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A Mediterranean drifters dataset: 1998 - 2022

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Abstract. Over a hundred of experiments were realised between 1998 and 2022 in the Mediterranean Sea using surface Lagrangian drifters, at coastal and offshore level. Raw data were initially unified and pre-processed manually by eliminating spikes and wrong positions or date/time information. The integrity of the received data packages was checked, and incomplete ones were discarded. Deployment information was retrieved from an initial excel database and campaign notes for each drifter and integrated into the PostgreSQL database, realised and maintained by the National Institute of Oceanography and Applied Geophysics (OGS) in Trieste (IT). This database also collects a variety of metadata about the drifter model, project, owner and operator. Subsequently data were processed using standard procedures of editing and quality control developed for the OGS Mediterranean drifter dataset to remove spikes generated by malfunctioning of the sensors and obtain files with common characteristics. Drifter data and plots of each track were also visually checked to remove any point not identified by the automatic procedure and clearly erroneous. Drifters' trajectories were split into two or more segments that have been considered as different deployments, in case of specific drifters' behaviours. Data were interpolated at defined time intervals to temporarily unify tracks. From the original 138 experiments, a dataset of 204 tracks was obtained, available from the public open-access repository in SEANOE (SEA scieNtific Open data Edition) at https://doi.org/10.17882/90537 (Ribotti et al., 2022).

Keywords: Mediterranean, drifter, Lagrangian data, surface circulation, quality control

1 Introduction

In oceanographic research, a large use of surface drifters started in the early '80s to study ocean surface dynamics, particularly during the U.S. Coastal Dynamics Experiment (CODE) described by Davis (1985), with the design, testing and use of light weight, inexpensive drifters. They were tracked by radio direction finding triangulation and also the new satellite Global Positioning System (GPS) launched in 1978. These drifters, named CODE, are still used nowadays, greatly improved in their data transmission systems.

In general, drifters are designed in order to follow the sea currents for long distances while minimising the direct effects of wind and waves acting on the elements protruding outside the sea surface.

In 1991 the Global Ocean Observing System (GOOS) programme started led by the Intergovernmental Oceanographic Commission (IOC) of UNESCO followed, in 1994, by its European component EuroGOOS that highlighted the operational oceanography value for society (Woods et al., 1996). The activities related to operational oceanography promoted the use of drifters also for the management of emergencies at sea, like oil spills or contaminants (Pisano et al., 2016), and the validation of numerical forecasting systems (De Dominicis et al., 2016; Sorgente et al., 2016).

The Italian National Research Council in Oristano (CNR hereafter), used drifters for research purposes linked with scientific projects, mainly focused on the study of local or sub-basin surface dynamics or on the calibration and validation of oceanographic prediction systems, in the framework of physical and operational oceanography.

CNR started its activities with drifters in 1998-1999. Early activities consisted in the usage of a single drifter in 15 coastal experiments for six months, along with the use of a multiparametric probe, to study the hydrodynamics inside the Gulf of Oristano (table 1), western Sardinia. The adopted instrument was a Coastal Lagrangian Drifter (CLD) designed and realised by a small Italian enterprise equipped with GPS and digital network (GSM) data transmission (Ribotti et al.,

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2000, 2002). Due to technical problems, experiments stopped to restart ten years later with different objectives and adopting a different type of drifters. In 2009 and 2010, CNR implemented a numerical oceanographic and oil spill prediction system limited to the Bonifacio Strait area in collaboration with the local Coast Guard. For the calibration and validation of the implemented numerical models, 9 experiments (table 1) were conducted inside and outside the Bonifacio Strait by using US CODE drifters with satellite transmission (Cucco et al., 2012; Ribotti et al., 2013). As some experiments were carried out in La Maddalena Archipelago, a coastal area characterised by narrow channels and small islands, due to the high risk of stranding, CNR modified the instruments inserting a switch, to turn them on or off, useful to re-use the recovered drifters.

In the framework of operational oceanography, in September 2014 CNR participated to an international exercise at sea on oil spill combat and Save And Rescue (SAR) activities launching three new Spanish satellite drifters, named Ocean Drifter (ODi; table 1), with solar panel and temperature sensor, specifically designed for oil spill studies. After the exercise, drifters were released in western and southern Sardinia coastal waters to investigate the main surface hydrodynamics.

Since the end of 2015 to nowadays, new GPS, cost effective, handy, and durable drifters produced by a Spanish enterprise, were adopted by CNR in several field activities. Different types of instruments were used, feasible for coastal (with GPRS transmission) or for offshore areas (with satellite transmission), with a switch and rechargeable batteries that permitted the use of the same drifter in different experiments. These drifters were deployed in 112 experiments all over the central Mediterranean Sea (table 1) with acquisitions from few hours to more than 12 months for purposes linked to both physical/biological (Quattrocchi et al., 2021a,b) or operational oceanography activities (Ribotti et al., 2019; Sorgente et al., 2020).

Recently, the OGS in Trieste has re-elaborated all 138 drifters' experiments following standard and state-of-the-art procedure (editing and interpolation), then creating a dataset, freely available online.

In this paper we describe drifters' characteristics, procedures of data acquisition and processing in detail and how tracks have been rebuilt in the dataset to make any potential user aware of the available product's quality.

2. The drifters

The CNR conducted over 138 experiments in the Mediterranean basin with surface Lagrangian drifters in 12 years, not continuously, between July 1998 and April 2022 (month of the last recovery), at coastal and offshore level (table 1 and figure 1).

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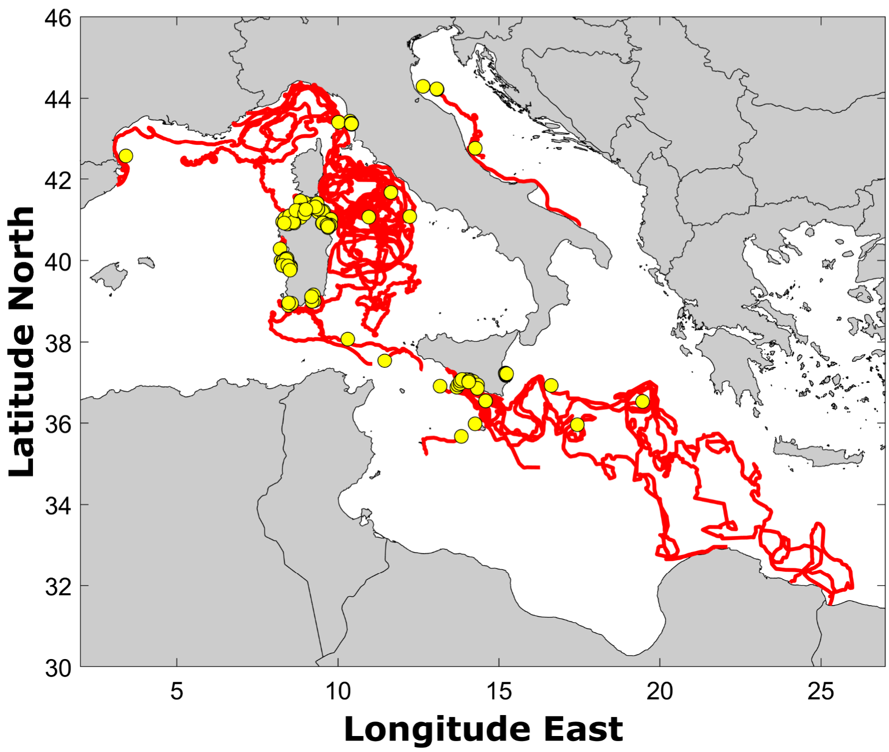

Figure 1. In red all 138 drifters' tracks acquired during the experiments between 1998 and 2022 (yellow dots represent the last position data).

Year	Start month	# experiments	Start area	Type of drifter
1998	July	1	Oristano Gulf	CLD
	Aug.	6	Oristano Gulf	CLD
	Oct.	3	Oristano Gulf	CLD
1999	Jan.	5	Oristano Gulf	CLD
2009	May	1	Asinara Gulf	CODE
		1	Tyrrhenian Sea	CODE
	June	2	Bonifacio strait	CODE
	Aug.	1	Bonifacio strait	CODE
2010	Mar.	2	Bonifacio strait	CODE
	Sept.	1	Bonifacio strait	CODE
		1	Tyrrhenian Sea	CODE
2014	Sept.	1	South Sardinia	ODi
	Oct.	1	West Sardinia	ODi
2015	Dec.	5	North Tyrrhenian	LCA
2016	Feb.	5	North Tyrrhenian	LCA
	March	4	North Tyrrhenian	LCA

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	July	1	Cagliari Gulf	LCA
2017	March	6	West Sardinia	LCA
	June	4	West Sardinia	LCA
		3	Sicily	LCA
	July	1	Sicily	LCA
	Oct.	14	Sicily	LCA, LCE
	Nov.	4	Sicily	LCE
2018	May	4	North Adriatic	LCA, LCE
		2	Sicily Channel	LCE
	June	1	South Adriatic	LCE
		1	West Sardina	LCA
	July	1	West Sardina	LCA
		3	N-E Sardinia	LCA
	Sept.	3	Tyrrhenian Sea	LCE, LCH
		10	Asinara Gulf	LCA, LCE
		1	Gulf of Lions	LCE
2019	June	1	North Adriatic	LCE
		2	N-E Sardinia	LCA
	July	2	N-E Sardinia	LCA
	Sept.	6	Asinara Gulf	LCA, LCE
		4	N-E Sardinia	LCA
	Oct.	1	West Sardinia	LCE
	Nov.	4	N-E Sardinia	LCA
2020	May	2	Port of Olbia	LCA
	Oct.	9	Asinara Gulf	LCA, LCE, LCH
2021	Oct.	2	South Sardinia	LCE
		1	Tyrrhenian Sea	LCE
	Nov.	5	South Sardinia	LCE, LCF

Table 1. List of the 138 experiments between 1998 and early 2022. Acronyms indicate drifters per type: CLD, CODE, ODi, and the SouthTEK Nomad family LCA (GPRS), LCE (offshore), LCH (hybrid), LCF (with temperature sensor). Dates (year and month) and Starting Area indicate when/where the drifter was initially deployed.

Lagrangian drifters produced and sold by 4 different enterprises have been used in the years, with different characteristics in data transmission, structure, repeatability of the experiments, dimensions, batteries, management of the experiments.

2.1 Tracks 1998-1999: Coastal Lagrangian Drifter or CLD

The CLD was realised by InnoTech S.c.r.l., an Italian company located in La Spezia and specialised in marine instruments. The drifter was designed just for coastal use. It transmitted its GPS position, by a Trimble Lassen™ SK8, at a frequency of 5 minutes by a GSM mobile phone. The maximum operating time of the buoy was approximately 72 hours. The housing of the drifting buoy was in PVC with an electronic unit, a rechargeable battery pack and antennas. Dimensions and weight were 140 cm high (h) x 27 cm in diameter (d) per 12.5 Kg, respectively (figure 2A). The acquired position data was transmitted through a commercial modem to a dedicated software on a computer. This software, in a Windows™ environment, allowed the automatic reception of data from the buoy, provided for the control of the correct functioning of the system and for a quick and easy setting of the operating parameters (selection of the buoys used, interval of acquisition of the data, etc.). Transmitted data were collected into files in several formats including ASCII format with the extension DAT. This drifter was used for about six months, between July 1998 and January 1999 (table 1), for experiments of a few hours with the aim to study the surface circulation of the Gulf of Oristano (western Sardinia).

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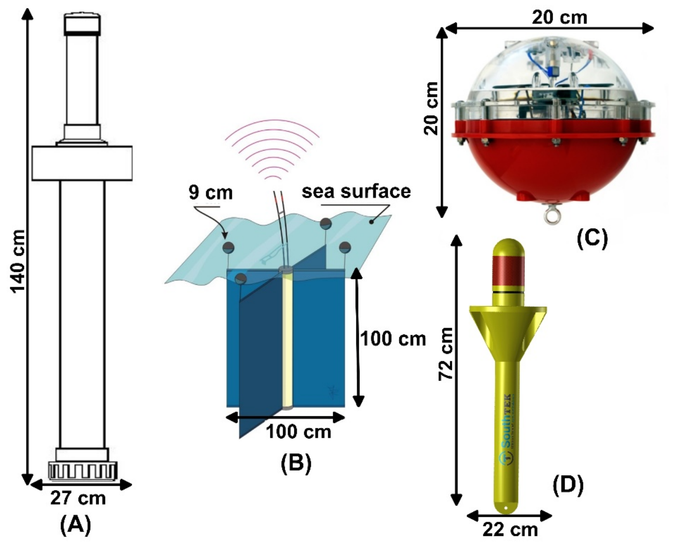

Figure 2. The four types of drifters used with their dimension in centimetres: A) CLD; B) CODE; C) ODi; D) LC (credits: ODi (C) from Albatros' leaflet; LC (D) from SouthTek's website)

2.2 Tracks 2009-2010: the CODE

Between May 2009 and September 2010 (table 1), CNR used the ArgoDrifter or CODE by Technocean (FL, USA) for studies in northern Sardinia. The instrument consisted of a white cylinder of 110 cm (h) x 15 cm (d) (figure 2B) with four arms placed at 90° each other supporting four blue sails, for a total area of about 25 m^2. Power was through batteries permitting operation till a year with an hourly data acquisition frequency, and were fitted with an ARGOS satellite transmitter, a GPS and a temperature sensor. Drifter position was measured by both satellite triangulation and GPS. GPS and ARGOS differ substantially in their accuracy of the positioning measurements. GPS accuracy has an average error of 4 m, with an ellipse of variance of axes of about 5-7 metres (Barbanti et al., 2005); the position measured by ARGOS satellite triangulation varies being linked with the number of visible satellites used from a minimum of 1 with an error of about 1.5 km to 3 or more satellites with less than 50 m of error. Direct slip measurements (Poulain et al., 2002; Poulain and Gerin, 2019), with acoustic current metres, show that CODE drifters follow surface currents with a tolerance of 0.1 percent of the wind speed and a movement consistent with the Ekman dynamics near the surface and a velocity component to the right of the prevailing wind. The wind-induced slips and the Ekman surface currents can also be estimated from drifter data using simple regression models which include complex drifter velocities and surface wind products (Ralph and Niiler, 1999; Rio and Hernandez, 2003; Centurioni et al., 2009; Poulain et al, 2009, 2012, 2013). These models show that the CODE wind-driven currents (slip + Ekman + Stokes) in the Mediterranean are about 1% of the wind speed, at an angle of about 30° to the right of the wind.

Drifters were set to measure their position every 4 minutes during each experiment strictly linked with the presence of satellites. In 2010, CNR modified CODE drifters inserting an external on/off switch, not present in the original instrument. This made it possible to carry out different experiments with the same instrument even after months. Data was downloaded from the ArgosWeb site, managed by the French Collecte Localization Satellites (CLS), in ASCII and/or in binary format. Subsequently they were subjected to post-processing, using Matlab codes provided by the OGS in Trieste. The median of the data was calculated for each interval then eliminating data outside the range established by the mean +/- three times their standard deviation.

This type of drifters was mainly used in northern Sardinia (Asinara Gulf and Bonifacio Strait) with some tracks acquired also in the northern Tyrrhenian Sea. Experiments have length from a few hours to over one month and realised to study the circulation in the Bonifacio Strait and La Maddalena Archipelago and the validation of a forecasting system for oil spill combat (Cucco et al., 2012; Ribotti et al., 2013) in the framework of the Italian SOS Bonifacio project (http://www.sosbonifacio.cnr.it/).

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2.3 Tracks 2014: the Iridium Ocean Drifter (ODi)

In September-October 2014 (table 1; Sorgente et al., 2015), CNR used the Iridium Ocean Drifter (ODi), made by the Spanish Albatros Marine Technology SA. It was a small, low-cost, and compact surface buoy to track sea currents obtained by a GPS module based on Iridium satellite data transmission system (Short Burst Data - SBD), a global full ocean coverage bidirectional satellite communication network. It was composed by two identical halves of a spherical drifter of 20 cm in diameter (figure 2C) and about half of it protruded above the sea surface. The ratio of drag area in the water to drag area outside the water was 16.9 (Callies et al., 2017). This makes it optimal for oil spill tracking and search and rescue operations. Its 5-litre volume and 3 Kg of weight allowed the use of a holey-sock drogue, while the presence of a solar power charging module, realised to reduce battery size, gave a theoretically unlimited autonomy. Standard measurements were GPS position/time, temperature, and battery level. The sampling frequency and transmission frequency were user-configurable through its software and internet connection. A sail (0.5 m length and diameter) was attached below every drifter to enhance the drag below the water surface. Data was acquired with a frequency of 20-30 minutes, during experiments. Despite the interesting structure suitable for studies on oil spills at sea, the drifter showed some technical problems that limited its use in long experiments. A first launch was scheduled in September 2014 in the Gulf of Cagliari, south Sardinia, with an acquisition over one month long in the framework of an exercise at sea, named Squalo 2014, with the local Coast Guard. Data was used to validate a high resolution ocean oil-spill forecasting model. Another short deployment, of less than 6 hours, was made a few nautical miles off the Oristano Gulf, western Sardinia.

2.4 Tracks 2015-2022: coastal and offshore Nomad drifters

Since December 2015 (table 1), CNR has been using Lagrangian drifters of the Nomad family produced by the Spanish SouthTEK Sensing Technologies S.L.. The buoys were of three types: coastal GPRS, offshore satellite and hybrid, using GPRS under mobile coverage otherwise the satellite transmission. Both GPRS one, namely the Coastal Nomad, and the satellite ones, the Offshore Nomad, are made in plastic, yellow colour, 72 cm (h) x 22 cm (d) (figure 2D) with a weight of 2.895 Kg. The same for the Hybrid Nomad drifters. The lithium batteries allow operations up to 7 days to the GPRS and several months to the satellite drifters. When in the water, only the yellow cylindrical head of about 16 cm is over the sea surface. Drifters transmit data in real time to a web portal called LD Manager where positions can be visualised in real time and data downloaded in different formats. Each drifter was identified by a letter, after the prefix LC, for type of transmission or sensors installed. So, *A* stands for a coastal GPRS drifter (LCA) while *E* for offshore satellite ones (LCE), *F* for offshore drifters with the temperature sensor (LCF) and *H* for hybrid drifters (LCH). The latter transmits both by GPRS, when in the GSM covered areas, and satellite when offshore. Below the water, two different drogues, namely *Pila* and *Satis*, could be anchored through a swivel shackle. The *Pila* was composed by two black joined plastic circles of 30 cm in diameter and used to follow the first layer of water, while the *Satis* was an orange PVC sea-drogue floating anchor 50 cm long, linked to the shackle through 3 mm polyester rope and positioned immediately below the drifter. Just in two experiments in the northern Adriatic Sea in 2018, for specific project reasons, the *Satis* drogue was positioned at 14 m depth on drifters LCE00234 and at 20 m on LCE00236, while once in 2019 at 14 m depth on drifter LCE00354. Data acquisition frequency varies from 5 minutes to 12 hours between experiments, but also during a single track, because of several situations or objectives like drifter deployment or recovery, distance from the coast, aim of the experiment. Usually for Coastal Nomad drifters (LCA) we used frequencies of acquisition between 5 and 30 minutes while for Offshore Nomad drifters from 15 minutes to 12 hours. Thanks to its ease of use, in drifter management or in data visualisation and downloading, their use is still going on. In the years they have been used for environmental and oceanographic studies both at coastal and offshore scale but also for the validation of ocean forecasting and oil-spill systems in open ocean (SOS Piattaforme project, http://www.seaforecast.cnr.it/sos-piattaforme) and coastal areas (Sicomar plus project; http://www.seaforecast.cnr.it/sicomarplus) or ports (Geremia project, http://seaforecast.cnr.it/geremia). Experiments have length from a few hours to over 12 months with data covering the most of the dataset presented here.

3. Data processing method

Pre-processing of all 138 tracks started immediately after the end of any experiment. From each file, repeated positions or wrong date/time in data were manually deleted as spikes, visible on plotted tracks, usually generated by failure of the GPS receiver. On CLD data, then before the year 2000, spikes were particularly present as GPS was mainly for military

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use with systematic wrong position till 950 m. Over the years the positioning system accuracy improved thanks to an increase in the availability of the number of satellites and in the improvement of GPS receivers.
After this first raw check, a unique excel file including all the experiment data was generated and drifter data were prepared to be ingested and elaborated by the procedure implemented at OGS as schematically shown in figure 3.

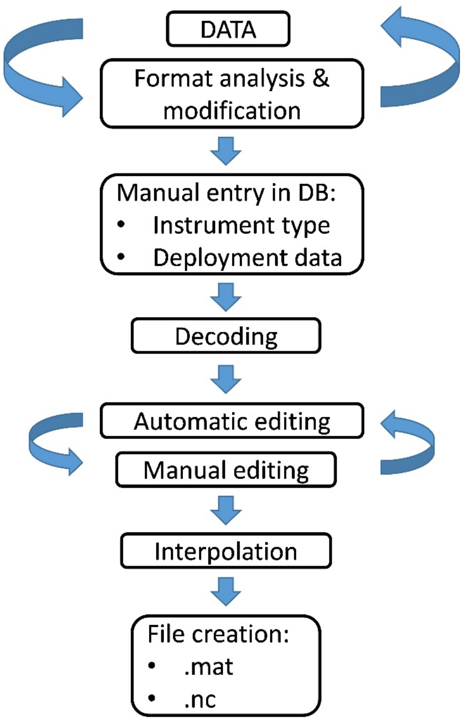

Figure 3. The processing procedure implemented at OGS from data acquisition (top) to file creation in Matlab/NetCDF formats.

This procedure is the result of more than 15 years of experience improving scripts and tests and is capable of handling over 80 different types of drifters, processing them in the same way, and providing a common and therefore easily comparable set of files and metadata (Gerin and Bussani, 2011; Menna et al., 2017). As a first step, the original excel file collecting all tracks was splitted into several text files corresponding to the data provided by the different drifters. These files may include data from different experiments. Deployment and recovery information was retrieved from the original dataset and from the experiment notes and filled into a database management system based on the PostgreSQLfree software (https://www.postgresql.org/) at OGS. The database was then enriched with other important metadata as the type and characteristics of the instruments, the owner and the principal investigator.
Ad-hoc decoding scripts were then implemented so as to associate the values contained in the files to the corresponding parameters (i.e.: time, longitude and latitude) and extract the data into single experiments discarding repeated set of data. Exceeding spaces and spurious characters were removed to obtain data files compliant with the ASCII standard.
Decoded drifter data were then edited through the automatic procedure that replaced location errors with *NaNs*, evaluating: positions outside the Mediterranean; possible GPS data acquired before the beginning of the experiment; duplicated data due to transmission repetitions; duplicated GPS position acquired at different times; data having speed larger than 300 cm/s (deployment position was considered good); data having speed larger than a threshold from a polynomial fit of degree 4 (calculated every 20 points); position data collected at wrong time; positions on land.
After the automatic editing procedure, some erroneous data still remained and required a visual check with the decision of an operator in order to be removed manually. In case of important temporal gaps or acquisition frequency modification during the drifter experiment, the drifter trajectory was split into two segments and considered as two different deployments. New recovery/deployment information was included in the database and the automatic procedure

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relaunched. In case of stranding, the automatic editing procedure discarded only the data on land and was unable to recognise the moment when the drifter went ashore. A dedicated custom Matlab tool assisted the operator to define the exact stranding time.

Edited data were then interpolated at uniform intervals using a kriging optimum interpolation technique based on the correlation of the data (Hansen and Poulain, 1996). In particular, drifter data with acquisition frequency between a few minutes and 2 hours were interpolated at 1-hour intervals, while those with acquisition frequency till or more than 6 hours at 3-h and 6-h intervals, respectively. The velocities were then calculated as finite differences of the interpolated position. From the original 138 experiments, 366 drifter tracks were edited. The shortest composed of a few data only were deleted, not allowing for a good interpolation. At the end of the whole procedure, the final dataset consists of 204 interpolated drifter tracks (figure 4).

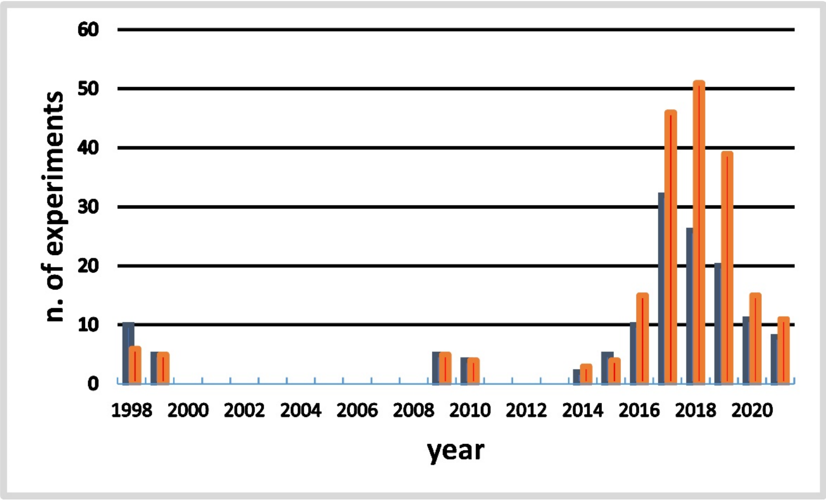

Figure 4. The histograms show th number and distribution per year of start of the experiments between 1998 and 2021 before (in grey) and after (in orange) the splitting of the tracks.

These splitted tracks mainly cover some areas of the Mediterranean like the seas around Sardinia, the northern Tyrrhenian Sea, with the highest concentration of data for the whole period, and the Liguro-Provençal basin while just a few in other areas like the Adriatic Sea, the Ionian Sea or the Gulf of Lions (figure 5).

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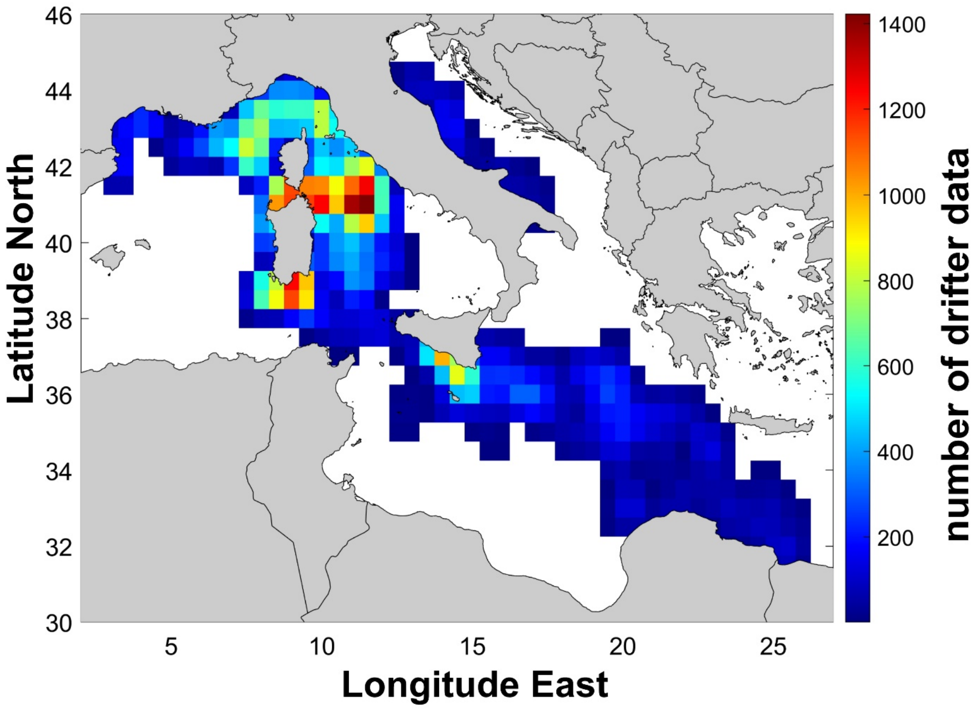

Figure 5. The distribution of drifters' data per pixel of half degree for the whole period 1998-2022. White pixels mean no data.

This figure highlights the areas mainly of interest in several research projects that requested surface current experiments like the Bonifacio Strait, the northern Tyrrhenian Sea and the Sicily Strait often used for the validation of ocean numerical systems (Cucco et al., 2012; Ribotti et al., 2013).

4. Data availability

The dataset described is publicly available and free from the data repository in the *SEANOE* (SEA scieNtific Open data Edition) service at https://doi.org/10.17882/90537 (Ribotti et al., 2022). The presented dataset is composed of the interpolated data in NetCDF files which include time, latitude, longitude, zonal and meridional speed, and metadata.

5. Discussion and conclusion

Between mid-1998 and 2021 the CNR collected drifters' data from 138 experiments carried out all over the Mediterranean in the framework of scientific and operational projects or international exercises at sea for preparedness and response activities to oil spill or SAR emergencies. Despite funding projects' objectives, experiments at sea were planned to use data also for different activities or scientific interests and/or needs like the validation of ocean circulation or oil spill models. So, as for any scientific measurement, there is always a duality between "fit for purpose", i.e., the projects that funded drifters and experiments, and "fit for use", i.e., the possibility of reusing the data for different objectives. This

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duality was facilitated by rechargeable drifters (the most of those in the dataset) that, after recovering, could be used in further experiments and new data acquisitions.

Then, after the pre-processing of the data by the CNR in Oristano followed by the accurate elaboration by the OGS, all data in the dataset are comparable between them, even if realised with different drifters and in different years. Further, this dataset is also compliant and can be interfaced with the other drifter datasets produced by OGS in the Mediterranean and Black Sea which collect about 1700 drifter data starting from 1986 (Menna et al., 2017; Menna et al., 2018a; Menna et al., 2018b; Menna et al., 2019; Gerin et al., 2020), then permitting to have a huge amount of drifter data available for scientific purposes in the Mediterranean basin (circulation, climate, etc).

Moreover, these data are not part of other already existing databases and, therefore, they can be found just in this dataset. Last, the dataset presented here collects 204 interpolated drifter tracks till April 2022 (end of the last experiment; see table 1), but authors are going to include those acquired in future experiments. Then we can image it as open and not definitive, often updated with new and comparable surface Lagrangian data.

Author contribution

AR led some projects with the use of drifters, all experiments, and the writing of the paper. AB finalised editing procedures described in the paper and collaborated on the paper writing. RG verified all data, realised the dataset, and collaborated on the paper writing. MM verified all processed data and collaborated on the paper writing. AS prepared all experiments and collaborated on the paper writing. RS and AC led some projects with the use of drifters and collaborated on the paper writing.

Competing interests

The authors declare that they have no conflict of interests.

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