ESA Discovery and Preparation – OSIP

Campaign on Remote Sensing of Plastic Marine Litter

TRACE

Detection and tracking of large marine litter based on high-resolution remote sensing time series, machine learning, and ocean current modelling

Executive Summary Report

Issue 1.0

29 September 2022

Ref.: TRACE-ESR

ESA contract no. 4000132038/20/NL/GLC

EUROPEAN SPACE AGENCY

CONTRACT REPORT

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

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Project name: **Detection and tracking of large marine litter based on high-resolution remote sensing time series, machine learning, and ocean current modelling**

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Reference no.: **TRACE-ESR**

Issue date: **29.09.2022**

Issue and revision: **1.0**

ESA contract no.: **4000132038/20/NL/GLC**

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Table of Contents

Acronyms

AOI	Area of interest
CNN	Convolutional Neural Network
FDI	Floating Debris Index
OSIP	Open Space Innovation Platform
RGB	Red, green, and blue spectral bands
SAR	Synthetic-aperture radar
TOI	Time of interest

1. Project goal and concept

The overall goal of the TRACE project was to build a remote sensing based fully automated system for the detection and tracking of large marine litter and accumulation patches of smaller litter items in order to obtain precise and reliable data on floating macro-litter regarding their quantity, position, accumulation zones, material properties, floating depth, and sources. The tracking mechanism has been implemented by coupling the daily satellite-based detections with an oceanographic forecasting system and by a two-step object matching approach.

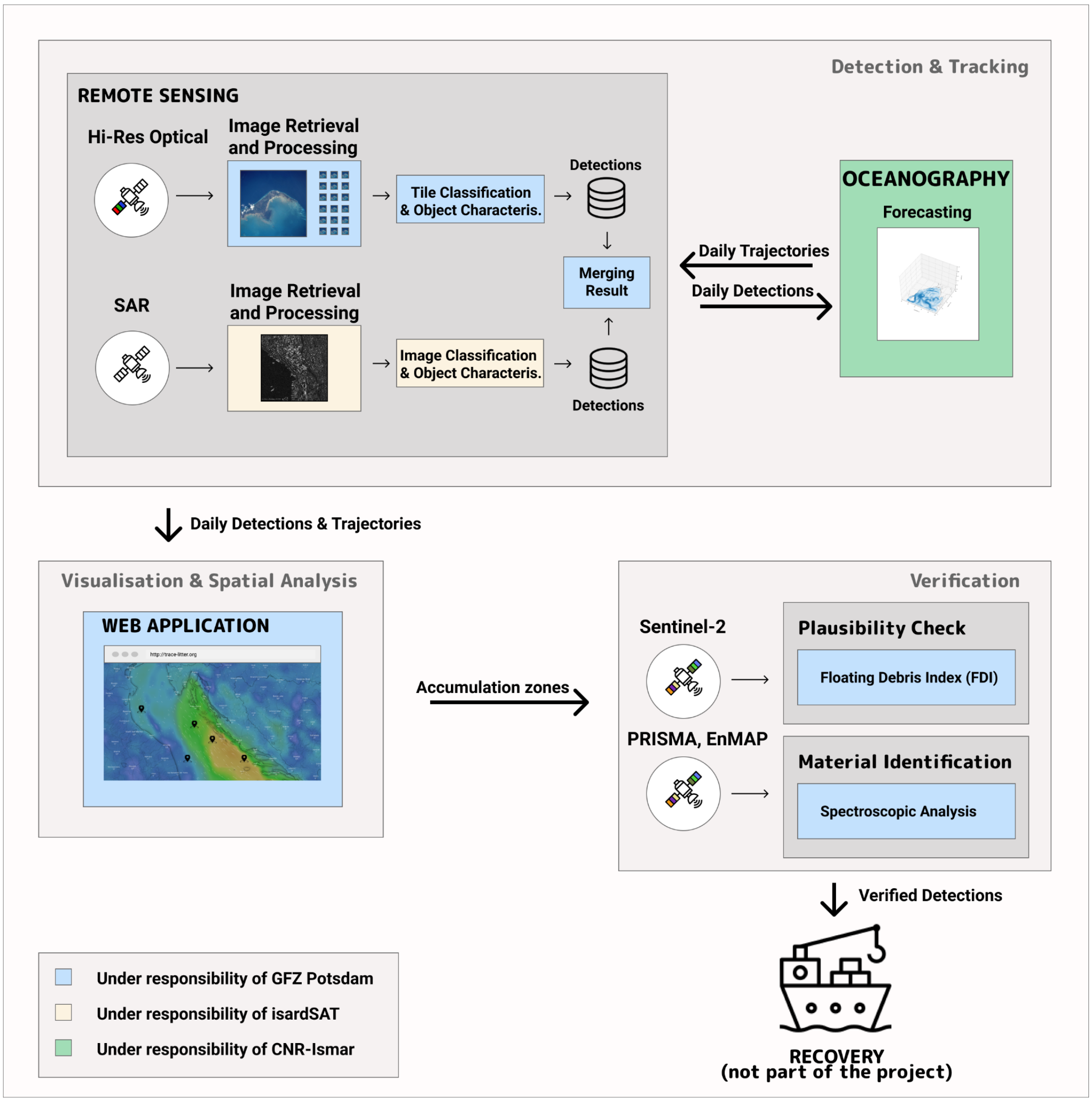

Figure 1: General idea and concept of the TRACE system showing its components, their interplay, and the data processing flow on a general, abstracted level

The developed TRACE system (Figure 1) consists of components for remote sensing data analysis (floating litter detection based on high resolution optical and SAR data), an oceanographic forecasting system, GIS operations, and a web interface for visualising the results. Daily optical (PlanetScope) and SAR (Sentinel-1) data is processed with machine and deep learning models in order to detect large floating litter and litter accumulation patches (box "Remote Sensing"). Due to the continuous movement of the floating litter and the unavoidable difference in acquisition times, both data types need to be analysed separately (instead of synergistic analysis or data fusion approaches) and the detection results are merged and stored in a database. The coordinates and timestamps of the litter detections are then handed over to the oceanographic forecasting system (box "Oceanography: Forecasting") which forecasts spatial density fields of the litter objects in 1 hour steps for the next 40 hours. Litter tracking is then made possible by a two-step matching algorithm: First, we compare the daily detections (from optical and SAR data) with the forecasted density fields of the detections of the day before. Second and subsequently, if a floating object is detected within the forecasted area of a previous detection (step 1) we analyse if the two detected objects match e.g., in size, shape, colour, and brightness. If so, it is labelled with a unique ID and tracked day-by-day over the whole testing phase of the TRACE system (or later in near-real-time if operated in near-real-time mode). The whole process is repeated day-by-day enabling virtual litter tracking visualised in the web application (box "Web Application"). The web interface can be also used to identify litter accumulation zones. When the oceanographic forecasting system predicts that a larger amount of litter will accumulate within a fairly small region for a certain period of time, a plausibility check (see same-named box) based on the Floating Debris Index (FDI) (Biermann et al. 2020) or other ad hoc (plastic) debris indexes recently developed can be done based on Sentinel-2 (S-2) images. Additionally, hyperspectral satellite data can be acquired on-demand for the predicted AOI and TOI (box "Material Identification"). Spectral analysis methods can then allow the identification and quantification of plastic material among the floating debris. Validated detections are indicated in the web interface to support litter recovery actions, e.g. by predicting the optimal time for recovering litter accumulation patches, particularly when they are moving close to a coast or being trapped by gyres, eddies or at ocean fronts (box "Recovery"). Moreover, the web interface allows locating source regions representing the first important step on the way to eliminate sources and prevent litter dispersal.

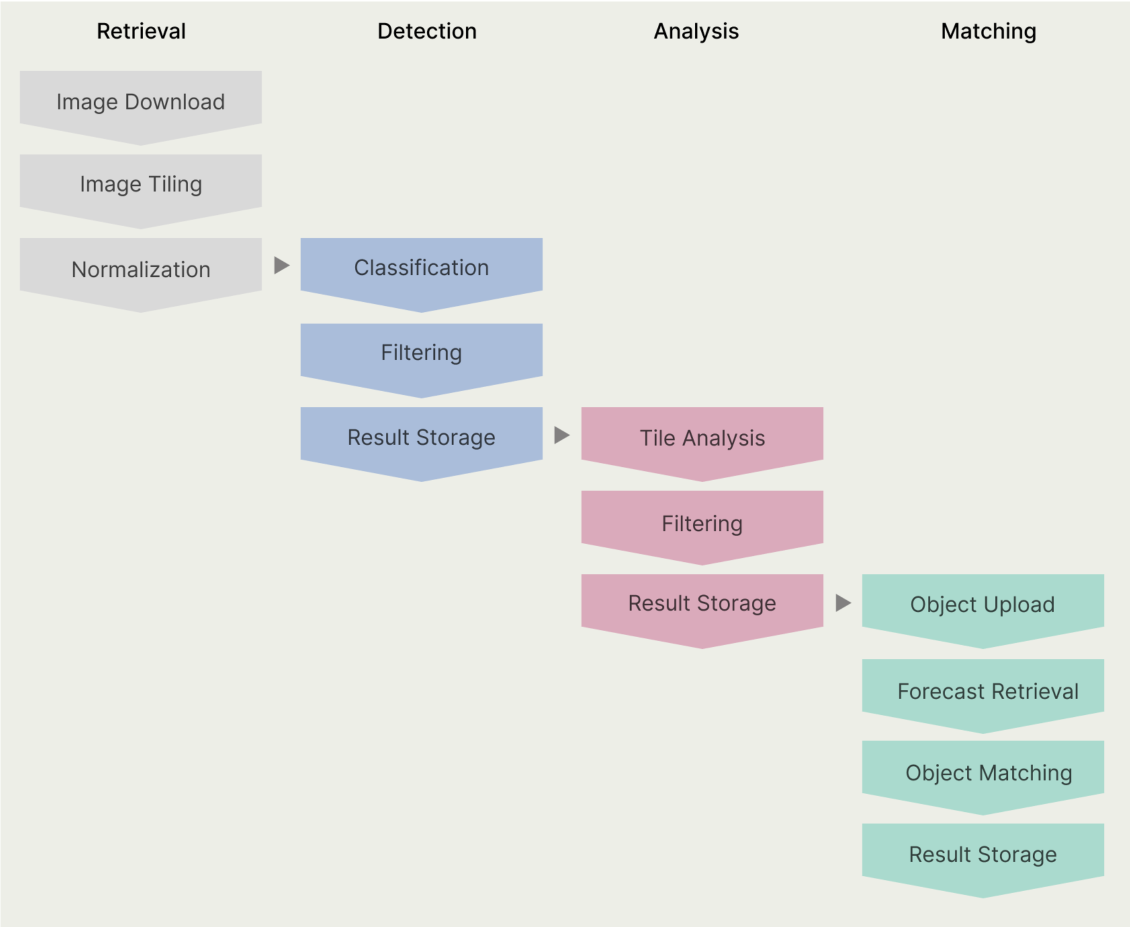

Figure 2: Process flow in TRACE

2. Study area and first test run

Different studies from recent years come to the conclusion that the Mediterranean Sea is - beside the five large subtropical ocean gyres in the North and South Atlantic, in the North and South Pacific and in the Indian Ocean - one of the global hotspots of marine plastic litter (Cozár et al. 2015; Cocca et al. 2018; Suaria and Aliani 2014; Suaria et al. 2016). The average amount of macro-litter (> 20 cm) observed along fixed trans-border transects in the Mediterranean Sea was in a range of 2-5 items/km2, with the highest amount found in the Adriatic basin (Arcangeli et al. 2018). The elongated, semi-closed, shelf basin has a large number of freshwater inputs mainly along the Italian coast, among which the Po river is the most relevant and represents the tenth largest source of marine litter in the Mediterranean Sea (Liubartseva et al. 2019).

Therefore, we have chosen the northern part of the Adriatic as our study area and analysed a time series of PlanetScope and S-1 data for the period from 28th of May to 3rd of June, 2021.

The detection components (optical and SAR) have both been validated based on independent datasets with high accuracies above 90% (see FR). In the first tryout we therefore focused on the interplay of all components of the TRACE system including the oceanographic forecasting system. Especially the connection between remote sensing based daily litter detection and daily oceanographic forecasting, which is realised by the matching and tracking component, is supposed to sort out false positive detections which are expected to occur in large numbers.

The results that we are presenting here are those of the very first complete run of the whole system applied to the time series from May 28th to June 3rd, 2021 over the North Adriatic. Figure 3 shows all floating objects detected by SAR (light grey) and optical data (dark grey) between May 28th to June 3rd, 2021. It is noticeable that most SAR detections are located around the mouth of the river Po and most of the PlanetScope detections are close to the coast. Sentinel-1 SAR data has been recorded at 3 points in time within the time period. However, most of the SAR detections result from only one of these dates. As it was found during the training process and application of the SAR detection model in other locations that the model generates many false positives in wavy seas, we assume that most of these detections at this date are false positives, too.

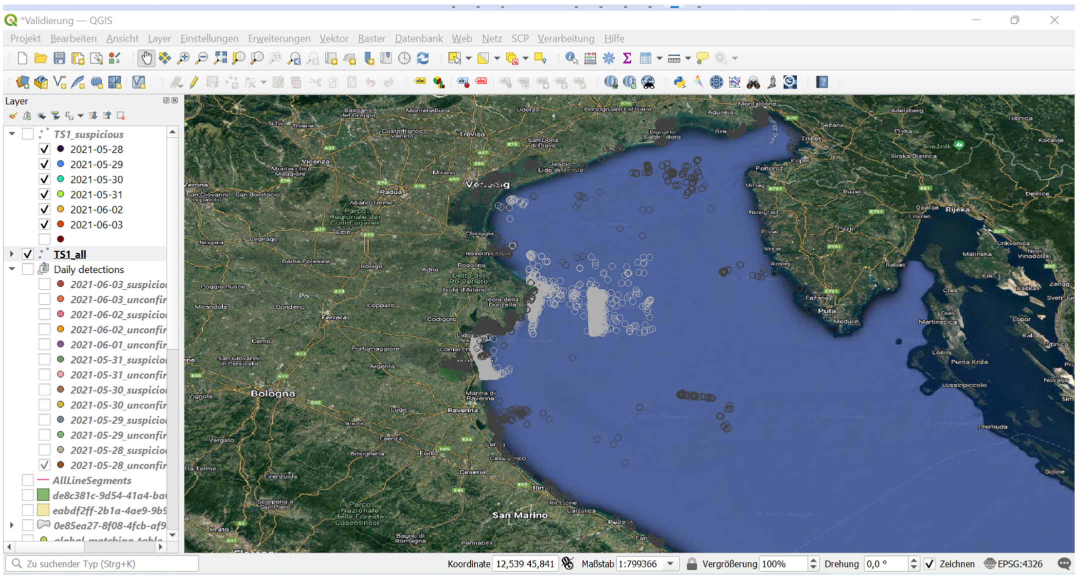

Figure 3: Floating objects detected by SAR (light grey) and optical data (dark grey) between May 28th to June 3rd, 2021

In contrast to SAR, the optical detections can be inspected visually in the RGB images to get an impression of their plausibility. They can be clustered into coastal and off-shore detections. Unfortunately, most if not all off-shore detections appear to be false positives due to clouds. At the same time, most if not all of the detections close to the coast appear to be false positives due to sea bottom texture in shallow waters, turbid sediments, white caps and small boats. Principally, a high number of false positives is not a problem if the matching and tracking component works well and sorts them out. Figure 4 shows those detected floating objects in colour which have passed the matching procedure successfully, thus being marked as "suspicious". It can be seen that only a few detected objects have been matched to others, all of them lying close to the coast.

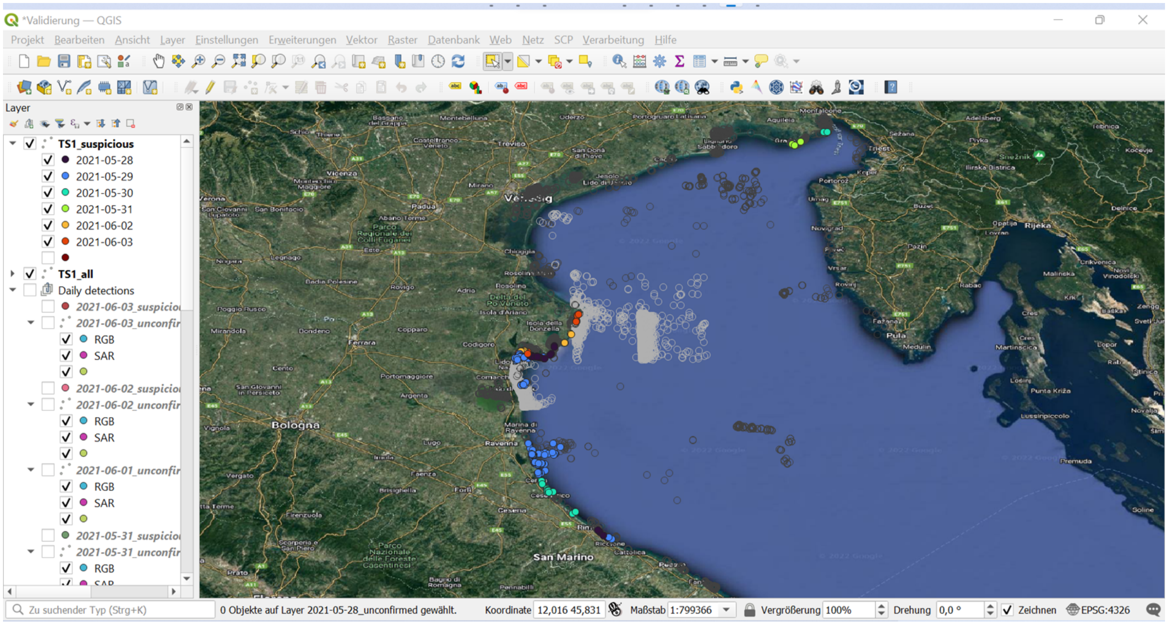

Figure 4: Floating objects marked as "suspicious"

Visualising the connections between the matched pairs of floating objects gives more insight into the algorithm (Figure 5). By coincidence it can happen that a very similar object or structure appears at the forecasted position. Coincidences as displayed in Figure 5 happen regularly close to the coast due to sea bottom structures, turbid sediments, white caps, and small boats. However, it is very unlikely that such coincidences happen 2 times in a row. Consequently, all the false positives including those that have been matched once across 2 days can be turned into true negatives when we count only those floating objects as floating litter which the system detects and matches across at least 3 days in a row. However, in the analysed time series our system wasn't able to detect and match a floating object three times in a row. Amongst others, the cloud situation as well as data gaps could be a reason for that but also that we need to fine-tune and improve our system (which is actually normal after a very first run). However, it could also be possible that there are no large floating objects present in our time series which can be detected with data having a pixel size of 3 m, respectively 10 m.

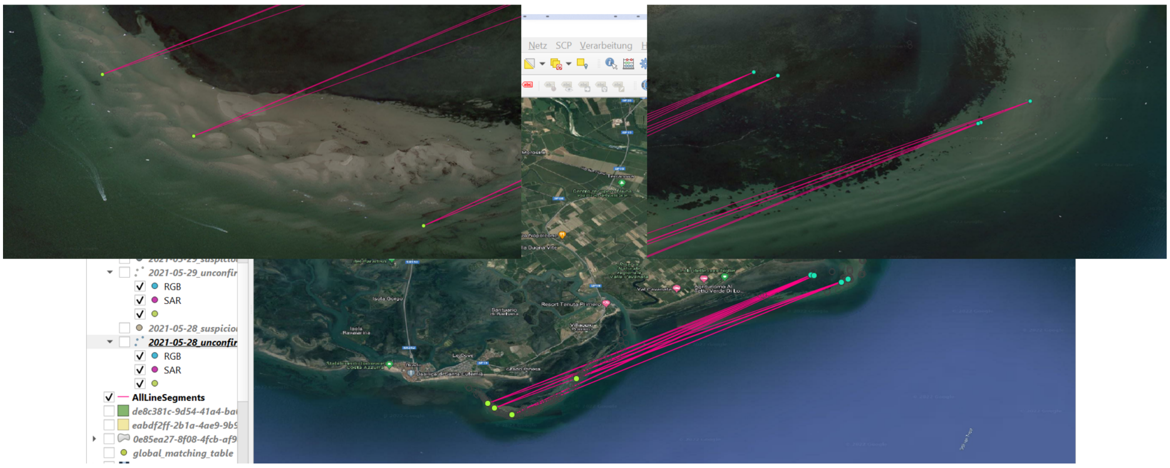

Figure 5: Visualised connections between the matched pairs of floating objects. In this example there were small boats anchoring in the shallow water at both locations, the place of the initially detected floating objects (on the right) and within the forecasting polygons of these initial objects at the next day (on the left)

3. Future steps

We were able to demonstrate that coupling daily remote sensing data and oceanographic forecasting models enables the distinction between geo-stable objects (e.g. buoys, small rocks), actively driving objects (e.g. boats) and passively drifting objects such as marine litter. However, no large marine litter has been tracked for 3 or more days. Several ideas for improving, optimising and fine-tuning the TRACE system have been collected during the project (Figure 6). We assume that these will bring the breakthrough. On top of these, it could also be an option to improve the detection capability of our CNN regarding fronts and filaments which are known to be large enough, though not stable in their shape and usually dissolving after a couple of hours or days.

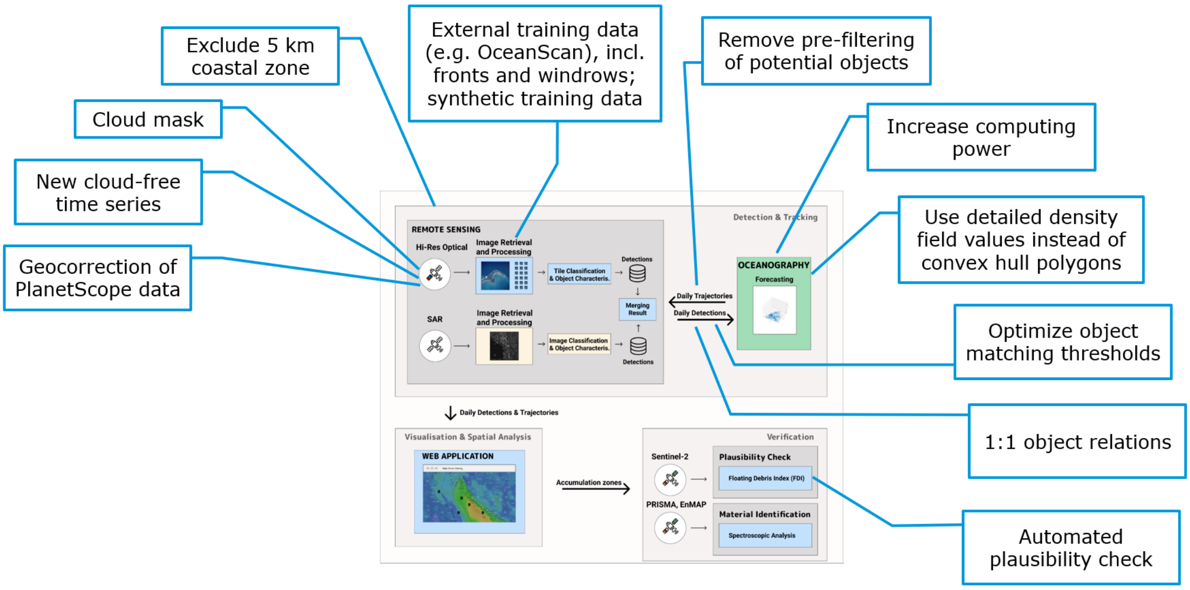

Figure 6: Ideas for extending, improving, and fine-tuning the TRACE system

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