted by EUMETSAT and the FRM4SOC Phase 2 project from 5 to 7 December 2022 at the EUMETSAT Headquarters in Darmstadt, Germany and online on WebEx.

Fiducial Reference Measurements (FRM) are a suite of independent, fully characterised, and metrologically traceable ground measurements that follow the guidelines outlined by the Quality Assurance Framework for Earth Observation (QA4EO) of the Committee on Earth Observation Satellites (CEOS). These FRMs provide the maximum return on investment for Copernicus satellite missions by delivering, to users, the required confidence in data products as independent validation results and associated uncertainties on both ground-based and satellite measurements over the entire duration of a mission.

In 2016 – 2019, European Space Agency funded the first phase of the FRM4SOC (Fiducial Reference Measurements for Satellite Ocean Colour) project to improve ocean colour validation through a series of proof-of-concept tasks. The FRM4SOC Phase 2 - funded by the European Commission - was launched by EUMETSAT in April 2021.

The FRM4SOC Phase-2 OCR Workshop was organised to introduce, collect feedback and seek community consensus in discussions on implementing the principles, guidelines and tools developed during the project. The workshop gathered different interest groups of the ocean colour community (Figure 1) – the leading experts in the field (project Expert Review Board, ERB), representatives of agencies (EUMETSAT, ESA, NASA, NOAA, SANSA), scientists performing the ocean colour in-situ measurements, and manufacturers of ocean colour radiometers (TriOS, Sea-Bird Scientific, CIMEL, Water Insight).

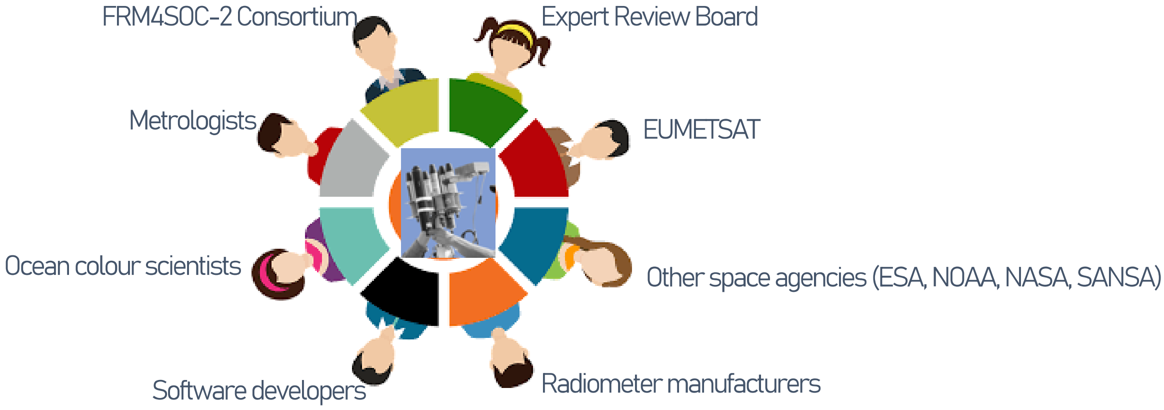

Figure 1. Cross-section of the FRM4SOC Phase 2 workshop forum.

3. Presentations

The workshop was organised as a seminar, with plenty of room for discussion after every presentation to get feedback from the community and bring the community closer to a joint agreement.

The FRM4SOC Phase 2 project has several tasks (Figure 2), serving one overarching goal – to promote the adoption of FRM principles across the OC community (Figure 2).

The main developments presented by the project consortium were:

- General principles of the FRM (existing resources and lessons learned).
- Implementing the principles of FRM by establishing the network of radiometric measurement with FRM quality indicator (FRMOCnet consisting of FidRadDB, HyperInSpace Community Processor, and OCDB).
- Guidelines for
    - calibration and characterisation (cal/char) of radiometric instruments,
    - laboratories performing cal/char of radiometric instruments,
    - operating the radiometers and measurement procedures,
    - evaluating measurement uncertainty,
    - conducting comparison measurements.
- Specifications of minimum requirements for qualification of individual ocean colour radiometers and their measurements as FRM.
- Ocean Colour In-Situ Database (OCDB). https://ocdb.eumetsat.int.
- Calibration and characterisation database (FidRadDB), contained in OCDB.
- HyperInSPACE Community Processor, https://github.com/nasa/HyperInSPACE.
- Overview of laboratory and field inter-comparisons organised during the project.

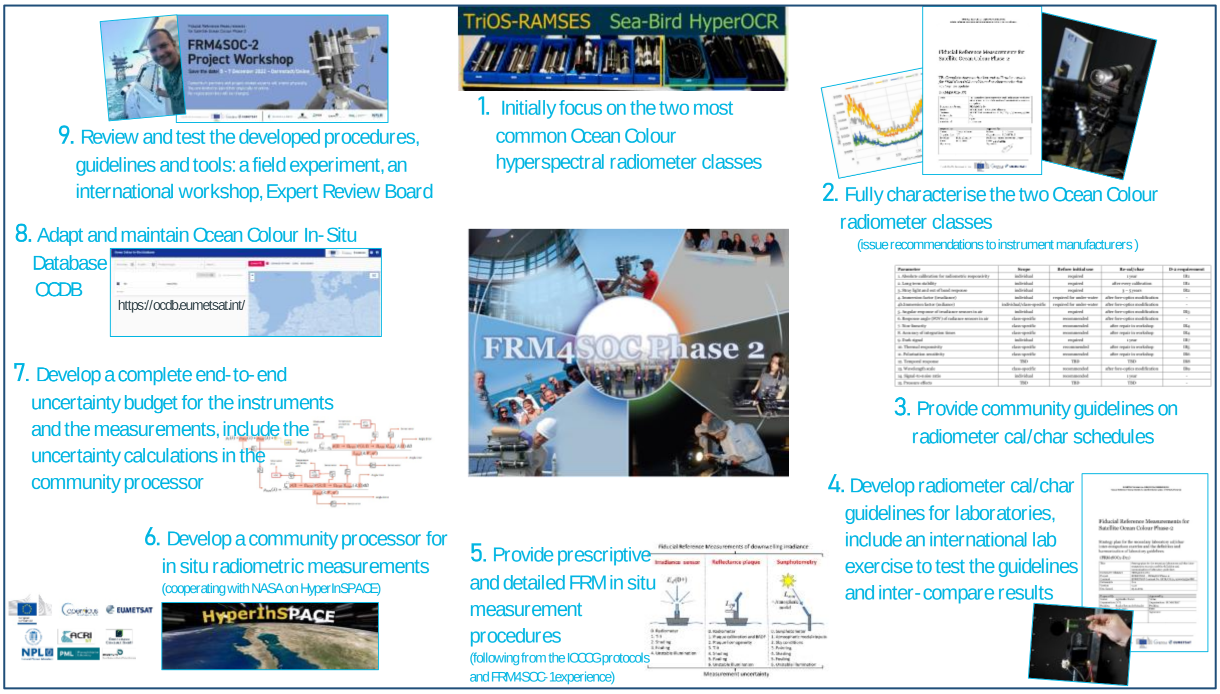

Figure 2. Tasks and flow of the FRM4SOC Phase 2 project:
several tasks, one overarching goal –
to promote the adoption of FRM principles across the OC community.

The following discussions were initiated by two keynotes – “FRM resources and community needs” by S. Bernard (SANSA), “The user perspective” by A. C. Banks (HCMR), and comments from the members of the ERB on reviewed deliverables.

The presentations are available for download at the FRM4SOC Phase 2 project website at https://frm4soc2.eumetsat.int.

Day 1 (05.12.2022) - Field radiometers, Chaired by M. Ligi (UT)

1. Fiducial Reference Measurements for water radiometry – existing resources and lessons learned (R. Vendt, UT).
2. Keynote 1 – FRM resources and community needs (S. Bernard, SANSA).
3. Laboratory guidelines for radiometer calibration and characterisation (I. Ansko, UT).
4. Community guidelines on radiometer cal/char requirements and schedules (V. Vabson, UT).
5. Full characterisation of the field radiometers (TriOS-Ramses and Sea-Bird HyperOCR) (I. Ansko, UT).
6. Long-term strategy plans for laboratory comparison at a global level across agencies and metrological institutions (A. Bialek, NPL).
7. FRM4SOC Phase 2 laboratory comparison (V. Vabson, UT)
8. Minimum requirements for qualification of instruments and their measurements as 'FRM'; possible steps and strategy towards instrument 'FRM certification'; specifications of minimum requirements for manufacturers (K. Ruddick, RBINS).

Day 2 (06.12.2022) – Procedures and tools, Chaired by M. Ligi (UT)

1. Keynote 2 – The user perspective (A. Banks, HCMR)
2. Introduction of the FRMOCnet (FidRadDB, Community Processor, OCDB) (R. Vendt, UT)
3. Guidelines for operating the radiometers and measurement procedures (K. Ruddick, RBINS)
4. End-to-end uncertainty budget for the instruments and the measurements (A. Bialek, NPL)
5. Instrument calibration and characterisation database (FidRadDB) (K. Ruddick, RBINS)
6. HyperInSpace Community Processor practical demonstration, hands-on training (A. Deru, ACRI-ST)
7. In situ measurement database (OCDB) practical demonstration, hands-on training (U. Lange, Brockmann Consult)
8. Results from the field campaign at AAOT – testing the procedures, guidelines and tools (G. Tilstone, PML)
9. Community Processor validation (A. Deru, ACRI-ST)

Day 3 (07.12.2022) – Discussions, Chaired by J. I. Gossn and E. Kwiatkowska (EUMETSAT)

1. Discussion on the conclusion points from previous days between Expert Review Board (ERB) and FRM4SOC Phase 2 consortium.
2. Round table discussions of the developed procedures, guidelines and tools
3. Discussion of how to ensure/support the adoption of FRM principles across the community

4. Discussion points

4.1 Introduction

Reaching FRM quality can be overwhelming, especially regarding new groups or scientists entering the field. There is some confusion about the term FRM among the experts in the area, depending on their background – e.g. laboratory or in-situ personnel. Therefore, the guidelines to produce FRM quality measurements must be clear and as straightforward as possible, also regularly audited "living" documents that consider the new developments in the field. On the other hand, it is not easy to provide universal guidelines, whereas detailed procedures depend on a particular instrument type and configuration used. Most researchers already have procedures and tools for their data management, and they would need the motivation to switch to a different flow. Still, probably the most challenging but unavoidable part of reaching FRM is the evaluation of measurement uncertainty. Here the community is expecting the application of a unified processing scheme and tools (community processor) to support the work of scientists. To address the needs and expectations of the community, the FRM4SOC Phase 2 project aims to ensure the adoption of FRM principles by establishing a network of FRM quality measurements (FRMOCnet). Transferring to new, unified procedures and tools should be as smooth as possible. For example, the input data formats should be defined so that scientists conducting the measurements would only need to make simple adjustments to their files to be ingested into the FRMOCnet system.

At the same time, the requirements need to stay realistic to reach the best possible quality of the measurements. Currently, some unrealistic expectations exist for in-field measurement uncertainties originating from heritage documents, e.g. as suggested once for specific wavelengths in oceanic waters and later extended to other parts of the spectrum and different aquatic conditions without further analysis. Establishing the expectations and requirements for measurement uncertainty realistically is critical to meet the objectives of any mission.

During the two phases of the FRM4SOC project, several types of OCR instruments were calibrated and characterised in the optics laboratory of Tartu Observatory (TO), University of Tartu (UT). The FRM4SOC Phase 2 project focuses on the two most common OCR types – the TriOS RAMSES and Seabird Scientific HyperOCR. Analysing the characterisation results collected in the project was still ongoing, so only the preliminary results could be presented. There was clear feedback from the project ERB and community to find the most significant uncertainty contributions that the OCR must be characterised for, as these characterisation measurements are time-consuming and expensive. Furthermore, there aren't many laboratories capable of doing all these characterisations. There are two things to be studied further to understand what kind of uncertainty sources make significant contributions to account for. First – how much does a parameter in the input influence the overall uncertainty of the measured parameter (in the output of the processing chain)? Second – a large enough (statistical) batch of instruments has to be characterised to conclude class-based uncertainties for a specific instrument type. Only then justified simplifications to the uncertainty budget can be made. A reference radiometer with significantly smaller systematic errors could effectively serve to prioritise OCR characterisation needs.

Another issue raised about class-specific uncertainties was how to define class-based limits. It seems obvious to take a sample from a sensor-type production as a member of one class. Still, different versions/modifications of a specific type exist as manufacturers make improvements over time. Also, one can make improvements during the maintenance of a sensor (e.g. replacing the cosine collector), so relying on the production period is also not straightforward.

Currently, a lot of data is collected about the calibration of OCR. Analysis of the long-term calibration history of the OCR types in focus reveals that, on average, an absolute radiometric responsivity change of 1% per year is typical. It is evident that all the OCR instruments must be calibrated at least once per year and, if possible, before and after a measurement season, but in the case of extensive campaigns, also directly before and after the campaign. General feedback from the user community is that there is a lack of funds to perform regular calibrations and even fewer resources for the comprehensive characterisation of OCR. A common conclusion was that users need financial support for calibration and characterisation activities to comply with the FRM quality requirements. Space agencies need to look for available options to provide such support.

The FRM4SOC Phase 2 project focuses on developing standard processing schemes for above-water radiometry only. Still, the community also has a strong interest in having guidelines and tools for underwater measurements. It was noted that NASA is working on a processor for underwater measurements. However, the task is complicated due to the variety of systems and methods in use. Therefore, the general conclusion from the workshop concerning the FRM4SOC Phase 2 project was that even though there is a significant need for such a tool for underwater measurements, the current study on above-water measurements needs to be completed first.

In the framework of the current FRM4SOC Phase 2, two comparison measurement campaigns were organised – a laboratory comparison for calibration of OCR and a field comparison at the AAOT in the gulf of Venice. There were six participants in the laboratory comparison. In the field comparison at AAOT, seven above-water (2 × TriOS Ramses, 2 × Sea-Bird Scientific HyperOCR, TriOS Ramses G2 with sun tracker alias SoRAD, HYPSTAR, and PANTHYR) and two in-water systems (Sea-Bird Scientific HyperPro II and TriOS Ramses on a floating buoy) were deployed. Analysis of data from both comparisons was still ongoing during the time the workshop was held.

Finally, combining and implementing the knowledge collected during the project activities into community-wide practice needs regular training, especially for the starting scientists/institutes. EUMETSAT is looking into merging these training needs with their already established training programs. Initial training could be implemented, e.g. in the form of winter schools, as summer is already a prime time for measurements.

4.2 FRM general

- FRM definition needs clarification throughout the community.
- The definition of the expected FRM uncertainty threshold must be realistic (dependent on water types and spectral regions).
- Research teams need motivation/reward for switching from current practices to implementing FRM principles, guidelines and community tools.
- Research teams need financial support for implementing FRM guidelines, and tools, calibration of instruments, and participating in comparison measurements.

4.3 Specifications of minimum requirements for qualification of individual ocean colour radiometers and their measurements as FRM

Strategies to achieve operational FRM

- Provided FRM4SOC Phase-2 documents include guidelines on how laboratories, instruments and scientists can achieve compliance with FRM requirements.
- “Certification” (the term used in the project’s SoW) is confusing in the FRM context. Therefore, further communication and documents refer to “gaining FRM quality flag” instead of “FRM certification”.
- **We need to provide operational solutions immediately for users to achieve FRM quality compliance.**
- A possible way to demonstrate compliance with the FRM is “self-declaration” by **following the checklist of requirements and guidelines** as defined in “D-2, Specifications of minimum requirements for qualification of individual OCRs and their measurements as FRM and process for inclusion of any new instrument models and measurements in the FRMOCnet”.
- **Verification on compliance** with FRM– by whom and how?
    - It is not feasible to establish/engage an independent evaluation body (e.g. certification bodies, commissions, agencies).
    - Research groups/institutions must be able to prove compliance with the FRM requirements at all times. E.g. regular presentations at relevant community forums (workgroup meetings, e.g. S3VT, conferences).
- **Regular participation in comparison and training events**.

- Dedicated training activities are needed to ensure uniform understanding and implementation of FRM principles and procedures. Participating in focused training events can be interpreted as a part of the quality assurance process described in the projects' SoW as "FRM-certified measurements".
- Regular participation in comparisons is an essential means of quality assurance and control.
- Regular training programs must be initiated.
  - User group meetings.
  - Dedicated summer/winter schools.
  - Align the training with existing events.
    (ECR target, EUMETSAT program, IOCCG IOCS and SLS).
  - Combine training with comparison events.
  - Combine training with actual field campaigns (e.g. participation of supervisors).
- Provide users with standalone learning materials (videos, publications, guidelines).

- **Establish supporting activities**:
  - Provide supported (paid) calibrations for institutions making FRM measurements.
  - Provide financial support to participate in training and comparisons.
  - Establish a pool of (calibrated) instruments for a loan.
  - Develop and apply a portable travel standard instrument – a reference radiometer acting as a community-accepted reference for in-field measurements.

4.4 OCR calibration and characterisation

General

- The proposed OCR cal/char program and schedule are provided in "D-8, Guidelines for individual OCR full characterisation and calibration."
- Guidelines on methods and instrumentation are provided for laboratories performing cal/char in "D-12, Harmonised cal/char lab guidelines, including lab protocols for FRMOCnet OCR models".
- Laboratories performing calibration and characterising of OCR must have implemented a quality management system according to the ISO 17025 standard or equivalent (valid ILAC recognised accreditation preferred).
- Extensive work on cal/char of two common OCR models (TriOS Ramses and SeaBird Scientific HyperOCR) over preceding studies, including the FRM4SOC Phase 1 and 2, is summarised in "D-7, Complete characterisation and calibration results for FRMOCnet OCR models and re-characterisation routine: an update."

- Analysis of the long-term calibration history of the OCR types in focus reveals that, on average, an absolute radiometric responsivity change of 1% per year is typical. It is evident that all the OCR instruments must be calibrated at least once per year and, if possible, before and after a measurement season, but in the case of extensive campaigns, also directly before and after the campaign.

Requirements for OCR

- Specification of performance parameters of OCR as manufacturer's specification is needed.
- International standards/recommendations specifying the requirements for the essential properties of OCR are needed.
- Guidelines on selecting an OCR with a suitable specification for a measurement task are needed for users.
- "D-27, Specifications of minimum requirements for qualification of OCR instruments as FRM instruments for manufacturers" (not presented at the workshop)

Approach for characterisation

- The terms "individual" and "class-based" instrument characterisation are rather confusing – an explanation in presented documents would be needed.
- Individual characterisation of radiometric instruments gives the most objective input information to the overall uncertainty budget.
- However, instrument users need to understand which individual characterisations and additional measurement information is absolutely required and how to apply the characterisation results.
- Individual characterisation of instruments
    - is too expensive for users,
    - is time-consuming,
    - requires significant resources (infrastructure and expert personnel),
    - is not readily available due to a lack of cal/char laboratories capable of performing such characterisations,
    - may have an insignificant contribution to the overall uncertainty budget of the target measurement quantity.
- Therefore, a practical solution is needed for users.

  Apply the class-based approach for as many characterisations as possible. For that purpose:

    - Develop principles on which conditions the class-based characterisation can be used and how related class-based corrections and uncertainties can be applied (included in the HyperInSpace Community Processor).
    - Study of overall uncertainties for particular instrument configurations and environmental conditions and, as a consequence, prioritise individual instrument characterisations having the most significant impact.

- Develop guidelines on how to apply corrections and uncertainties from individual characterisations (included in the HyperInSpace Community).
- The requirements for cal/char frequency shall be based on monitored long-term trends and discovered specific effects.
- Provide a pool of calibrated and characterised instruments for a loan.
- Provide financial support (supported calibration of radiometers) to users.

Availability of cal/char services

- Pooling of resources is recommended to ensure the availability and homogenisation of required calibrations and characterisation (by selecting one/a few reference laboratories for the FRM network).
- Spare reference instrumentation is needed to avoid gaps in service availability, provide inherent quality control (comparisons), and validate uncertainty budgets.
- In addition, the presence of several cal/char laboratories is needed to
    - avoid gaps in the availability of service,
    - provide means for quality control (comparisons) and validation of uncertainty budgets,
    - provide balance in network homogenisation (using the same type of reference instruments) vs testing new equipment with the evolvement of technology (e.g. retirement of FEL lamps and engagement of new generation light sources).
- Universal guidelines for establishing and running a radiometric cal/char laboratory are provided. Such guidelines support emerging of new FRM-compliant laboratories to provide the service and thus also help to avoid a potential monopoly. However, considering the small customer niche and high costs of running an FRM-compatible cal/char lab, it is not likely to have numerous active laboratories in the area in future.

Communication with instrument manufacturers

- Close communication between cal/char laboratories, the FRM activities and instrument manufacturers is needed to ensure the transfer of essential knowledge and updates.
- Manufacturers have occasionally changed elements in producing instruments of one type over time (e.g. the material of cosine diffuser). It must be evaluated if such changes can be handled in the class-based characterisation approach.
- Characterisations of radiometers performed in the project suggest recommendations for improving the design of instruments (e.g. material of cosine diffuser, adding internal temperature sensor, etc.).

4.5 Comparison measurements

- Comparison measurements (either laboratory or in-field) are essential for quality control and validation of developed guidelines, procedures, uncertainty budgets and tools.
- Organising comparisons requires many resources from both sides – organisers and participants. That includes human effort, instruments, facilities, travel, transport, customs, etc.
- Financial support for organising and participating in comparisons is needed.
- The ISO 17025 standard requires laboratories with a compliant quality management system to participate regularly in comparison measurements.
- The period of participation in laboratory comparisons is set by a laboratory's operational quality management regulations – usually from 3 to 5 years.
- Not many laboratories can participate in the comparison for calibration of OCR (6 in the projects' comparison), and only a few laboratories perform characterisations.
- Depending on the complexity of the comparison and the number of interested laboratories, the comparison can be organised either in round-robin or bi-lateral form.
- Appointing a reference institute to organise regular comparisons would ensure sustainability and the required competence for such activity.
- Comparisons also serve for education and development – ensure uniform understanding and application of procedures.
- Comparisons help to identify instrument, system, procedure and method-related aspects that require improvement. Also, facilitate high-quality validation of data.
- A reference radiometer with significantly smaller uncertainty would provide the SI traceable comparison reference values. Development/engagement of such a reference instrument should be considered.

4.6 Operating the radiometers and in-situ measurement procedures

- It is aimed that the guidelines developed in the project will support users in collecting FRM-quality data.

- The guidelines must be understood and implemented uniformly.
- Currently, the procedures handle above-water measurements only. There is also a strong interest from the community to have uniform guidelines and tools for in-water measurements. However, due to the variety of methods and instruments in use, developing such universal means for in-water measurements is still too complicated.

4.7 Measurement uncertainties and the community processor

A tool (community processor, Figure 3) to propagate evaluated uncertainties has been developed. The system has two processing branches to follow depending on the available characterisation data:

- **Default branch**
    - Absolute calibration with uncertainty is available, but no characterisation data. No corrections will be applied, and class-specific uncertainties will be propagated.
    - Absolute calibration without uncertainty statement – the measurement is flagged as not compliant with FRM. However, data is still processed with class-specific uncertainties, and no corrections are applied.
    - Data submission with no reference to calibration is rejected.
- **FRM branch**
- Calibration and characterisation data are available with related uncertainties. Instrument-based corrections are applied, and residual uncertainties are propagated.
- A combined processing flow would be needed for a (probably most common) case when only partial characterisation data for an instrument is available. That option will be a part of future developments after the FRM branch is finished.
- Work on the estimation of uncertainty contributions is still ongoing. We have a growing knowledge base and test results of instrument characterisation tests used to estimate instrument-related errors robustly. Instrument-based corrections for most instrument-related effects (FRM branch in community processor) are being developed. Sometimes the approach has to be changed as new characterisation data becomes available.
- Due to the complexity of the measurement, we have yet to be able to evaluate some uncertainty contributions.
- The volume of the current study does not involve uncertainties due to the air-water interface reflection, platform perturbations, and temporal and spatial variability.

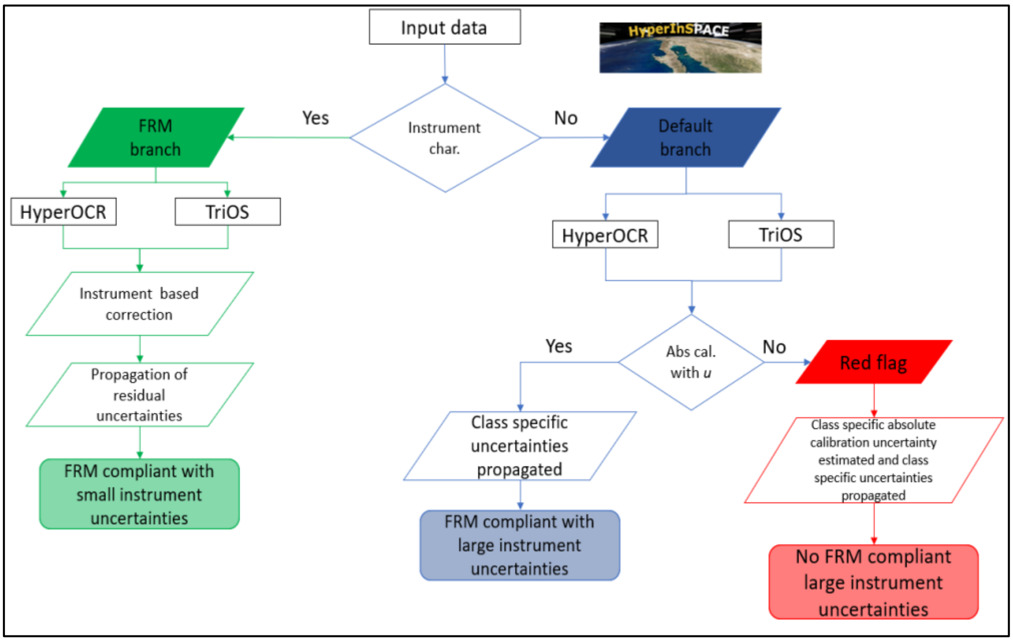

Figure 3. Evaluation of uncertainties in the HyperInSpace Community Processor.

- The first aim in handling the environmental and platform-related uncertainties is to define the conditions that qualify the measurements as FRMs.
- Comprehensive testing and validation of the full functionality of the community processor for different use cases, water types, and environmental conditions with simulated and actual measurement data are needed. This activity could be included in the optional extensions of the FRM4SOC project.
- The developed community processor is open for use and testing for the community.
- Practical guides on handling uncertainties and using the community processor will be provided to the community.

4.8 FRMOCnet

The FRM4SOC Phase 2 project aims to ensure the adoption of FRM principles by establishing a network of FRM quality measurements (FRMOCnet). The FRMOCnet consists of the radiometers database (FidRadDB), HyperInSpace community processor, and in situ ocean colour database (OCDB), Figure 4.

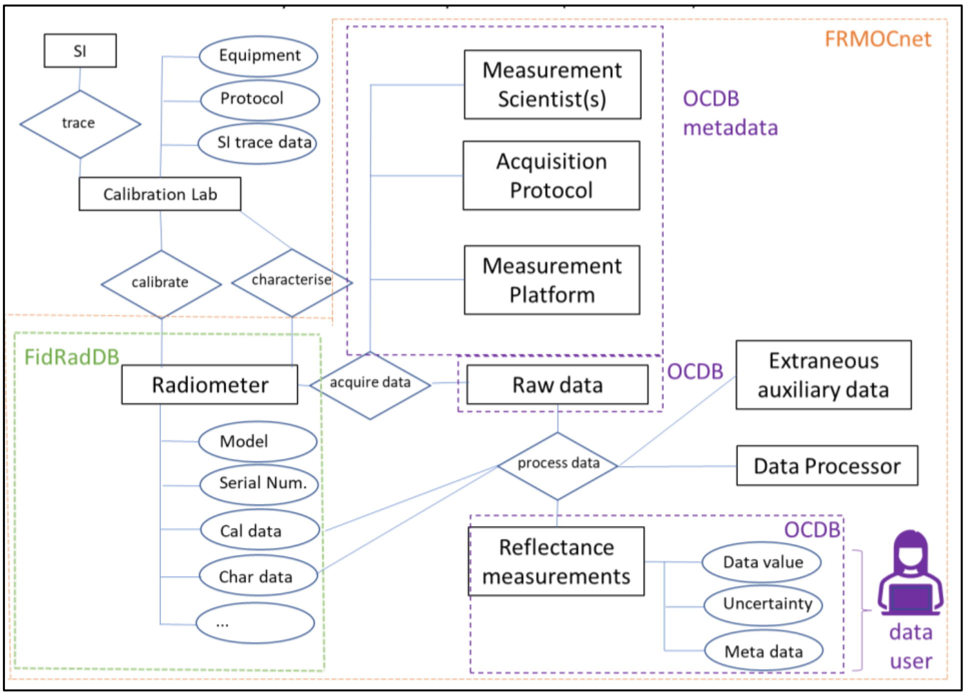

Figure 4. Simplified FRMOCnet entity-relationship model.

The main benefit of the developed network is that all needed data is kept together, processed uniformly, and the data formats match at each output/input of the flow (Figure 5). The collected data in the OCDB will include a flag for FRM compatibility. The database is compatible with the SeaBass data format. In future, the whole process can be automated. During discussions, it was suggested that making the data NetCDF-CF compliant may broaden the uptake by other user communities (e.g. the modelling community is also interested in marine products for data assimilation).

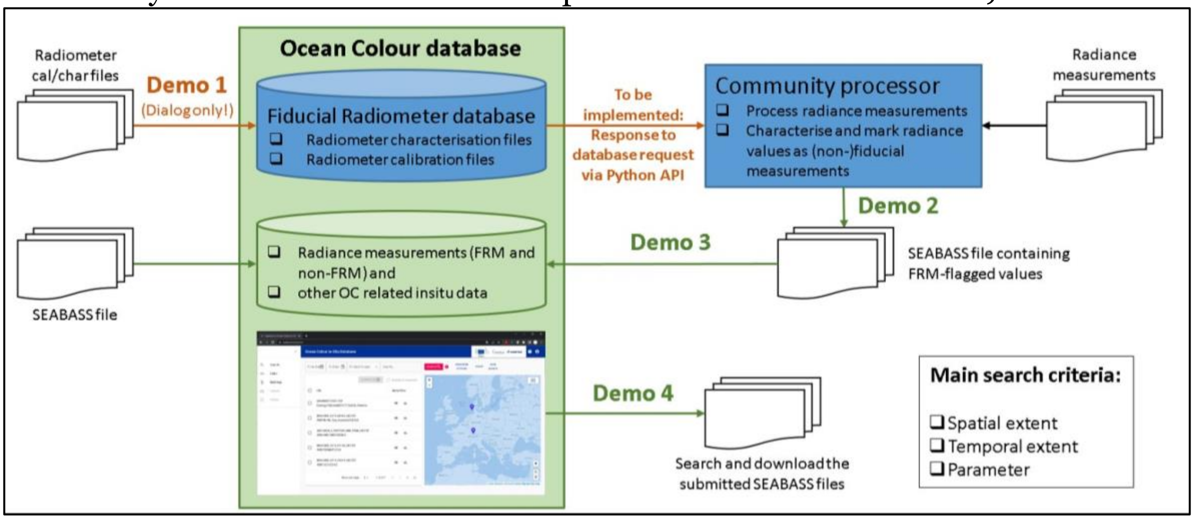

Figure 5. Data flow in the FRMOCnet.

4.9 User's perspective

- Users need guidelines on which individual instrument characterisations are required (prioritised).
- Users look for guidelines on how to apply corrections from characterisation.
- The guidelines and tools (FidRadDB, HyperInSpace Community Processor, OCDB) provided by the FRM4SOC project intend to address the points above.
- Users need more funding for the calibration and calibration of instruments.
  - Financial support is needed.
  - A pool of calibrated and characterised instruments for the loan would be helpful.
- More calibration laboratories are needed.
- Guidelines were requested on processing final matchup products and including uncertainties in satellite validation. Nonetheless, the focus of FRM4SOC-2 is put on in situ measurements.

4.10 Manufacturers' perspective

Manufacturers of radiometric instruments are interested in close cooperation with the user community and the FRM4SOC project.

- Reviewing and giving feedback to the developed guidelines.
- Being updated on requirements for calibration and characterisation of instruments.
- Participating in comparison measurements.
- Collecting feedback from users on possible changes in the behaviour of instruments.
- Providing feedback on changes in production over time. E.g. change of the material for cosine diffusers.
- TriOS assured that the factory replaces cosine collectors and re-characterises angular response for Ramses instruments if requested.
- Sea-Bird Scientific assured the continued production of HyperOCR instruments.
- CIMEL presented a CE600 radiometer – a powerful, thoroughly characterised, though expensive instrument.
- Future collaboration between manufacturers and the FRM4SOC project team is planned to ensure the compatibility of instrument file formats with the developed community processor and databases.
- Critical to the successful implementation of FRM principles is the application of SI-traceable metrology standards for calibration and the metrological end-to-end uncertainty budget on instruments and measurements

5. Conclusions

5.1 The following topics, guidelines, and tools were presented to the OC community.

- General principles of the FRM (existing resources and lessons learned).
- Implementing the principles of FRM by establishing the network of radiometric measurement with FRM quality indicator (the FRMOCnet consisting of FidRadDB, HyperInSPACE Community Processor, and OCDB).
- Guidelines for cal/char of radiometric instruments.
- Guidelines for laboratories performing cal/char of radiometric instruments.
- Guidelines for operating the radiometers and measurement procedures,
- Guidelines for evaluating measurement uncertainty,
- Guidelines for conducting comparison measurements.
- Requirements for qualification of instruments as an 'FRM' instrument.
- Calibration and characterisation database (FidRadDB).
- Ocean Colour In-Situ Database (OCDB) https://ocdb.eumetsat.int.
- HyperInSPACE Community Processor, https://github.com/nasa/HyperInSPACE.
- Overview of laboratory and field comparisons organised during the project.

5.2 Agreements on activities until the end of the main part of the FRM4SOC Phase 2 study.

- Implement the FRMOCnet consisting of FidRadDB, HyperInSpace Community Processor, and OCDB as presented in Figure 4 and Figure 5 and become "pre-operational", at least in terms of FRMOCnet.
- Complete the missing FRMOCnet links.

FidRadDB: Conclude the solution on submission and storage of cal/char files.

FidRadDB/OCDB:

- Ingest and publish FICE AAOT measurements.
- Ingest and publish instrument calibration and characterisation data from FRM4SOC.
- Provide data converter from manufacturer to FRM4SOC format.

OCDB: Solve the issues with ingestion and searching tools that have the highest impact on users' engagement.

HyperInSpace Community processor:

- Provide the ability to query FidRadDB/OCDB to ensure smooth ingestion of calibration files,
- Solve some reporting/plotting issues.
- Included FRM flag to the SeaBASS format output.
- Include the Lee 2011 BRDF approach to the FRM branch.
- Look for possibilities of creating NetCDF-CF compliance.

5.3 Suggestions for the FRM4SOC Phase 2 optional extension 1.

At the FRM4SOC Phase 2 workshop.

- Many examples of developing guidelines and tools for implementing the FRM principles were presented.
- Several good ideas for community building were proposed.
    - Bring together and keep good communication (regular meetings) between all active groups (Figure 1).
    - Bring together resources (facilities, instruments, tools) and opportunities (cruises, projects, etc.).
- However, the clear conclusion from the workshop was that the developed resources need to be brought to the community as soon as possible – i.e. aim towards validation of satellite missions (Copernicus in particular) and demonstrate the FRMOCnet operations in the FRM4SOC Phase 2 follow-on activities.
- Although the original statement of work of FRM4SOC phase 2 optional extension 1 focuses on methods and uncertainties for "complex waters", EUMETSAT agrees to re-assess the tasks to realise the ideas and conclusions from the workshop.
- The key points for adjusted focus in optional extension 1 are suggested as follows:
    - **Remaining gaps in the uncertainty evaluation.**
    - **Comprehensive testing and validation of full functionality of the community processor.**
    - **Community engagement.**
    - Update of procedures.
    - Maintenance and updates of FRMOCnet.
    - Focus only on above-water measurements and postpone the developments on in-water and bio-optical measurements.

Remaining gaps in the uncertainty evaluation

- Application of the correction for the air-water interface reflection.
- Effect of optical perturbations from the mounting platform/ship.
- Specific water type-related uncertainties.
- Evaluation of the combined effect of OCR characterisations on the overall uncertainty budget.
- Updates on instrument characterisation (integration time, pressure effects, temporal response).

Comprehensive testing and validation of full functionality of the community processor

- Analysis with community-measured data collected using fully characterised instruments and simulations for different water types, environmental conditions, and locations.
- Reach a better understanding of the combined effect of OCR characterisations on the overall uncertainty budget, thus leading toward more class-based instrument characterisations.
- Provide recommendations on selecting values for data filters.

Community engagement

Going "operational" and supporting users to implement the FRM flow.

- Organise dedicated **training** events
  - in workshop format (FidRadDB, CP, OCDB, procedures) and
  - hands-on in actual in-field conditions.
    (understanding and application of procedures – FRM flagging),
  - combining training events with dedicated comparisons
    (e.g. FICE-AAOT) and suitable user campaigns.
- Provide **project-supported calibrations** for instrument users.
  - The project would calibrate a limited number of radiometers (~5 sets) to the participants of the FICE-AAOT comparison.
  - In return, the users shall process the data with HyperInSpace Community Processor and deliver the data to OCDB.
  - Instruments characterisations and shipping are to be funded by instrument users.
- Establish a **pool of calibrated and characterised instruments** for a loan.
  - A service for the community with a requirement to process the data with HyperInSpace Community Processor and deliver the data to OCDB.
  - JRC has kindly offered to provide a complete TriOS system
    (3 instruments: two radiance units, 1oneirradiance, connection cables, data logger, a rotating stage, and pneumatic pull)
  - With this system, the project can set the first proof-of-concept of the instrument pool and offer the service to the community.
  - The project would provide the pre- and post-deployment calibration and characterisation of the pool instrument system.
  - Instrument shipping is to be funded by users.
  - To avoid misuse of the system and gain implementation of the FRM principles, the users of the pool instruments must first pass FRMOCnet training.
  - The pool could be advertised through https://frm4soc2.eumetsat.int, and a submission form would be available.

    - Criteria for selecting an instrument pool user from applicants and terms of the loan shall be developed.
- **Field Comparison Exercise (FICE)**
    - The comparison exercise at the AAOT would focus on implementing uniform understanding and applying FRM principles, procedures, and the FRMOCnet by combining the measurement campaign with training activities.
    - The training would combine the measurement sessions at the AAOT with on-shore workshops. Possibly in several rotating groups to involve more participants (e.g. three groups of 5 trainees rotating in 3 days).
    - Criteria for selecting participants for the comparison exercise shall be developed (e.g. priority should be given to early career scientists, postdocs and PhD students).
    - A subset of participants not having FRM-compliant OCRs could use the instruments from the instrument pool.
    - Measurement data collected during the FICE-AAOT would be used for testing and validating the elements of the FRM4OCnet.
    - Options to develop/engage a portable standard instrument to act as an in-field reference (radiometer) should be evaluated.

Update of procedures

Update the current version of measurement procedures (D-6)

- with details on Sea-Bird Scientific HyperOCR instrument and
- possible aspects of different water types.

Maintenance and updates of FRMOCnet

Maintenance and updates for sustained operation and developments in the project as described in the SoW

- FidRadDB,
- OCDB,
- HyperInSpace Community Processor.

In addition, the project would benefit from

- Assignment of DOIs to the OCDB entries;
- Publishing peer-reviewed articles on highlights of the FRM4SOC Phase 2 achievements.