Low-cost drifters: some applications for water monitoring

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***Abstract*—This study presents the design and implementation of low-cost drifters, along with different water monitoring applications. The first application presented is related to the tracking of marine litter from the Arno river mouth (central Italy, Tyrrhenian Sea), while the second one concerns the study of the dynamics of a volcanic lake in central Italy (Lago Albano). Both the implementation phase and the field experience benefited from an integrated approach of low-cost equipment, citizen science and numerical modeling.**

***Index Terms*—low-cost drifters, marine litter tracking, numerical modeling, citizen science, lake dynamics**

I. Introduction

Drifters are floating devices advected through the hosting waters by the activity of wind or current. A branch in a river, a bottle carrying messages in the sea or a piece of plastic in a lake can be considered floating drifters. Indeed, the visual inspection of the evolution of such objects in the water can be an important proxy of the forcing factors of the motion and provide rough estimates of the measurement of the currents, for example. This is a way currents were estimated in the past. In more recent years, what used to be a natural or ad-hoc but simple floating object, evolved significantly. Today, we could say that a drifter is a floating device equipped with specific tracking systems, data transmission systems and possibly additional instrumentation for the monitoring of chemical, physical or biological parameters of the hosting waters. These devices are widely used in research applications with different characteristics depending on the specific purposes. Some of the most common applications are large-scale ocean current mapping, oil spill monitoring and search and rescue operations. Examples of drifters widely used for surface and subsurface purposes like ocean circulation, river plume dispersion or planktonic advection are SVP [1], CODE [2], CARTHE [3] drifters, which try to best represent the action of current by minimizing the Stokes drift and the wind effects. Conversely, devices like ARGO SPHERE are mostly used for oil spill, thus they are designed to be as well sensitive to the wind effect. In general, if the target parameter is the current, drifters will be manufactured to minimize the effect of wind, and possibly be provided with a drogue. Vice versa, if our target is the monitoring of parameters or objects whose motion is mainly influenced by the wind, the drifter's windage (the area exposed to wind action) will be consequently increased. Recent drifter designs combine these two approaches and allow to adjust the drag-area ratio according to the different applications of interest ([4] and [5]). The most common system of communication of commercial drifters is based on satellites (IRIDIUM, Globalstar-SPOT, ARGOS). However, this implies high costs, additional loads on the devices and a considerable set of batteries to sustain power. Ad-hoc low-cost drifters were devised and implemented, and two examples of their application are presented in this work.

In one case they were used to study the marine dynamics and fate of litter of riverine origin, in particular from the Arno river mouth in one case. In the other case they were applied to the study of the circulation and temperature distribution in Lago Albano, a lake of volcanic origin located in central Italy.

II. MATERIAL AND METHODS

A. Application to marine litter tracking

Although rivers are one of the most important sources of litter into the sea, studies on marine litter dynamics of riverine origin are yet rather few, and the most important processes involved in their evolution are still poorly understood. In the framework of SeaCleaner project (https://sites.google.com/view/seacleaner/home-page), studies in this direction had been started in the recent years ([6], [7], [8]) through a joint collaboration between INGV and CNR in Italy, focusing on the Marine Protected Area of San Rossore, located north of the mouth of the Arno River in Tuscany, adopting an integrated citizen-science and more traditional science based approach. This allowed to build, also through the strong involvement of civil society, simplified protocols based on the MSFD in order to categorize the beached litter in 5 pilot areas of the Tuscany Region and to start the comprehension of the main dynamics of marine litter recharging and flushing from the beaches in these areas. Through the additional support of the projects ML-DAR (A multidisciplinary method to study the Marine Litter Dispersion from the Arno River mouth: a study case to support citizen science) and ML-CSA (Study the Marine Litter dispersion: Citizen Science Application case) the prosecution of these studies was possible. The idea behind the study is to use modern consumer software and hardware technologies to track the movements of real anthropogenic marine debris (AMD) from rivers and to integrate this innovative approach with the use of numerical models for the planning of the deploy campaigns at sea, for the optimization of the recovery phase of the drifters and for a further support in the interpretation and comprehension of the driving processes of marine litter dispersion in the sea.

B. Low-cost marine litter design and implementation

Following the categorization done in the area of interest, the most representative typology of litter resulted in plastic bottles and flat shaped wooden chunks. The innovative idea standing at the base of the low-cost drifter design and implementation was that the best way to mimic a piece of garbage was by using a *real piece of garbage*. Prototypes of tracking bottles and wooden tablets were thus assembled, as it is presented in Fig. 1, where the upper panels represent the drifters sketches (bottle and tablet shaped respectively in the left and right panels) and the lower panels represent examples of realization. The drifters are composed of a support (either a bottle or a wooden tablet), solar panels, GSM and GPS antennas and a tracker. In the beginning, two solutions were tested: one using commercial devices based on TPK-905 tracker manufactured by Winnes, and another one using ad-hoc tracking software and hardware, based on MADUINO SIM808, a card provided with GPS receiver, GSM connectivity, and an SD card slot. The ad-hoc system presents several advantages compared to the commercial one: it is much more economic, additional sensors can be connected so that more parameters can be acquired, data can be acquired also in the absence of GSM signal and recovered in delayed mode, no delivery time for the commercial components of the drifter are needed since the ARDUINO technology is ready and quick to procure from the internet. Last but not least the system is very easy to assemble, thus it strongly favors the involvement of non-specialized staff, as high-school students for example, following our citizen science based approach. A high number of students were indeed involved in the assembling and deployment of the low-cost drifters. A regular file of drifters' data consists of a record of data regarding the object at a certain regular frequency. In the case of the ad-hoc system the frequency is customizable according to the user's need. Several deploy experiments were at first performed to test the two systems, and then to understand the main dynamics of litter evolution in the sea.

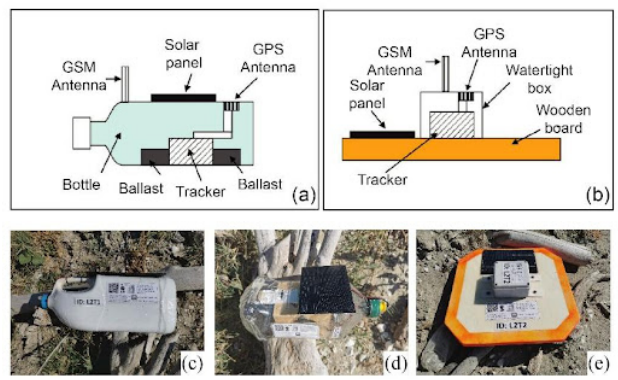

Fig. 1. Scheme of the two types of Marine Litter Trackers (MLT). Courtesy of [9].

C. Numerical modeling system

In order to optimize the planning of the experiments, the recovery of the drifters once beached and to further understand the driving mechanisms of litter dispersion, a cascade of numerical hydrodynamics and lagrangian models was implemented and used both in forecast and delayed mode. The hydrodynamic component is based on SHYFEM [10], a 3D finite element model inclusive of tides and nested at the open boundaries into the Copernicus MED-MFC analysis and forecast products [11]. The high resolution implementation of the SHYFEM model takes the bottom topography from the EMODnet Bathymetry portal (http://portal.emodnet-bathymetry.eu/) and it is resolved over 21 vertical layers. The horizontal resolution of the mesh varies from 3000 m offshore to 200 m approximately in the coastal strip. The SHYFEM implementation was run in hindcast mode for a year and validated versus the available data of temperature and SSH proving to be robust and accurate and able to reproduce small scale coastal features such as localized turbulence and the Arno river plume. The atmospheric forcing is provided by ECMWF (European Centre for Medium-Range Weather Forecasts) fields. Surface currents from the SHYFEM model outputs and from Copernicus MED-MFC products, were used as forcing for the OceanDrift module of the open-source framework OpenDrift [12]: the fields from the hydrodynamic high resolution model in the coastal area, while the ones from the CMEMS products in the open sea. In addition, the lagrangian particles are forced with ECMWF analysis and forecast atmospheric fields. The lagrangian model was calibrated and validated with the position data collected by the low-cost drifters during several launches performed during 2021, using the wind drift factor (WDF) as parameter for validation. The two different typologies of litter (bottles and tablets) showed different responses to wind and currents related to their shape in the real world, whereas the calibration exercise didn't allow to identify a clear distinction of WDF according to the shape of litter yet, most likely due to the restricted number of launches and of drifters used for the cal/val statistics yet. Some important findings for the interpretation of the fate and dynamics of marine litter from the Arno River mouth were achieved through this integrated approach. The driver of bottle shaped litter is mainly the wind, most likely due to greater windage with respect to tablets, whereas these latter are mainly driven by surface currents. When the wind and currents are aligned bottles travel faster, while when currents and winds diverge, tablets tend to follow the current and bottles tend to follow the wind, which becomes the main driver for sudden strandings as well. The integrated analysis of modeled wind and ocean data, together with low-cost drifter data, allowed also to interpret marine litter behavior according to the different seasons.

D. Application to lake dynamics

In Lago Albano (Italy) anomalous degassing of likely magmatic origin is present at irregular intervals. A water overturning or a mixing of deep and shallow waters could bring CO_2 from the bottom of the lake to the surface, with potential dispersion of CO_2 that increases the hazard in the surrounding areas [13]. Such overturns occur when the equilibrium of the water-column stratification is modified by water density variations. At Lago Albano, these variations occur generally in the winter, whereas in the other seasons the temperature vertical profiles indicate well stratified water masses with a pronounced thermocline between 30-50 m depth. In a climate change perspective, the lake dynamics could change towards an equatorial regime [14], with a progressive inhibition of the overturning and the consequent accumulation of the CO_2 in the lake, further increasing the hazard when a sudden CO_2 release may occur.

E. Low-cost drifter design and implementation in the lake case study

These processes in the Lago Albano are being studied in different frameworks through the integration of in-situ observations and numerical modeling. The availability of measurements for the calibration and validation of the numerical models is extremely important, thus also the modeling tools would take advantage from an increased number of available observations. Beside the recent enhancement of fixed monitoring instrumentation and the attempt of continuous seasonal in-situ campaigns for physical and geochemical purposes, a step forward towards the increase of measurements and the observed lake circulation was done by means of application of low-cost drifters also in the lake environment. In this case the purpose was the understanding of the lake currents and the collection of useful information on the observed circulation to corroborate the model results. For this reason a substantial modification in the shape of the drifters was applied, while the main characteristics of data acquisition, storing and transmission was left unvaried. In order to make the floaters more representative of surface and subsurface currents a drogue was added and a different support was used, similar to the one of CARTHE [3]. The float is a toroidal-shaped structure made of polyhydroxyalkanoates (PHA[1]), with an outside diameter of 38 cm and a diameter of the tube of about 8.5 cm. It was equipped with GSM-GPS antennas and a data logger. The drogue is made of a canvas mounted on a lightweight plastic tube frame. In order to maintain the drogue in an upright position, a lead weight of approximately three ounces is attached to the lower central part. An example of this kind of drifter is presented in Fig. 2. Two field campaigns were carried out in August 2022 and in May 2023, respectively, and temperature and positions data were recorded every 15 minutes. The outcomes of the experiments, which showed circular trajectories following the lake shape in conditions of moderate wind and more direct diameter-following trajectories in case of more intense wind, will be used to verify the capability of the numerical model to represent the surface lake circulation. Since temperature is a fundamental parameter for the study of the water overturning, the drifters were equipped with additional sensors of temperature.

F. Numerical modeling of the lake

In order to investigate the physical processes and the thermodynamical properties of the lake, the 3D finite element model SHYFEM [10], already used in the numerical modeling system of the marine litter tracking experiments previously described, was implemented in Lago Albano. The resolution of the mesh is the following: between 35 m and 62 m in the horizontal, while in the vertical it goes from 1 m in the upper levels to 3 m in the deeper levels. Even if the available measured lake bathymetry [15] is at very high resolution (2 m) the chosen horizontal and vertical model resolutions represent the best compromise between the computational running time and the degree of detail that the analysis aims to explore. The atmospheric forcing, represented by zonal and meridional wind components, 2 metre air temperature,

[1]PHA are a class of biopolymers made from renewable carbon instead of fossil fuels: they are extracted from the fermentation of corn sugar.

Fig. 2. Low-cost CARTHE-like drifter used in Lago Albano.

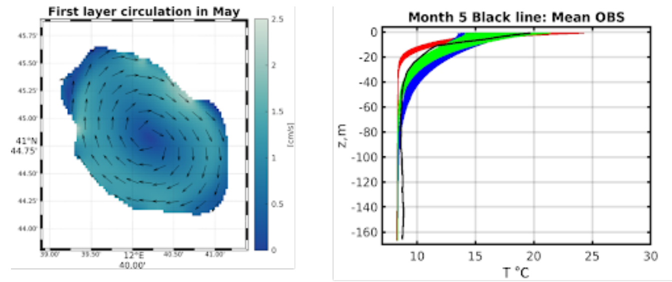

Fig. 3. Climatological simulation results. Left panel: horizontal surface circulation for the month of May. Right panel: vertical profiles of temperature (black line represents the mean observations of May, colored lines represent the modeled vertical profiles under different values of vertical diffusion).

2 metre dew point temperature, mean sea level pressure, total precipitation, total cloud cover and surface short-wave (solar) radiation downwards is derived from the ERA5 reanalyses data set with hourly frequency and 1/4 of a degree spatial resolution [16]. Initial conditions for the model simulations performed are homogeneous temperature and salinity fields starting from observed mean profiles, while initial 3D velocity is set equal zero. The model is now in a calibration phase, intended to qualitatively reproduce the most significant features connected to the lake overturning. In particular, a complex parameter setting phase aims to adequately simulate the temperature seasonality, the vertical profile of temperature and the formation of the thermocline during the warm season. To this purpose a simulation of the climatological year was conducted forcing the model with a daily atmospheric climatology based on the ERA5 reanalyses data from 1979 to 2019. The climatological simulation was then compared to the observed profiles of temperature, which were collected at sparse depth and are very irregular in terms of distribution throughout the years and the seasons. In Fig. 3 we show preliminary results: the modeled mean surface currents (example for the month of May, left panel in Fig. 3) present mainly an anticyclonic pattern, consistent with the information provided by people involved in the management of lake activities. The vertical temperature profiles from model results (right panel in Fig. 3) are in good agreement with observed profiles during the month of May.

III. Summary and Conclusions

This short manuscript presents two applications of in-house assembled, low-cost drifters used to study the dynamics of litter of riverine origin (from the Arno River in particular) in the Tyrrhenian and Ligurian Sea, and the circulation general dynamics of the monomictic Lago Albano, in central Italy. The drifters proved to be robust and fit for both purposes, and they present several advantages with respect to commercial ones. In both cases the studies are based on integration of observations and numerical models of marine and lake circulation, coupled with lagrangian models of particle (virtual drifters) dispersion. The use of numerical models helps interpret the dynamics of the studied environments and optimize the planning of the campaigns and the drifters' recovery phase. In turn, the data collected by the low-cost drifters are extremely useful for the models for calibration/validation purposes. Additionally, the simplicity of the low-cost drifter system favors a citizen-science approach to the study of these research issues, particularly through high schools students but not only confined to them, both in the phase of assembling the devices and in the phase on field during deployment and recovery. This manyfold methodology is proving to be very fruitful and further experiments and applications are expected.

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