Challenges on Optical Remote Sensing for Marine Litter and Floating Matter

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Introduction

Optical remote sensing plays an increasingly important role in monitoring floating matter. It complements existing techniques with the added-value of wide areal coverage and revisit times often missing in widely used instruments or available platforms. Spectral measurements (i.e., visible, near-infrared, short-wave infrared) from on satellite, airborne and handheld sensors have been crucial in demonstrating and exploring ways to detect, classify, identify and quantify floating matter (i.e., natural, anthropogenic), in the last decade. The main scope of interest in this field includes developing methodologies to better distinguish the diverse floating materials found in the natural environment and applying these methods to relevant monitoring efforts. The workshop session aimed to discuss the strengths, limitations and future directions with key areas of interest namely (a) Enhancing Spectral Differentiation - Refining multispectral and hyperspectral imaging to distinguish various floating materials based on their unique spectral signatures. (b) Improving Retrieval Algorithms - Development and validation of algorithms that leverage remote sensing optical data to detect and track riverine, coastal and offshore floating matter in general, and marine litter in particular. (c) Monitoring Spatiotemporal Variability - Establishing long-term datasets to analyse seasonal and regional trends and their links to environmental drivers. (d) Integrating AI for Automated Detection - Applying machine learning techniques to classify floating matter in optical imagery with higher precision. (e) Validating Remote Sensing Observations - Conducting in-situ measurements and radiometric analyses to enhance the accuracy of remote sensing data interpretation. (f) Assessing the Impact of Observational Conditions - Understanding how environmental factors and observation conditions affect floating matter detection in optical imagery. (g) Supporting Mitigation Strategies - Providing insights for policymakers, environmental agencies, and marine conservation efforts to foster stakeholder engagement in technological advancements.

Session Summary

Overview: The breakout workshop was coordinated by the members of the Task Force on Remote Sensing of Marine Litter and Debris (TF-RSMLD[1]). A brief history on the topic,

[1] https://ioccg.org/group/marine-litter-debris/

milestones and living resources available through the TF-RSMLD were presented as part of the welcome note. The urgency of harmonising the terminology was reiterated and highlighted using initiatives to establish recommended glossary supported by TF-RSMLD (GIZ, 2023; Goddijn-Murphy et al., 2024). An agency specific presentation provided updates on the past and currently ongoing projects funded by NASA. Three Early Career talks complemented the workshop goals of gathering insights into related ongoing research covering various methodologies (i.e., deep learning, spectral based indices/anomalies, numerical drift models) and revealing current challenges (e.g., data, technology). Our open discussions (**Figure 1**) with in-person and online experts covered multi-modal remote sensing technologies relevant for the multiscale and multi-platform monitoring of floating to slightly submerged matter in all aquatic environments. Floating matter discussed included anthropogenic materials mostly plastic waste and Sargassum among the diverse materials found in mixed accumulations at sea or inland water systems. Participants also put an emphasis on the use of alternative sensing techniques as it was seen as valuable in resolving gaps in capabilities of standard techniques, in line with stakeholder priorities.

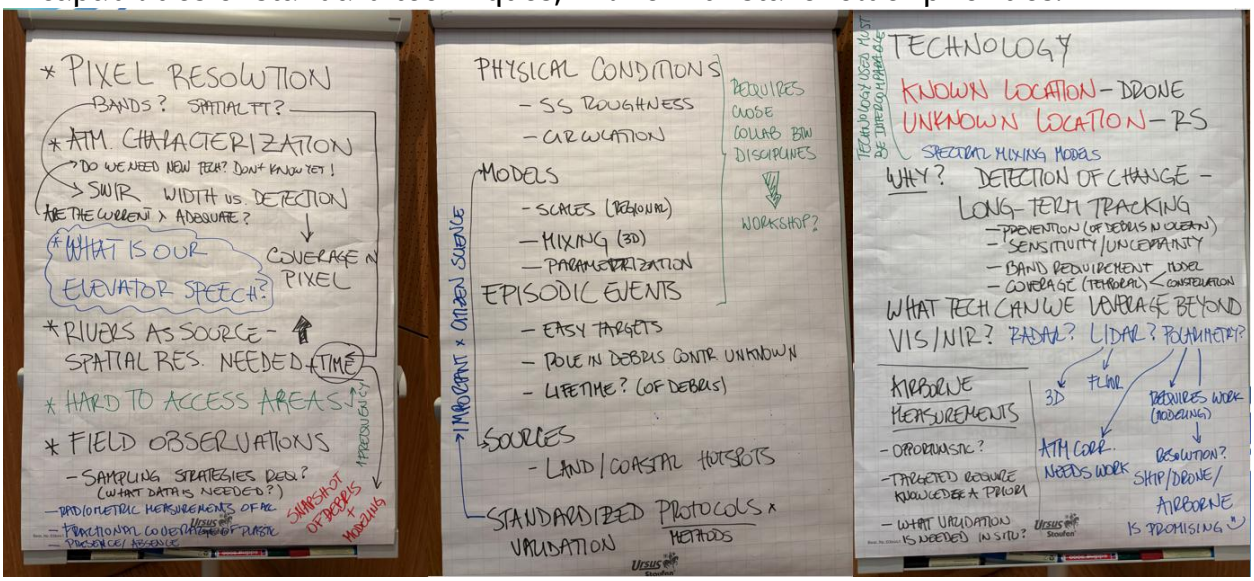

Figure 1. Summary of the interactive discussion during the workshop (Courtesy of Laura Lorenzoni).

Key questions: (i) How can optical remote sensing techniques be optimized to enhance the spectral differentiation of various floating materials, particularly marine litter, in complex environments? (ii) What are the main challenges in developing and validating retrieval algorithms for detecting and tracking floating matter, and marine litter in particular, and how can AI and machine learning contribute to improving accuracy? (iii) How can remote sensing data be effectively integrated with in-situ observations and models to support long-term monitoring, reporting, and mitigation strategies for marine litter pollution?

Agenda of Breakout Session

1430 - 1435 Introduction and goals of the session (Martinez-Vicente and Garaba)
1435 - 1450 Status updates of ongoing and completed research projects supported by NASA (Laura Lorenzoni, Chuanmin Hu - online, Heidi Dierssen)
1450 - 1505 Early Career flash talks
- Post-storm litter detection in reservoirs: Comparing machine learning and algebraic spectral approaches (Tomás Acuña Ruz)
- Marine plastic pollution: From remote detection to hydrodynamic models (Laura Corbari)
- Machine and deep learning framework for pelagic sargassum detection and fractional cover estimation (José Manuel Echevarría Rubio)

1505 - 1530 Interactive open discussion
1530 - 1600 Coffee Break
1600 - 1700 Interactive open discussion
1700 - 1730 Summary of recommendations

Review of Existing IOCS Recommendations

The following recommendations were compiled from the fifth IOCS meeting in 2023
1. Develop of the remote sensing of marine litter and debris roadmap. **What**: Living open-access document to be reviewed and revised every 2 years. **Who**: TF-RSMLD with the support of Space Agencies and stakeholders. **When**: Draft expected April 2024. **Update 2025**: Open issue now refined in [**IOCS25-R1**] and [**IOCS25-R2**].

2. Develop hyperspectral library and database. **What**: Curated open-access hyperspectral reference library of diverse endmembers for algorithm development and sensitivity analyses from controlled experiments, and in-situ observations with matchups or reference RGB photos. **How**: Data mining and community contributions (e.g. Ocean Scan, TF-RSMLD one stop website). **Who**: TF-RSMLD with the support of all stakeholders. When: Ongoing and draft version expected October 2024. **Update 2025**: A library collection is ready via an ESA-NASA supported activity (Ohall et al., 2025) and refined in [**IOCS25-R3**].

3. Define sampling protocol. **What**: Living open-access protocols for remote sensing of floating matter from ships-of-opportunity, citizen science, or upcoming agency campaigns. How: Stakeholder engagement to define essential metadata, and affordable, easy-to-use, and sustainable sensors for databases. **Who**: TF-RSMLD with the support of all stakeholders. **When**: First draft expected June 2024. **Update 2025**: Open issue now refined in [**IOCS25-R1**] to [**IOCS25-R3**].

4. Engage stakeholders and downstream users. **What**: Create a published document to communicate the realistic capabilities and limitations of relevant remote sensing technologies with regards to detection, identification, quantification, and tracking applications through community generated infographics and terminology. **Who**: TF-RSMLD with the support of all stakeholders. **When**: Ongoing and linked to [**IOCS25-R2**].

5. Get priorities from stakeholders. Determine the "why?" or "so what?"—why do the stakeholders care? Determine how stakeholders want the information, what actions they plan to take from the data products, and their management outcomes, to dictate the level of data/information. Assess the impact story—determine the stories that can be highlighted to display the effects of science on mitigating pollution impacts. **What**: Expected deliverables could be in the form of an article on the lessons learned from stakeholder interviews. **Who**: The article is anticipated to be generated by the TF-RSMLD. **When**: Towards the end of 2024. **Update 2025**: Open issue now refined in [**IOCS25-R1**] and [**IOCS25-R2**].

New IOCS Recommendation(s)

The proposed new refined recommendations complement the list from IOCS 2023.

[**IOCS25-R1**] Need for a sustainable strategy for supporting remote sensing of floating matter initiatives. **What**: The strategy should be defined through specific funding calls to support a coordination action including a series of workshops for the co-creation of the strategy. There is need to have specific funding for continuous support of experts pre- and post-workshop leveraging existing expert groups (e.g., IOCCG TF-RSMLD, IMDOS). A status-review workshop is required to identify and chart a way forward to address key points namely (i) revisiting the initial policy and science requirements for floating litter from previous efforts (Martínez-Vicente et al., 2019) as well as community discussions e.g., SPARSE Workshop 2025[2], Ocean Optics 2024[3], IOCS Meeting 2023[4], Remote Sensing of Marine Litter Workshop[5] (ii) harmonising concepts, create translation tables for terminology to define metrics of interest for retrieval from satellites (e.g., concentration vs surface coverage), sampling protocols, methodologies as well as essential metadata (iii) assess techniques that provide a finer definitive distinction of marine litter from diverse floating matter (iv) exploring the sampling options to produce valuable in situ data to advance remote sensing through mid-to-large scale suborbital field campaign supported by citizen science and (v) defining a roadmap. **Who**: Space agencies are urged to continuously support existing resources (e.g., IOCCG TF-RSMLD) to further engage the stakeholders including IMDOS, Early Careers for continuity and advancement on remote sensing of floating matter. **When**: Short-term workshops for upcoming field campaigns. Mid-term for establishing tiger teams or working groups for the development and delivery of a roadmap. Long-term implementation of the roadmap by the agencies.

[**IOCS25-R2**] Foster inter and multidisciplinary active collaboration and continuous engagement. **What**: Supporting activities that aim to have input/outcomes leveraging diverse expert communities (e.g., citizen science, ocean colour, numerical modelling,

[2] https://sites.google.com/unisi.it/sparse2025/home
[3] https://oceanopticsconference.org/
[4] https://iocs.ioccg.org/wp-content/uploads/2023/05/bw-description-rsmld.pdf
[5] https://atpi.eventsair.com/remote-sensing-of-marine-litter/

industry, civil society, non-profit organisations, environmental agencies) for holistic remote sensing solutions. Further engage and extend membership of the IOCCG TF-RSMLD to facilitate renewal of members, incorporate more Early Career researchers as well as advance interactions with diverse expert communities (e.g., FutureEarth, IMDOS). **Who**: IOCCG TF-RSMLD in coordination with the IOCCG Executive Committee with the specific support from Space agencies as detailed in [**IOCS25-R1**]. **When**: Short term by adding inter and multidisciplinary elements in ongoing activities and planned funding calls.

[**IOCS25-R3**] Sustain the extension of open access fiduciary and high quality open-access reference libraries through an evaluation of multimodal approaches. **What**: Support with funding calls of studies with field campaigns that explore multimodal technologies (e.g., SAR, LIDAR, polarimetric, optical) and multiscale platforms (e.g., drone, aircrafts, CubeSats, satellite). Evaluation of proposed concept missions (Livens et al., 2022; Martinez-Vicente, 2022; Cózar et al., 2024) must include known hotspots (e.g., dams, deltas, ocean gyres), and areas linked to discharges from extreme weather events (e.g., tsunamis, flooding, accident spills). In situ sampling of target materials should cover where possible the diversity of floating matter of both natural and anthropogenic items. Datasets should follow a FAIR policy. **Who**: Space agencies with the expert support of existing expert communities (e.g., IOCCG TF-RSMLD, IMDOS). **When**: Short to mid-term.

[**IOCS25-R4**] Prioritize and facilitate tasking requests of satellite imagery where possible after extreme events and/or during dedicated field sampling. **What**: Space agencies to expedite quota request proposals by scientific community to task commercial multimodal satellite missions for open-access representative datasets documenting diverse floating matter especially after extreme weather events (e.g., tsunamis, flooding). **Who**: Space agencies. **When**: Short to mid-term.

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Figure 2. A group photograph of some of the in-person attendees including the six online participants.