ESA Discovery and Preparation – OSIP
Campaign on Remote Sensing of Plastic Marine Litter

AIR-SOS Executive Summary

AIRBORNE & SATELLITE OBSERVATION STRATEGIES FOR MARINE LITTER MONITORING

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PML Plymouth Marine Laboratory

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CONTRACT REPORT

The work described in this report was done under ESA contract.

Responsibility for the contents resides in the author or organisation that prepared it.

CONTENTS

ACRONYMS

AIR-SOS	Airborne & Satellite Observation Strategies for marine litter monitoring
SFX	SkyfloX
PML	Plymouth Marine Laboratory
AW	Aufwind
GA	General Aviation aircraft
ORCA	Optical and Radiofrequency Constellations on Aircraft
DOCS -2	SkyfloX Pilot project for Demonstration of ORCA constellation Services (ongoing)
FoV	Instrument Field of View
FR24	Flightradar24 (source of flight data)
MAIA	Multispectral sensor (9 bands)
Micasense	Multispectral sensor (5 bands)
Lake Buccaneer	Seaplane used in this project

1 Introduction

1.1 Problem statement and project summary

Marine Litter is a global issue and can be found in all the seas from the equator to the poles, and in freshwater systems, such as rivers and lakes. Most of the marine litter is plastic and, as plastic production continues to increase, greater impacts are expected. Plastic marine litter dramatically affects marine life and ecosystems and has a great economic impact

The emerging field of satellite remote sensing for plastic detection is promising, but reliable *in situ* validation data are required to improve algorithms and approaches.

SkyfloX, Plymouth Marine Laboratory and Aufwind proposed to include General Aviation airplanes to validate and assess marine litter detection. The AIR-SOS (AIRborne & Satellite Observation Strategies for marine litter monitoring) study aimed to collect high-quality and high-resolution data in coastal waters near the mouth of the River Elbe. A seaplane (Lake Buccaneer) was used to collect Multispectral data coincident with Sentinel-2 satellites overpasses to validate current algorithms and methodologies. In this way, the project assessed and demonstrated the value of the aircraft as a platform for validation of Sentinel-2 data.

For this project a multidisciplinary team was required. SkyfloX has experience with payload design and flight campaigns from previous projects with large consortia (DOCS- 1 flight campaigns/ DOCS-2 payload design[1]), whereas Plymouth Marine Laboratory has experience in Marine litter detection projects including the PML-led ESA OPTIMAL feasibility study, which demonstrated the ability to detect floating marine vegetation, plastics and debris in ESA Sentinel-2 satellite imagery. Aufwind has expertise in flight training, flight operations and aircraft maintenance, as well as compliance management in aeronautical areas. Aufwind also owns a Seaplane LAKE LA-4-200, formerly used for oil spill surveillance in the Northern Sea, which is used for this project.

The ability to fly sensors on General aviation Aircraft at lower cost, at lower altitudes (visual cross-checks) and the possibility to perform in situ measurements (sea-landings) makes this a multi-functional 'platform' suitable to for systematic validation of satellite remote sensing detection of marine litter. Ultimately, our methods and sensors could be used to complement satellite observations using multiple general aviation aircraft or the ORCA constellation (Optical and Radiofrequency Constellations on Airplanes[2]).

The AIR-SOS project was kicked off in June 2020 and was completed in Nov 2021.

Figure 1 *Image of the LAKE Buccaneer used for the AIR-SOS project*

[1] https://business.esa.int/projects/docs
[2] https://skyflox.eu

1.2 Project Rationale and Objectives

The project has been executed in several phases. The first phase (pre-flight preparations) focused on the selection of the sensor(s) to be used for the flight campaign, the payload design and the flight test campaign preparations (receiving flight clearances/ certification/ making of the flight-plan). The next phase, the flight campaign, included the integration of the payload, a test flight and data acquisition flights. The data from the flight campaign has then been processed and evaluated alongside Sentinel 2A/B data in the final phase. The final phase also included simulations and assessments for the technical/regulatory and business aspects for the use of such payload systems on multiple GA aircraft and commercial aircraft for marine litter detection.

Objectives

The AIR-SOS study aimed to address the problem of limited validation data, by collecting *in situ* data over the coastal waters outside of the Elbe River using a seaplane. The main objectives of this study are summarized below:

1. Assessing the capability of selected onboard sensors
2. Validate and optimize the PML Floating Debris Index and atmospheric correction for floating marine litter detection using imagery from flight test alongside Sentinel-2A/B Multi-Spectral Instrument (MSI) data.
3. Evaluate the use of general aviation (GA) planes/ seaplanes in marine litter detection from technical, regulatory and business points of view.
4. Evaluate the use of ORCA (constellation of commercial planes with sensors) in marine litter detection as above

The main overarching theme has been to see if any of these aforementioned points are capable to enhance/ complement data value from existing Sentinel satellites (through fusion of data and validation of methods) and thus provide an effective/ consistent service for marine litter detection.

2 Pre-flight preparations

2.1 Sensor selection

Two sensors have been fixed to the wing of a seaplane. The two selected sensors, the MAIA[3] and Micasense RedEdge-MX camera[4], have been used for detecting patches of floating debris , with a focus on patches that contain plastic litter, but also seaweed, blooms of cyanobacteria, plant material washed from the land, and varied types of seawater (turbidity) composing the background of any detections.

Figure 2 *Illustration of the MAIA sensor on the left (9 bands) and the Micasense RedEdge on the right (5 bands).*

[3] 9 Band multispectral sensor: https://www.spectralcam.com/maia-tech/

[4] 5 band multispectral sensor: https://micasense.com/rededge-mx/

2.2 Payload design and placement

The AIR-SOS modification to the Lake Buccaneer makes it possible to attach and operate up to 4kg (within specific dimensions) camera systems inside each wing.

The sensors are housed in a box allowing the sensors to be attached with different viewing angles (as required to avoid adverse effects of e.g. sun glint on the water surface). In addition, a hatch system allows the payload to be covered during water landing for protection of the sensor. Note that the ILS (MAIA irradiance sensor and GPS) and DLS (Micasense irradiance sensor and GPS) are placed at the tip of the wing facing upwards, as they required unobstructed sky view.

2.3 Flight Approvals and Certification

In order to fly and collect data the necessary regulatory and flight approvals were received. The AIR-SOS assembly flew under non-commercial non-complex operations rules (Part-NCO). The AIR-SOS flying activity is regarded as non-commercial operation by the authorities. Approvals for low flights and landings also had to be requested from the relevant aviation, naval and environmental authorities. For this project the AIR-SOS activities received the following approvals:

- Legal permission to fly all the missions with a minimum flight altitude of 500 feet above land or sea (Germany and Denmark).
- Approvals to fly down to 500 ft above mean sea level and landing permission within Danish and international territory. Concerning landings in Germany, due to the nature of the area (marine national parcs) landing and low flights were prohibited.

Regarding certification of the AIR-SOS, the modification to the Lake Buccaneer by installing the structural (and electrical) provisions to allow installation of sensor in the wing, was certified with the frame of a "Minor Change to Type Design", as defined by EASA (European Aviation Safety Agency).

2.4 Flight plan/ operational procedures

For the AIR-SOS project an Aircraft Operations Manual (related to the aircraft requirements, list of equipment and specific procedures for the aircraft), Minimum Equipment List and a Task and Operational Area Manual (related to the flight procedures and operational areas of the flight campaign) have been set up. These procedures include coordination with Search and Rescue and Air Traffic Control. In particular, the operational Area Manual describes the flight acquisition procedures, the operational area and the crew responsibilities.
A Decision Matrix was also defined, allowing the pilot to determine quickly what steps to take depending on the nature of the target area/ object of interest. Based on this Matrix the flight pattern and the degree of attention/ time spend on the target area are classified with different gradations. The importance level assigned to each observed item of interest, triggers a corresponding acquisition effort.

3 Flight Campaign

The flight campaign was preceded by ground tests (to test the sensors) and reconnaissance flights. In addition, preferred weather conditions, satellite overpass timing, and timing of the flights were discussed in advance, to increase the value of the data.

The flight campaign consisted of several flights, performed carrying the MAIA and Micasense, in German and Danish territories. For the MAIA, the flights occurred on 23 and 25 June 2021, supplying a dataset of around 130GB of images over sea. The MAIA flights didn't find accumulations of floating litter, but it captured many other features (ships, buoys, containers, dams/bridges). A lot of natural features were captured as well (such as foam from an algae bloom, sea spume, bird flocks, mudflats, submerged channels, wave crests, discolorations).

For the Micasense, the flight occurred on 12 Sep, supplying a dataset of around 10GB. The Micasense didn't find accumulations of floating litter, but it captured many other features (sailing ships, coastal areas of harbour, wave crests). Both of the aforementioned data are useful for training the algorithms.

Figure 3 *Flight paths for the MAIA and Micasense sensor acquisition flights (red concerns the flight on 23 June, blue the flight on 25 June). Yellow concerns the Micasense flight over the Flensburg Fjord on the 12th of Sept).*

4 Processing Results

Basic processing chains were set up for the MAIA and Micasense data. For post-processing both data were visualized using SNAP. In SNAP, data were examined in all bands but particularly the NIR for highlighting surface features, and the NDVI for additionally highlighting different water types and/or photosynthetically active materials (algae).

To match the data collected by the MAIA and Micasense, Level 1C products (at-sensor radiance) from Sentinel-2 were downloaded on days closest to the seaplane flights (same day ± 1 day).

To generate a Level 2 product, ocean and atmospheric components (scattering and absorption) were subtracted from surface reflectance values using ACOLITE (Atmospheric Correction for OLI lite version 20181210.0). Although all satellite images from this time were very cloudy, the Sentinel-2 data acquired on the 26th of June – the day after the MAIA was flown, showed a gap in the cloud that allowed us to attempt a match-up.

To enhance detection of patches materials floating on the ocean surface in Sentinel-2 imagery, the data was examined in the visible (RGB) and the floating debris index (FDI) and Normalised Difference Vegetation Index (NDVI) was applied in SNAP.

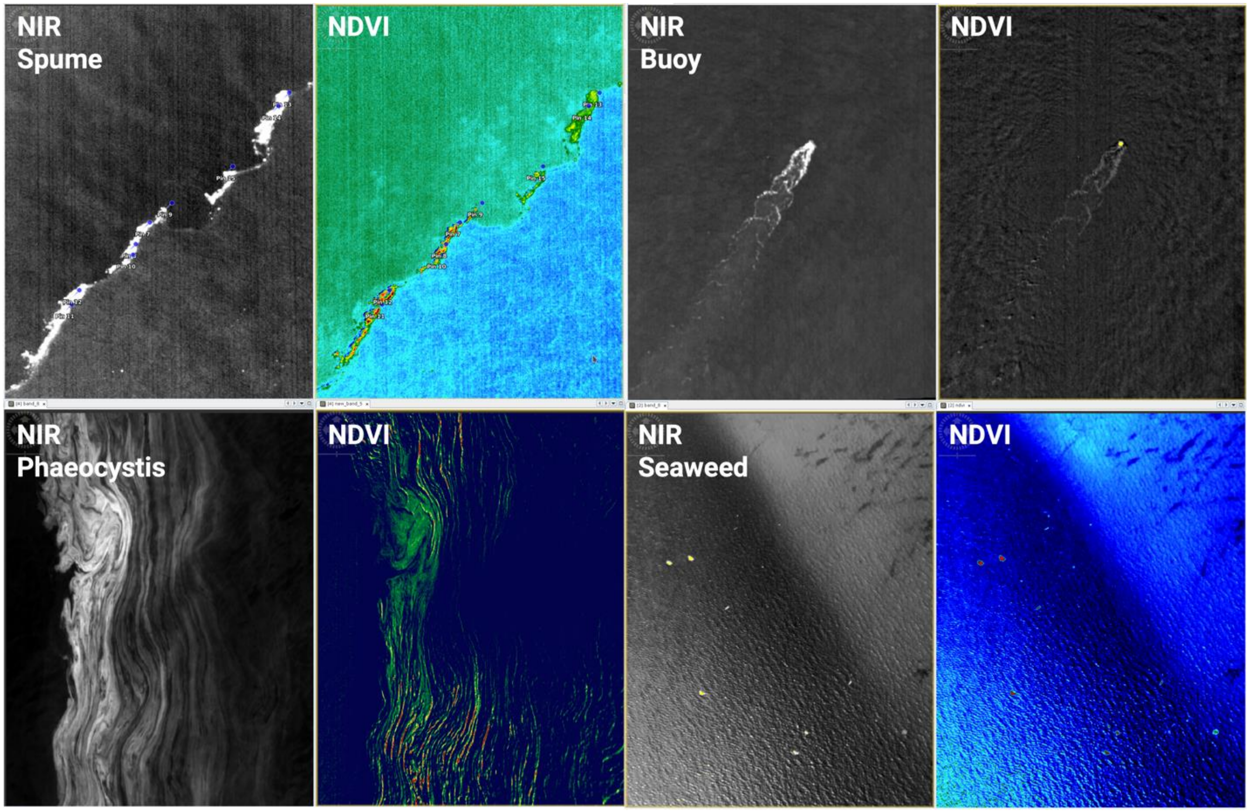

Figure 4 *Selection of MAIA data showing different water types, objects and floating materials detected during the seaplane flight over the Elbe River section of the German Bight. These detected water types, objects and materials are displayed here in the MAIA NIR band and a simple NDVI.*

To generate spectra of the bloom imaged by the seaplane and by satellite, approximately 13 pixels from the MAIA and 30 pixels from Sentinel-2 image were selected and extracted for comparison. These pixels contained highest concentrations of Phaeocystis foam.

Based on data collected by Biermann et al. (2020), it was possible to compare this spectral signature of Phaeocystis foam with spectra from other natural materials, as well as plastics. In **Figure 5**, the spectra of the bloom (shown in black) is displayed with *Sargassum* seaweed (green), driftwood (orange), sea foam / spume (dashed blue line), plastics from two sources (red and grey lines), as well as Case 1 seawater. Phaeocystis foam has a novel and distinct spectral signature that is clearly different to other sources of floating materials in the marine environment.

Thanks to the results from AIR-SOS, an entirely new category, Phaeocystis, is included in PML's debris classification (plastic discrimination) machine learning library.

Figure 5 *Example library of floating materials that are being used to help identify and discriminate natural sources of floating debris from plastics. Phaeocystis very distinct spectral shape will now form part of future machine learning training libraries for plastic identification.*

5 ORCA potential for system

The AIR-SOS' project main focus lies on the flight campaign using a seaplane to evaluate the sensors flown to detect marine litter and validate the algorithm used to process the acquired data. To ensure a continuation of this project on a bigger scale (i.e. a lasting test campaign using multiple general aviation/seaplanes, leading up to an operational marine litter monitoring service using commercial aircraft/ORCA), the extra work required to use sensors on multiple GA's or onboard commercial aircraft was assessed. In addition, simulations are performed to simulate ORCA coverage, and a business evaluation was made to get a better insight in using multiple aircraft (GA or ORCA constellation) for marine litter detection.

5.1 ORCA potential for marine litter: simulation results

5.1.1 Objective of Simulations

Simulations performed to simulate the potential coverage of the ORCA system. Coverage for Europe and several plastic hotspots has been evaluated based on flight data from Flightradar24. Specific case studies, focused on river deltas/discharge areas, one of the major sources of plastic litter into the marine environment, have been assessed. In particular, the simulations focus on the Mediterranean and North Sea areas and rivers that flow into these areas and an initial insight is given into the potential coverage of a couple of global rivers (Citarum, Yangtze, Ganges, Niger, Indus and Pearl River).

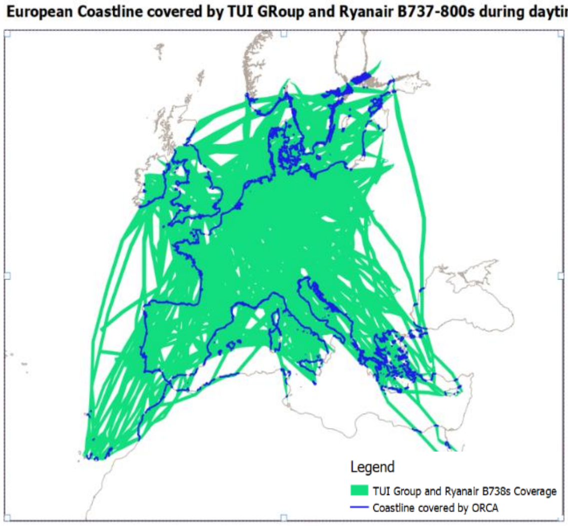

Figure 6 *Coverage of the European coastline by TUI Group and Ryanair combined fleet of single type (B737-800) during daytime hours (7am-7pm).*

5.1.2 Simulations summary

The simulation results confirm the coverage potential of ORCA for the identification of marine litter, and several European hotspots show interest for initiating a demonstration for a marine litter service, namely:

- North Sea – all seasons (Weser, Elbe, English Channel, Rhine)
- Western and Central Mediterranean - all seasons (in particular, the areas of Barcelona, Valencia, Po discharge area, Adriatic Sea and Tyrrhenian Seas).
- Eastern Mediterranean (Aegean Sea) - during the summer months.

For eventual rollout in other parts of the world, the following list of river deltas show interest:

- Citarum river delta (all seasons)
- Yangtze river delta (all seasons)
- Pearl river delta (all seasons)

5.2 Business Analysis

The problem: Satellite remote sensing offers the best available technology for collecting standardised optical imagery on extensive spatial scales. For detection of floating marine macroplastics, however, few studies have shown success.

The solution: Equip general aviation aircraft with multispectral cameras to produce a high-resolution data product that allows accurate detection of floating marine litter, leading up to, eventually, an operational marine litter monitoring service using a constellation of commercial aircraft: ORCA.

General Aviation (GA) aircraft, specifically sea planes, may be fitted with multispectral cameras that autonomously operate without intervention from the pilot. Such “GA data” is of far higher resolution than satellite data (25x higher compared to 10m resolution Sentinel-2 data), and can play a complementary role in the analysis & detection of floating marine litter.

Three primary customer segments are identified: NGOs, Government, and Research Institutions. Various NGOs exist to deal with the problem of (plastic) marine litter. An example is Ghost Diving: a non-profit organization committed to fighting the threat of ghost nets.

Governmental bodies may furthermore be interested in the data. The team contacted the Port of Rotterdam who explained the situation in The Netherlands: Rijkswaterstaat (water management, national governmental organization) tackles the issue of plastics in water on a national scale while Municipalities tackle the problem on a local scale: for example, the Rotterdam Municipality cooperates with the Rotterdam Harbor. In the case of The Netherlands, it is therefore primarily Rijkswaterstaat who can be considered a potential customer.

Furthermore, national coast guards are considered a promising customer. All North Sea countries have committed to perform regular air surveillance over their waters in order to maintain international emission standards for ships, under the Bonn Agreement. The SkyfloX data service may decrease the number of hours coast guard aircraft are required to operate, resulting in estimated yearly savings of €50-250K, and/or may increase the chances of detecting polluters.

Academic institutions may also be considered a customer of the data, such as AIR-SOS partner Plymouth Marine Laboratory, but also bodies such as Earthwatch Institute Europe, College of Life and Environmental Sciences (UK), National Institute of Aquatic Resources, etc.

A financial analysis has been performed to evaluate the economic viability of a data provision service with seaplanes. The fixed and variable costs have been mapped and estimates are made on potential revenues, drawing parallels with industry peers. The base case scenario allows for a positive return on investment over the course of 5 years.

6 Next steps/ conclusions

The AIR-SOS project showed that small aircraft (seaplane or similar) can be used as a platform to test sensors and promote marine litter research.
Flight campaign related work has been established (design, certification, approvals, installation and operational procedures).
A wealth of data with various features has been created to further the current methodologies for marine litter detection research and a basic processing chain has been set up.

An entirely new category, Phaeocystis, is included in PML's debris classification (plastic discrimination) machine learning library. The Phaeocystis foam has a novel and distinct spectral signature that is clearly different to other sources of floating materials in the marine environment.
The know-how and lessons learned during this project will pave the way for more projects of similar nature.

The extra work required to use sensors on multiple GA's or onboard commercial aircraft (ORCA) has been investigated. The assessment of the technical, regulatory and business aspects outlined the steps to follow for expansion of such activities to multiple aircraft, in order to create a lasting marine litter detection service. In addition, simulations indicate there is potential in the use of the ORCA constellation as a marine litter detection platform.

Transferable know-how for future projects

- Flight procedures and mission plans can be replicated for future GA/Seaplane missions
- Payload design for the installation of the sensor to several types of conventional metal airplane design
- Certification for new types of aircraft, is expected to profit from the knowledge gained in the first certification
- Basic processing chain set up
- Algorithm optimized

Ways forward for continuation on this project

- Use GA (or even current seaplane) to evaluate new types of sensors.
- Use General aviation aircraft/ seaplanes for regular campaigns collecting data to create a growing database
- Equip commercial transport airplanes with marine litter detection payloads to form ORCA constellations for daily plastic litter monitoring.