Deep water hydrodynamic observations around a Cold-Water Coral habitat in a submarine canyon in the Eastern Ligurian Sea (Mediterranean Sea)

Tiziana Ciuffardi[1], Zoi Kokkini[2], Maristella Berta[2], Marina Locritani[3], Andrea Bordone[1], Ivana Delbono[1], Mireno Borghini[2], Maurizio Demarte[4], Roberta Ivaldi[4], Federica Pannacciulli[1], Anna Vetrano[2], Davide Marini[5], Giovanni Caprino[5]

[1] ENEA - Centro Ricerche Ambiente Marino Santa Teresa, Via S. Teresa, 19032 Lerici, La Spezia, Italy

[2] Consiglio Nazionale delle Ricerche - Istituto di Scienze Marine (CNR-ISMAR) Sede Secondaria di Lerici, Forte Santa Teresa s.n.c, 19032, Lerici, La Spezia, Italy

[3] Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata, 605 00143 Roma, Italy

[4] Istituto Idrografico della Marina, Passo dell'Osservatorio 4, 16134 Genova, Italy

[5] Distretto Ligure delle Tecnologie Marine scrl, Viale Nicolò Fieschi 18, 19123 La Spezia, Italy

Correspondence to: Tiziana Ciuffardi (tiziana.ciuffardi@enea.it)

Abstract. A 2-year dataset of a stand-alone mooring, deployed in November 2020 down the Levante Canyon in the Eastern Ligurian Sea, is presented. The Levante Canyon Mooring (LCM) is a deep submarine multidisciplinary observatory positioned at 608 m depth, in a key ecosystem area. The Levante Canyon hosts a valuable and vulnerable ecosystem of deep-living Cold-Water Corals (CWC), studied and monitored since 2013 through the integrated mapping of seabed and water column. The 2-year dataset, acquired on the mooring and presented here (data from November 2020 to October 2022), includes measurements conducted with both current meters and Conductivity Temperature Depth (CTD) probes, and provides information about the hydrodynamics and thermohaline properties across almost the entire water column. The observatory is still on-going and the dataset is regularly updated. All the described data are publicly available from https://doi.org/10.17882/92236 (Borghini et al., 2022). They must therefore be preserved and are of considerable scientific interest.

1 Introduction

The Mediterranean Sea is often seen as an incredible open-air laboratory ideal to study processes and ecosystems at different spatial and temporal scales. It is both a climate-change and biodiversity hotspot, characterised by a high level of marine endemism but also subjected to a constant increase in anthropogenic pressures (e.g. fishing, including deep sea, aquaculture, tourism, exploration and production of oil & gas, coastal development) and their effects (e.g. eutrophication, climate change, proliferation of alien species).

The huge biological complexity characterising marine communities makes the development of ecological monitoring increasingly indispensable, beyond the traditional time-consuming, high-cost sampling cruises, especially for the deep sea where less information is available. Furthermore, identifying and quantifying the effect of different anthropogenic stressors on marine ecosystems requires an integrative and multidisciplinary approach (encompassing the simultaneous measurement of biogeochemical and oceanographic variables). To this purpose, there are many observational systems and initiatives for the study and monitoring of the Mediterranean that see Italian institutions as main actors. One of these initiatives, in particular, is characterised by the collaboration, in terms of human resources, infrastructures and instruments, among: the Ligurian DLTM (Ligurian District of Marine Technologies acting as coordinator), CNR-ISMAR (National Research Council-Institute of Marine Sciences), ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), IIM (Italian Navy - Hydrographic Institute) and INGV (National Institute of Geophysics and Volcanology). These institutions have developed an observatory composed of two stations: the first one deployed at 10 m of depth in the Gulf of La Spezia, at the Santa Teresa Bay (where a smart observatory is under development, https://smartbaysteresa.com/), and the second one installed in the Levant Canyon in the Eastern Ligurian Sea (Figure 1), the so-called Levante Canyon Mooring (LCM hereafter). The coastal station monitors temperature, pressure, water conductivity and derived salinity (Bordone et al., 2022) and its main purpose is the study of coastal ecosystems, hydrodynamic processes and, in the long term, the effects of climate change. Moreover, the station hosts an experiment of plastic and bioplastic degradation in marine environments (De Monte et al., 2022).

The LCM provides temperature, salinity, pressure and horizontal currents in order to monitor the water dynamics in a Mediterranean sub-basin, extremely interesting for different aspects: the Eastern Ligurian Sea continental platform has a reduced extension and constitutes an exclusive marine observation point, not only because it is located inside the "Pelagos Sanctuary", an area with a high concentration of cetaceans, but also for the presence of the submarine Levante Canyon, an underwater canyon off Cinque Terre, almost parallel to the coast, which, due to the intensified bottom currents and the considerable contribution of sediments and organic substances, creates an environment favourable to the development and growth of valuable ecosystems such as deep corals.

The installation of the LCM was aimed to investigate this peculiar deep-sea area where a joint study by ENEA and IIM carried-out in 2013-2014, with the support of a ROV (Remotely Operated Vehicle), highlighted the presence of living colonies of *Madrepora oculata* (Cold-Water Corals, CWC) at a depth of about 570 m (see Figure 1 and Delbono et al., 2014; Pratellesi et al., 2014; Fanelli et al., 2017). These organisms give rise to deep ecosystems with high biodiversity, but suffer a strong impact caused by trawling. It is well documented that these kinds of areas should be prioritised in monitoring (e.g., Canals et al., 2006; Thurber et al., 2014), as they play a fundamental role in shelf-slope connectivity and in the ecological status of continental margins.

60

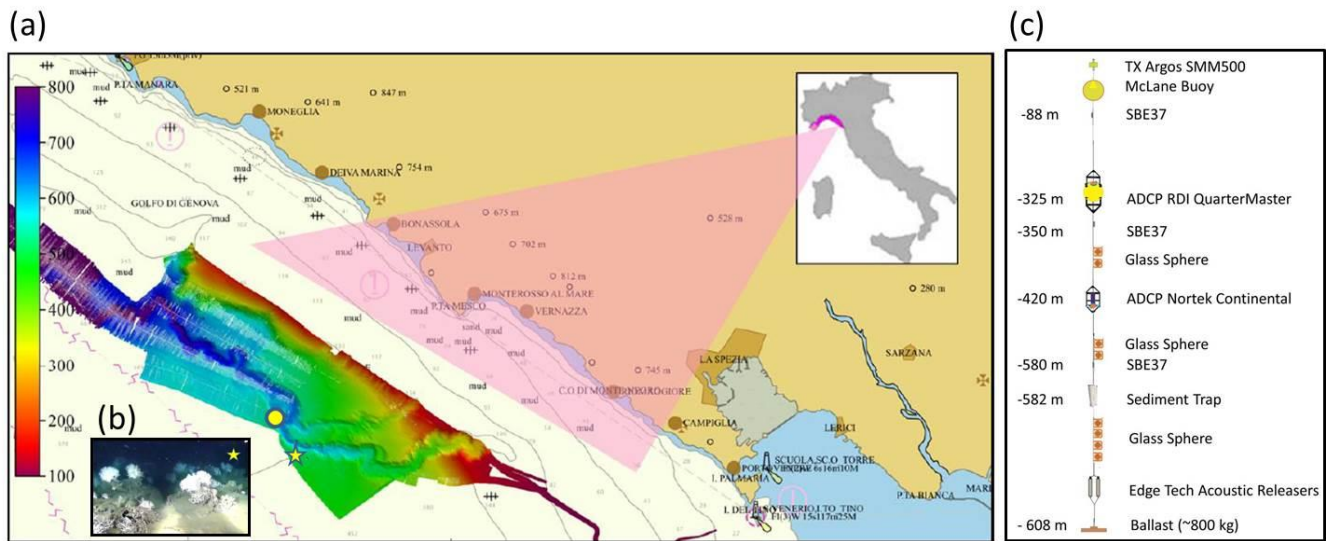



Figure 1: Study Area. panel (a) represents the Eastern Ligurian Sea with the superimposed 2D view of the Levante Canyon (modified from Pratellesi et al., 2014). The yellow circle represents the mooring while the yellow star is positioned at the point where dense populations of living, 1 m high colonies of *Madrepora oculata* were found by ENEA and IIM in 2014 (a detail is reported in panel (b)). Panel (c) represents the mooring layout (not in scale).

65   The coastal dynamic of the Ligurian Sea is characterised by an East-West cyclonic flux composed of waters arriving from both sides of Corsica Island: warm waters coming from the Tyrrhenian Sea through Corsica channel and cold waters rising from the Western Mediterranean current. Merging at the North of Corsica, these two circular fluxes generate a current with intermediate properties (Astraldi and Gasparini, 1992). Strong time (mainly seasonal) and spatial variations characterise Eastern Ligurian circulation with complex circulation patterns especially in summer. The area is characterised by several

70   sources of frontogenesis and development of meso-submesoscale instabilities (Ciuffardi et al., 2016): on the one hand, the interaction of coastal and shelf waters with the colder and saltier Northern Current (NC) at basin scale (Astraldi and Gasparini, 1985), on the other hand the interaction of coastal waters with buoyant river output, such as Arno and Magra rivers (Cattaneo Vietti et al. 2010; Schroeder et al. 2012). Wind forcing affects the upper layer circulation as well and therefore the interaction among water masses (Astraldi and Gasparini, 1986; Poulain et al., 2020). The interplay of water masses at different scales

75   generates meso-submesoscale fronts and filaments which have been recognized to play an important role in the surface dispersion and patchiness of various types of tracers (biological, pollutants and marine debris), as well as in the transfer from the surface to the interior ocean. The challenge in observing directly the submesoscale range, due to the high variability in both time and space, recently encouraged a transnational (Italy-France) multiplatform experiment in this same area under the framework of the JERICO-S3 Project, H2020 EU Programme (https://www.jerico-ri.eu/projects/jerico-s3/). In this context,

80   multiple observation platforms have been used to span across different scales and to provide comparable measurements (e.g., glider SeaExplorer, CTD probe, Ferrybox, CARTHE drifters). The area of interest is also monitored by a HF radar network

(CNR-ISMAR group, http://radarhf.ismar.cnr.it) providing continuous (hourly) sea surface current maps covering medium ranges (about 40 km) with high resolution (approx. 1.5 km).

Despite a few studies focused on the variability in the area at short temporal-spatial scales (Locritani et al. 2010; Schroeder et al. 2012; Berta et al. 2020; Poulain et al. 2020), there are no studies, to our knowledge, focusing also on deep hydrodynamics, due to lack of targeted observations in the area. The extended time-series presented in this work aims to fill this gap. Data were continuously collected between November 2020 and October 2022 and provide unique observations about hydrodynamic processes of the site.

2 Data and methods

Data comes from the LCM, a shared infrastructure located in the Eastern Ligurian Sea (Figure 1a), at around 600 m depth in the Levante Canyon, offshore the Cinque Terre Marine Protected Area at 44°05.443' N, 9°29.900' E (Ciuffardi et al. 2020). It was first deployed in October 2019, but the instrumented line accidentally detached from the mooring site and drifted toward the French coast where instruments were collected to be finally re-deployed in fall 2020. LCM is a stand-alone offshore mooring, dedicated to the long-term monitoring of hydrological properties of water masses. The installation and maintenance operations of the LCM are carried out thanks to the CNR Research Vessel "Dallaporta" and to the "Leonardo" operated by the Italian Navy, allowing the deep observatory to be positioned at about 6.5 nautical miles off the coast. The mooring operates in delayed-mode and is equipped with sensors that measure physical and biogeochemical parameters along the water column from 83 m to 580 m. The 530 m long mooring scheme is represented in Figure 1c. Starting from the bottom (Figure 1c), the offshore monitoring station is equipped with a sediment trap placed at a depth of 582 m, which provides information on the supply of sediments and nutrients from the surface to the seabed. Further above, CTD probes are placed at three different depths, respectively at 579 m, 335 m and 85 m. The LCM also includes two Acoustic Doppler Current Profilers (ADCP), placed respectively at 406 m and 325 m depth, that measure currents throughout the water column, in order to monitor the link between near-surface waters and deep ones.

Both the ADCP systems measure the intensity and directions of currents along the water column and have a temperature sensor in their transducer head. The CTD probe provides measurements of temperature and salinity (along with pressure). Acoustic releases guarantee the recovery, by bringing the entire instrumented line back to the surface during ordinary or extraordinary maintenance. LCM, still operative, is configured and maintained for continuous long-term monitoring. Ordinary maintenance operations are planned every 6-8 months, when the whole structure is recovered for instrumentation check, data downloading, and maintenance (e.g., changing batteries and sediment trap bottles, cleaning, sensors' calibration or substitution of components).

The upward-looking ADCP used is an RDI QuarterMaster (Teledyne RD Instruments USA, Poway, California), using a four-beam, convex configuration with a beam angle of 20° and a working frequency of 153.6 kHz. The instrument is moored at a

mean nominal depth of 325 m with a number of depth cells set to 44, a cell size of 8 m and a blanking distance of 3.5 m. The temperature sensor has the following characteristics: range -5 ° C to 45 °C, precision ±0.4 °C, resolution 0.01 °C.

115   The downward-looking ADCP used is a Nortek Continental (Nortek AS, Norway), using a three-beam, convex configuration with a beam angle of 25° and a working frequency of 190 kHz. The instrument is moored at a mean nominal depth of 420 m with a number of depth cells set to 30 and a cell size of 8 m and a blanking distance of 6.1 m. The temperature sensor has the following characteristics: range -4 °C to 40 °C, precision 0.1 °C, resolution 0.01 °C.

Velocity accuracy is ±1 %, ±0.5 cm/s and the sampling interval is 1h for both the RDI and the Nortek. The sound speed is
120   computed by the pressure and temperature sensors embedded at the transducer head joint to the assumed salinity.

The three SBE37 CTDs deployed have the following characteristics for conductivity and temperature sensors respectively: range 0 to 70 mS/cm and -5 to 35 °C, accuracy 0.003 mS/cm and 0.002 °C, resolution 0.0001 mS/cm and 0.0001 °C. The probes are also equipped with a Strain-gauge pressure sensor with an accuracy of ± 0.1% of the full-scale range.

2.1 Dataset and Metadata description

125   The collection is composed of 5 datasets containing observational data and related metadata from the LCM mooring site for the period November 2020 – October 2022. Five files, two for ADCP data (in NetCDF format) and three for CTD data (in CSV format), have been submitted, and each file description specifies the probe and its depth (Borghini et al., 2022). Time series of ADCP echo intensities have also been included in the submitted data set (https://doi.org/10.17882/92236), stored in the NetCDF files.

130   The Metadata report Dataset Information (DI) contains a brief summary description of the dataset and details about their geospatial position, temporal extension and data interval, the institution responsible for measurements, principal investigator name and contact, the observational network to which the mooring belongs, the keywords vocabulary used. The Variables in Dataset (VD) contain specific information about the data structure and variables. The ADCP dataset provides details about the station name, the geographical position, the time coverage, the bottom depth, the cell depth/range and the current components.

135   The ADCP and CTD variables in the dataset are reported as quality controlled as results of QC procedure reported in the next chapter. The headers of filtered ADCP variables are followed by the suffix "_QC" and the appropriate flags by the suffix "_QC_flag".

Mooring deployment and maintenance operations took place regularly twice a year (i.e., on the 02/10/2021, 21/06/2022 and 15/10/2022). Table 1 reports all the most significant meta information about each sensor.

140

145

Table 1: Summary of meta information about all the sensors installed on the Levante Canyon Mooring.

Instrument	Deployment depth (m)	Data Range	Sample interval	Sample Depth (m)	Resolution	Accuracy
CTD SBE37	88 m	Conductivity 0 to 7 S/m Temperature -5 to 45 °C	10 min	-	Conductivity 0.00001 S/m Temperature 0.0001 °C	Conductivity ± 0.0003 S/m Temperature ± 0.002 °C
RDI QuarterMaster ADCP	325 m	Velocity range: ± 5 m/s Temperature -5 to 45 °C	1 h	Upward orientation ~25-320 m (Δz=8 m)	Velocity 1 mm/s Temperature 0.01 °C	Velocity ± 1% ± 0.5 cm/s Temperature: ±0.4 °C
CTD SBE37	350 m	Conductivity 0 to 7 S/m Temperature -5 to 45 °C	10 min	-	Conductivity 0.00001 S/m Temperature 0.0001 °C	Conductivity ± 0.0003 S/m Temperature ± 0.002 °C
Nortek Continental ADCP	420 m	Velocity range: ± 5 m/s Temperature -4 to 40 °C	1 h	Downward orientation ~430-610 m (Δz=8 m)	Velocity 1 cm/s Temperature 0.01 °C	Velocity ± 1% ± 0.5 cm/s Temperature ±0.1 °C
CTD SBE37	580 m	Conductivity 0 to 7 S/m Temperature -5 to 45 °C	10 min	-	Conductivity 0.00001 S/m Temperature 0.0001 °C	Conductivity ± 0.0003 S/m Temperature ± 0.002 °C
Sediment Trap	582 m	-	15 days	-	-	-

2.2 Data quality check

All data from LCM, after maintenance operations, are subjected to a quality validation system according to international
protocols and standards (IOC-UNESCO).

A first visual check of CTD data time series was first applied in order to detect spikes and anomalous values. This was made possible after a statistical analysis of our dataset on the property (i.e., temperature and salinity gradient) distribution and frequency to identify the proper thresholds. After these quality checks, the CTD at 88 m has been cut off in the plots at mid-March 2022 disregarding Conductivity data (and consequently, Salinity and Density) that were affected by fouling artefacts or calibration issues. Temperature data at 88 m were assumed as reliable up to the beginning of August 2022. To avoid similar issues in future deployments, the probe drift will be regularly verified and calibrated by conducting vertical profiles using a SeaBird SBE 19 plus calibrated probe.

For the RDI ADCP, the adopted QC procedure was based principally on the 'Manual for Real-Time Quality Control of In-Situ Current Observations' by IOOS (2019), along with the Crout and Conlee (2006) report by NOAA. Four groups of tests have

160 been applied: a) the sensors' overall health, including tests for the sensors' tilt and speed of sound control. Pressure sensors extremes for in & out of water check. Along with the sensors' overall health, a temperature despiking test is also applied, b) the signal quality test that controls the quality of the Transmitting/Receiving signal and includes the Correlation Magnitude (CM) test and the Percentage Good (PG) ratio, c) the current velocity tests that ensure the validity of the measured current and include the Horizontal and Vertical velocity control and the Error velocity test, and d) the overall profile tests, that control the

165 Echo amplitude (intensity) test.

The analysis and processing of the NORTEK data are done using the SURGE program provided by NORTEK (https://www.nortekgroup.com/softwarelicense/surge). For the Post-Processing, the configuration is the following: a) the Sidelobe rejection is set to 90%, and by that, as it is downward oriented, it neglects data near the bottom, b) the Low signal to Noise Ratio (SNR) threshold is set up to 3dB, c) allow removing tilt effects, d) the velocity variation test neglecting data over

170 five standard deviations (std), and e) the echo spikes test limit is set up to 70dB. Also, a temperature despiking test is applied as in the RDI dataset.

Both RDI and the NORTEK ADCP data are post-processed using a first-level Quality Control (QC). Figure 2 shows RDI time series of pitch, roll and tilt for reference.

A set of flags is used to describe the results of the QC. The OceanSites and Copernicus Marine In Situ flag scales were adapted,

175 simplified, and adjusted for a delayed mode of operation for flagging the data (Copernicus In Situ TAC, 2021). Table 2 explains the flags used in all the datasets.

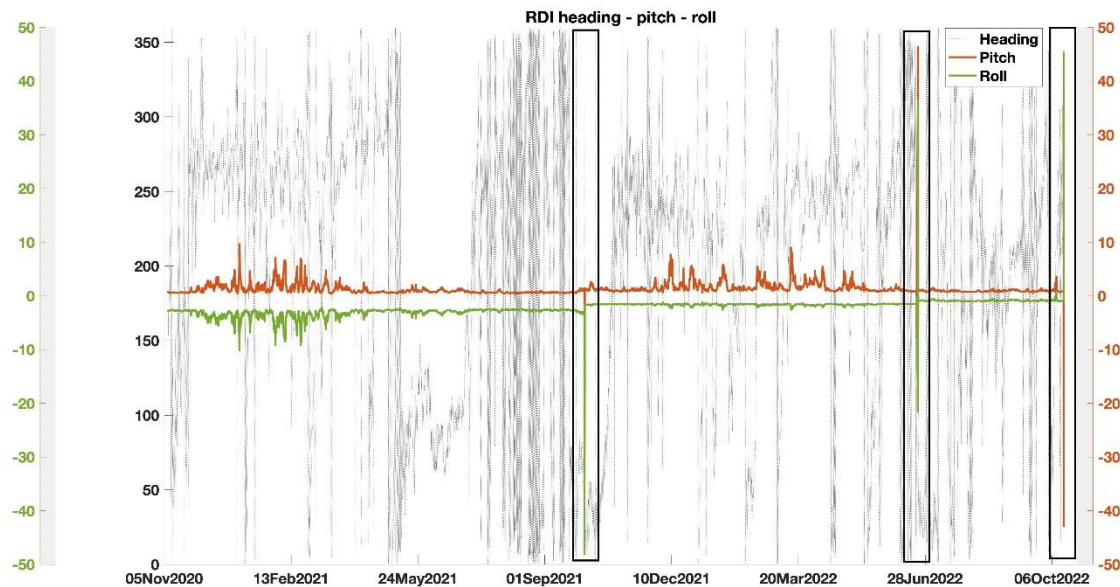



Figure 2: The heading, pitch and roll measurements (in degrees) from the RDI ADCP. The black boxes indicate each recovery.

180   **Table 2: Code of data qualifiers flags.**

Flags	Description	Result
0	-	No QC applied
1	Data have passed critical QC tests and are deemed adequate for use as preliminary data	Pass
2	Data are considered suspect or highly interesting to operators and users. They are flagged suspects to draw further attention to their operators	Suspicious data or high-interest data
3	Potentially correctable insufficient data. These data cannot be used without scientific correction or re-calibration	Potentially correctable bad data. These data are not to be used without scientific correction or re-calibration
4	Data are considered to have failed one (or more) critical QC checks. If they are disseminated at all, it should be readily apparent that they are not of acceptable quality	Fail
5	Value changed	Not Used
6	Value below detection	Not Used
7	Nominal values	Data were not observed but reported
8	Interpolated values	Missing data may be interpolated (Not used in our case)
9	Data are missing; used as a placeholder	Missing data

3. Results

The first two-year dataset of the LCM is presented here.

Hydrological data collected by the mooring and presented here (data from November 2020 to October 2022) include measurements conducted with both current meters and CTD probes, and provide information about the hydrodynamics and thermohaline properties across almost the entire water column. These data, presented below, constitute a fundamental knowledge for the understanding of the ecological conditions that apply to the CWC habitat and the conditions that favour the coral settlement in the Levante Canyon. Hydrological conditions along the water columns, through seasons and at the sea bottom are for the first time acquired in a deep observatory for long term monitoring of the health status of the *Madrepora oculata* ecosystem. A future work will integrate the observed hydrodynamic trends together with the LCM sediment trap data so that the interactions among oceanography, sediment input, biogeochemistry and spatial distribution of CWC biological communities will give an interdisciplinary overview and a deep understanding of the Levante Canyon system functioning.

3.1 Thermohaline records

Temperature records measured by the RDI ADCP (at 325 depth) and by the three CTD (at 88, 350 and 580 m depth) are presented here to compare data at different depths along the water column. Figure 3 shows the temporal sequence resulting from November 2020 to October 2022 across the canyon, considering both the CTD and ADCP measurements as regards temperature records around 325-350 m depth. The data are presented with a 3-day smoothing window. Temperature data recorded at 420 m depth by the Nortek ADCP have been disregarded as being too high due to electronic issues. As a fact, the instrument batteries discharged earlier than scheduled due to a probable overheating. On the contrary, it is interesting noting that the two time series at 325 m (ADCP) and 350 m (CTD) depth have synchronous fluctuations and slight differences. Temperature peaks are evident during winter 2020 and 2021, covering the upper water column around 88 m water depth. On the contrary, the intermediate and the deeper layers show less oscillations, even if some variability and colder periods are present. Interestingly the measurements cover the period during the spring-summer 2022, characterised by the exceptional heat wave that began in the second half of April 2022 and mainly overheated the central and north-western part of the Mediterranean. This heat wave is not so evident from our temperature records.

In the upper layer of the Levante Canyon the temperature recorded by the CTD at 88 m has a mean value of 14.33+/-0.35 °C with a minimum temperature of 13.44 °C in March 2022 and maximum of 17.93 °C in November 2021. At 325 m the ADCP highlighted an average temperature of 14.10+/-0.11 °C with a minimum temperature of 13.67 °C in May 2022 and maximum of 14.39 °C in February 2021, in accordance with the nearby CTD positioned at 350 m depth (mean temperature of 14.14+/-0.11 °C, minimum temperature of 13.68 °C in May 2022 and maximum of 14.42 °C in February 2021).

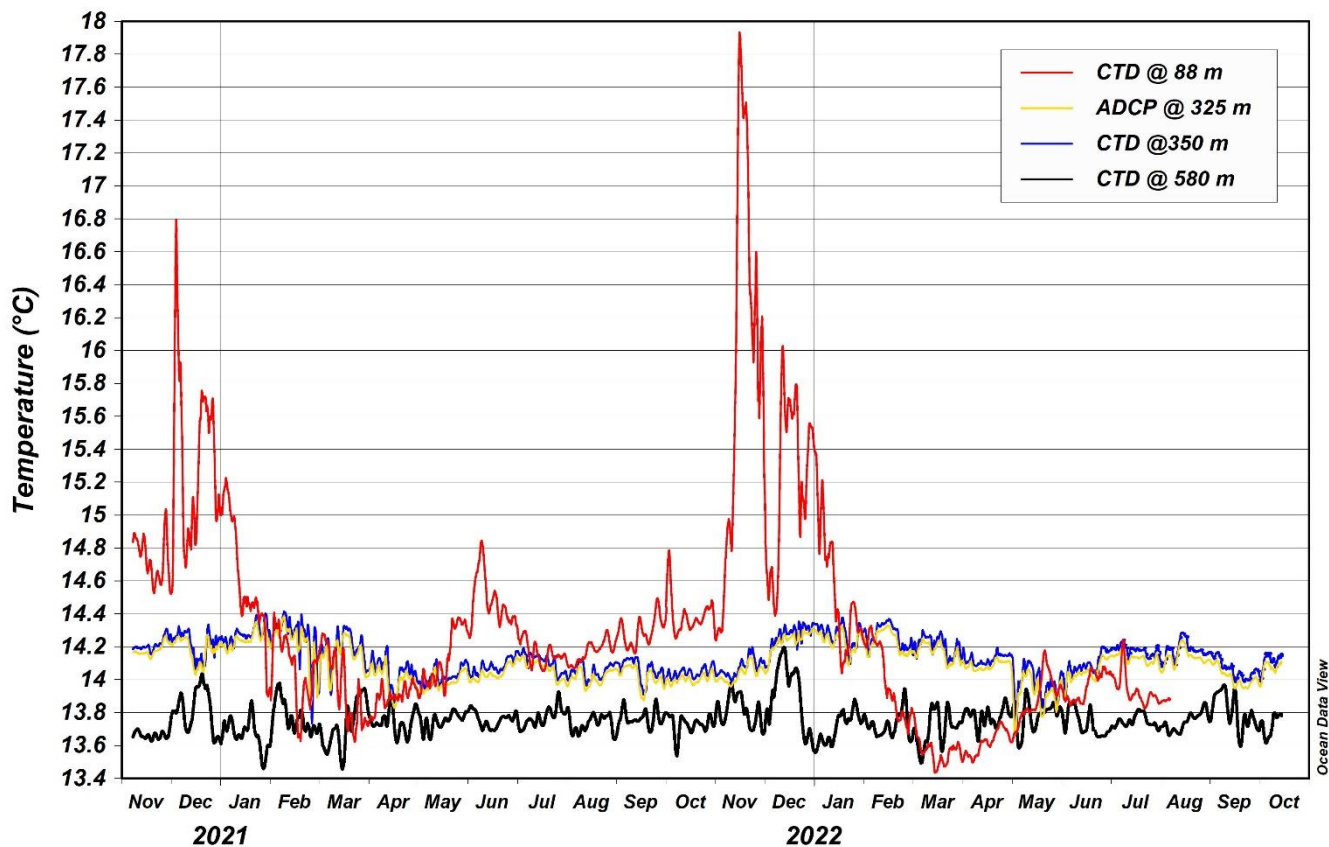



Figure 3: CTD and ADCP temperature records on LCM site. The data are presented with a 3-day smoothing window.

The mean difference between temperature measured by ADCP and CTD is in the range 0.03-0.05 °C (Table 3). In the deepest part of the mooring, near the bottom, at 580 m depth, the mean recorded temperature is 13.76+/-0.10 °C with a minimum temperature of 13.46 °C in March 2021 and maximum of 14.20 °C in December 2021.

The first CTD (from top, in the mooring layout) at 88 m depth well represents the seasonal cycle and the inter-annual variability in the first hundred metres of the water column, where temperature changes are more evident. In particular, the temperatures experienced high peaks during the autumn-early winter months: this is the result of a periodic annual cycle where surface warmer waters, after the summer heating, experienced strong vertical mixing from November until January, producing a period of vertical homogeneity of the surface layers (at least up to 88 m according to the measurements). Wind episodes from late summer through fall contribute to this vertical mixing. On the contrary, solar radiation in spring and summer periods results in the development of water column stratification with greater differences in the annual temperature variation at the sea surface compared with that in the underlying layers (at 88 m). The only exception looks like early summer 2021 when temperatures in the upper layer still oscillate, proving some inter-annual variability.

225 With regards to salinity measurements, the latest data from the CTD probe at 88 m and all the data from the CTD at 350 m were not plotted as they failed QC due to calibration issues. Hence the data at 88 m depth ends in March 2022 in Figure 4. In general, seasonal variability shows the necessity to have regular maintenance operations to have proper salinity measurements. The salinity is lower in the upper layer of the Levante Canyon, where the salinity recorded by the CTD at 88 m has a mean value of 38.01+/-0.05 PSU with a minimum of 37.87 PSU and maximum of 38.17 PSU. Near the bottom, at 580 m depth, the

230 time-series of salinity shows intermediate values with respect to upper and deeper parts: the mean recorded salinity is 38.54+/-0.03 PSU with a minimum of 38.48 PSU and maximum of 38.61 PSU. Again, larger oscillations are evident for the upper layer at 88 m depth, while salinity values are less variable in the deepest part of the canyon (Figure 4).

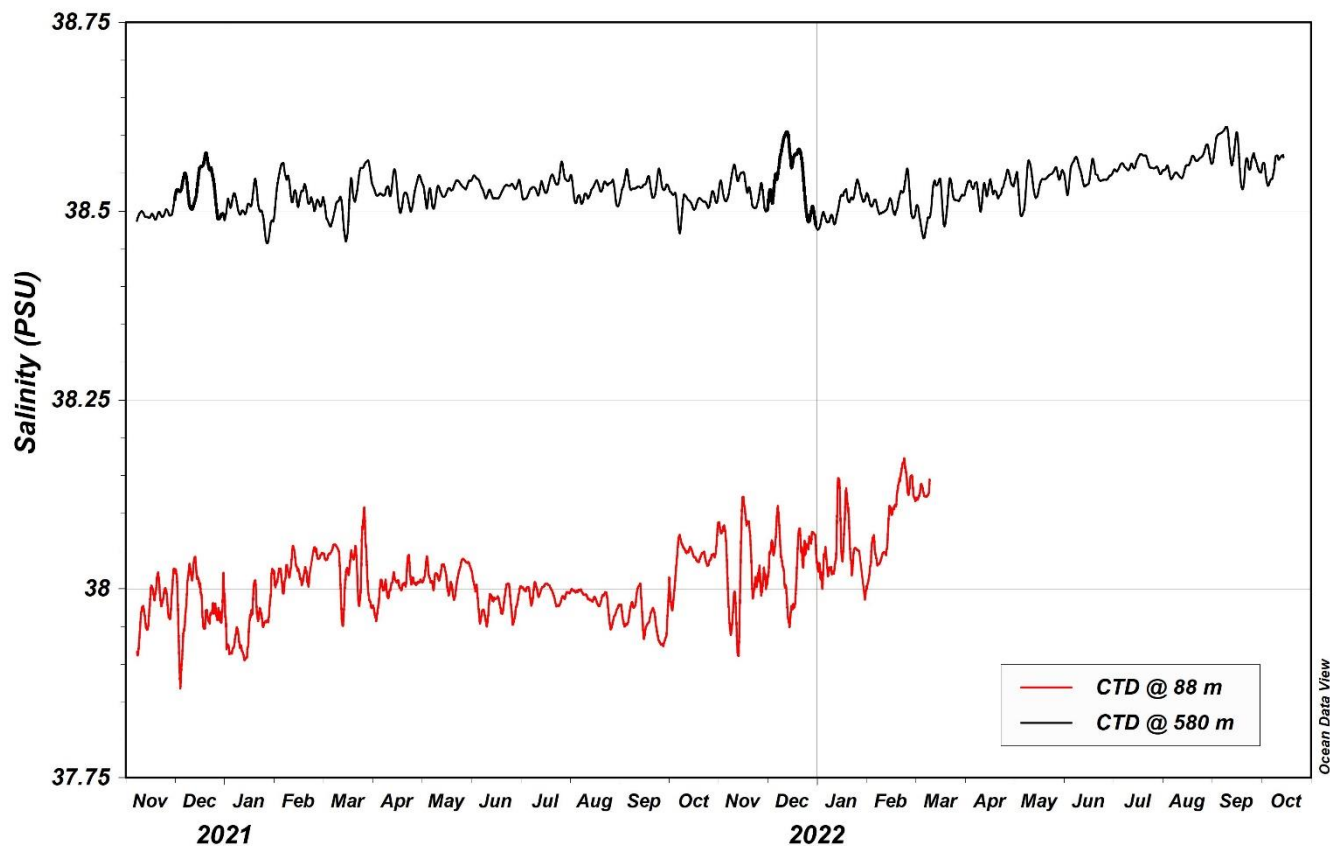



Figure 4: CTD salinity records on LCM site. The data are presented with a 3-day smoothing window.

235 The potential temperature vs. salinity (T S) diagram of the whole data set is shown in Figure 5. The large variability at 88m indicates the complex water mass structure subjected to strong seasonal influence of heat and water exchanges with the atmosphere, while close to the bottom there is a tight correlation indicating relatively unchanging water masses at these depths in the region, with values in the ranges 13.3-14.1 °C and 38.4-38.6 PSU, at 580 m depth. These values are consistent with the characteristics of the surface water of Atlantic origin (Atlantic water, AW; upper 150 m) and of the Levantine Intermediate

Water (LIW; from about 200 to 700 m depth) recorded for the western Mediterranean (Iacono et al. 2021; Fedele et al., 2022) and Ligurian Sea (Margirier et al., 2020; Prieur et al. 2020). Statistics about temperature and salinity records grouped by months are reported in Table 3 and Table 4.

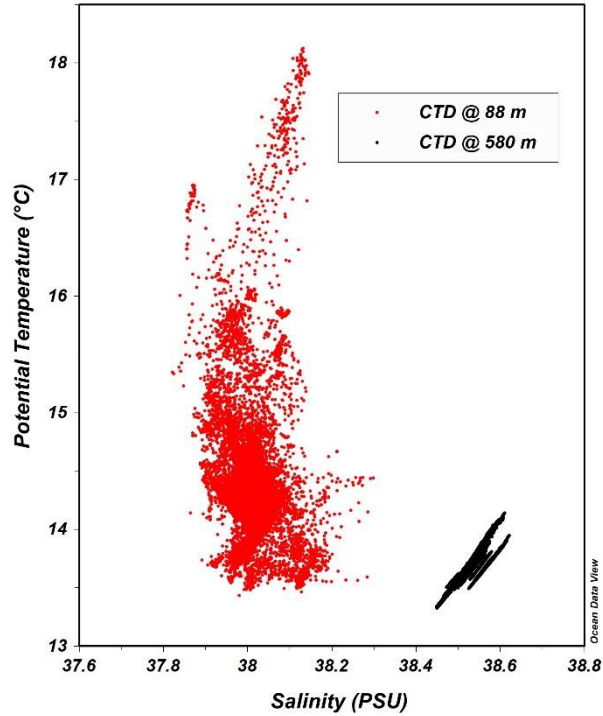



Figure 5: Temperature-salinity (T-S) diagram for the LCM site, obtained from CTD measurements covering the period November 2020 – October 2022.

Table 3: Statistical parameters of the 3-days averaged temperatures vs. months in the LCM site. SD stands for Standard Deviation. Both ADCP and CTD data are reported for the depth 325/350 m respectively. The mean difference between temperature measured by ADCP and CTD is in the range 0.033-0.051 °C.

Month	CTD @ 88 m				ADCP/CTD @ 325/350 m								CTD @ 580 m			
	Mean	SD	Min	Max	Mean		SD		Min		Max		Mean	SD	Min	Max
					CTD	ADCP RDI	CTD	ADCP RDI	CTD	ADCP RDI	CTD	ADCP RDI				
	(°C)				(°C)								(°C)			
January	14.585	0.356	13.898	15.399	14.278	14.243	0.057	0.053	14.094	14.088	14.401	14.358	13.693	0.092	13.461	13.882
February	14.131	0.153	13.625	14.408	14.266	14.227	0.106	0.099	13.735	13.849	14.415	14.385	13.751	0.086	13.623	13.980
March	14.052	0.167	13.435	14.280	14.197	14.161	0.084	0.077	13.907	13.891	14.327	14.282	13.705	0.121	13.457	13.949
April	13.894	0.064	13.497	14.009	14.088	14.047	0.069	0.068	13.860	13.829	14.204	14.142	13.759	0.062	13.618	13.897
May	14.105	0.164	13.619	14.379	14.002	13.951	0.076	0.081	13.676	13.668	14.161	14.113	13.767	0.070	13.585	13.943
June	14.477	0.152	13.843	14.845	14.078	14.038	0.076	0.049	13.676	13.890	14.161	14.150	13.750	0.061	13.654	13.865
July	14.173	0.077	13.826	14.384	14.148	14.107	0.050	0.047	13.997	13.969	14.242	14.190	13.761	0.048	13.686	13.928
August	14.165	0.062	13.855	14.302	14.112	14.073	0.080	0.077	13.965	13.932	14.286	14.240	13.742	0.052	13.638	13.862
September	14.292	0.083	14.159	14.494	14.066	14.020	0.059	0.057	13.910	13.874	14.169	14.120	13.788	0.083	13.596	13.969
October	14.398	0.112	14.248	14.786	14.062	14.022	0.048	0.043	13.967	13.950	14.164	14.110	13.725	0.059	13.537	13.801
November	14.636	0.337	14.238	17.934	14.134	14.097	0.083	0.085	13.993	13.958	14.309	14.268	13.749	0.100	13.626	13.983
December	14.920	0.280	14.388	16.793	14.237	14.204	0.078	0.074	14.033	14.030	14.353	14.312	13.869	0.161	13.590	14.199

Table 4: Statistical parameters of the 3-days averaged salinity data vs. months in the LCM site. SD stands for Standard Deviation.

Month	CTD @ 88 m				CTD @ 580 m			
	Mean	SD	Min	Max	Mean	SD	Min	Max
	(PSU)				(PSU)			
January	37.998	0.061	37.890	38.147	38.504	0.019	38.457	38.543
February	38.040	0.029	37.994	38.173	38.519	0.018	38.491	38.564
March	38.034	0.031	37.951	38.145	38.512	0.027	38.460	38.567
April	38.002	0.017	37.957	38.045	38.527	0.013	38.497	38.555
May	38.017	0.014	37.985	38.043	38.532	0.016	38.493	38.567
June	37.983	0.019	37.950	38.030	38.539	0.014	38.516	38.572
July	37.995	0.009	37.977	38.009	38.547	0.017	38.515	38.576
August	37.985	0.014	37.946	38.000	38.544	0.020	38.506	38.588
September	37.961	0.022	37.924	38.007	38.555	0.027	38.510	38.611
October	38.037	0.023	37.972	38.071	38.526	0.025	38.470	38.574
November	38.026	0.054	37.911	38.122	38.514	0.021	38.487	38.561
December	38.015	0.043	37.868	38.110	38.540	0.032	38.482	38.605

3.2 Hydrodynamic records

This section reports the hydrodynamic data measured by the two ADCPs along the water column in the LCM site, from 2020 to 2022. For better visualisation, in order to better solve the dynamic variability of the water column, data have been separated in 5 vertical layers of approximately 100 m each: UL (Upper Layer) 25-150 m, UIL (Upper Intermediate Layer) 150-250 m, IL (Intermediate Layer) 250-350 m, LIL (Lower Intermediate Layer) 400-500 m and BL (Bottom Layer) 500-600 m depth. For each layer, polar scatter diagrams have been plotted, with speed sorted every 0.2 m/s.

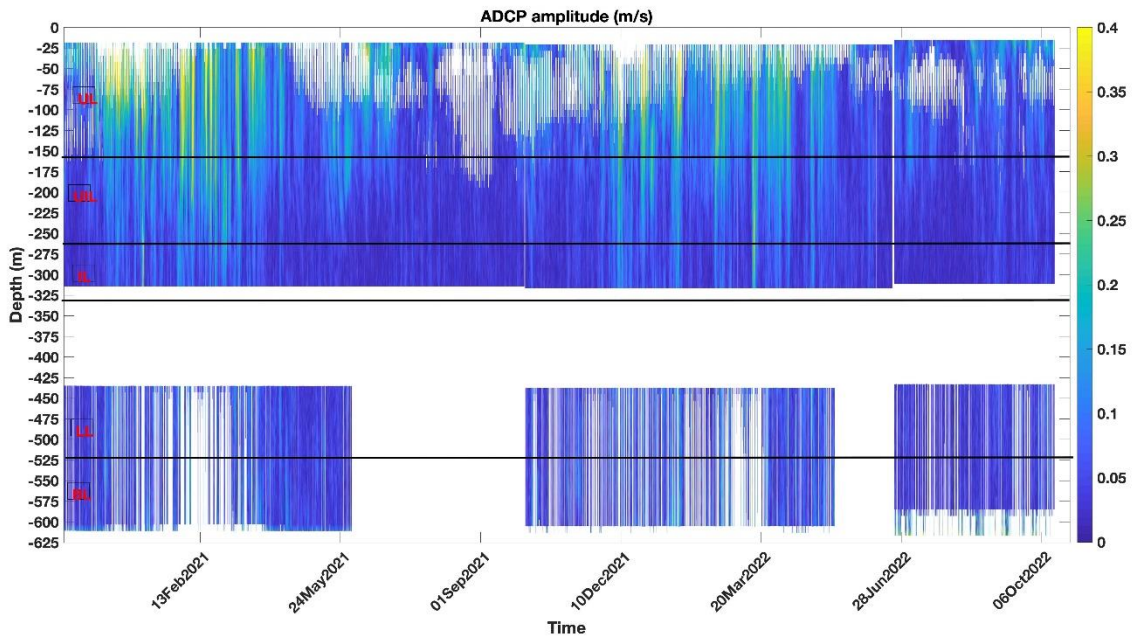
Figure 6 shows the 2-years-long ADCP records as vertical distribution of the speed module along the water column, while polar scatterplots are reported in Figure 7, which represent the direction and intensity of currents along the water column. Current data shows an average weak hydrodynamic field at the BL (0.06+/-0.02 m/s) able to reach a speed of 0.76 m/s at about 50 m water depth during events of strong current. From Figure 6, these currents are generally recorded during winter-early spring (between December and April) every year and affect the whole water column. Stronger currents also occur during summer 2021, but remain confined to the UL and UIL layers. The hydrodynamic field of the five selected layers is characterised by currents spreading between 120-180 °N and between 270-330 °N. This behaviour indicates a flow oriented toward the canyon axis (see Figure 1). A northward prevailing current component is evidenced by the reported scatter plots close to the bottom: in the two deeper layers (i.e., LIL and BL) this directional spreading slightly rotates assuming a North-South orientation. This is in accordance with the role of the topography that in a deep canyon acts modifying the current direction close to the bottom.

270

Figure 6: Currents speed records (in m/s) along the LCM water column (data filtered as described in the data quality check section), boxes on the left and straight lines indicate the 5 different layers assumed in the analysis (UL: Upper Layer; UIL: Upper Intermediate Layer; IL: Intermediate Layer; LIL: lower intermediate layer; BL: Bottom Layer)

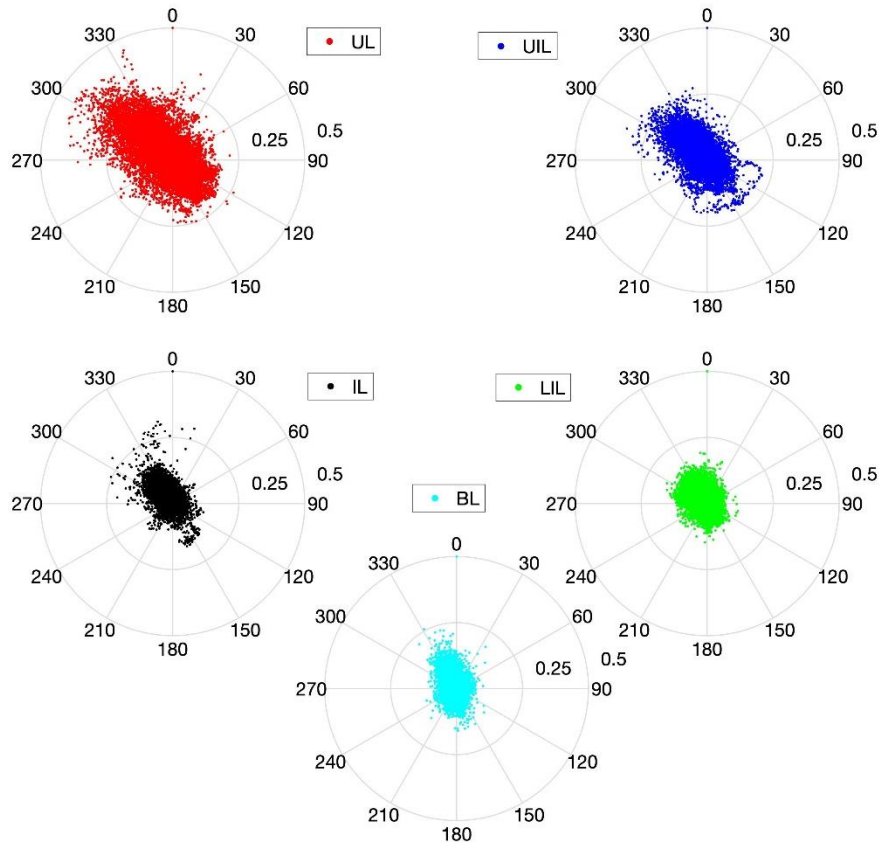



Figure 7: **Polar scatter plot of observed directional current velocity (m/s) on the LCM site. (UL: Upper Layer; UIL: Upper Intermediate Layer; IL: Intermediate Layer; LIL: Lower Intermediate Layer; BL: Bottom Layer).**

Figure 8 shows the time series of the five layers by applying a daily average smoothing. Focusing on the U (East) and V (North) components from the ADCP (Figures 9 and 10), the time series shows a reversal of the U component in summer/early fall both for 2021 and 2022. Especially in June-July period, the U component shows significant positive sign (from West to East), while the typical Northern Current (NC) negative sign (from East to West) prevails during winter, also associated with larger V magnitude compared to the summer period. The NC episodic and local reversal during summer has been observed as well in surface (1 m depth) by current maps from the CNR-ISMAR HF radar network covering the area nearby the mooring since 2016 (http://radarhf.ismar.cnr.it/). The future combination of these datasets gives the opportunity to further investigate the origin of the reversal, the coherence of the signal throughout the water column (also considering the typical strongly stratified waters profile in summer), and to what extent the current reversal affects the canyon dynamics.

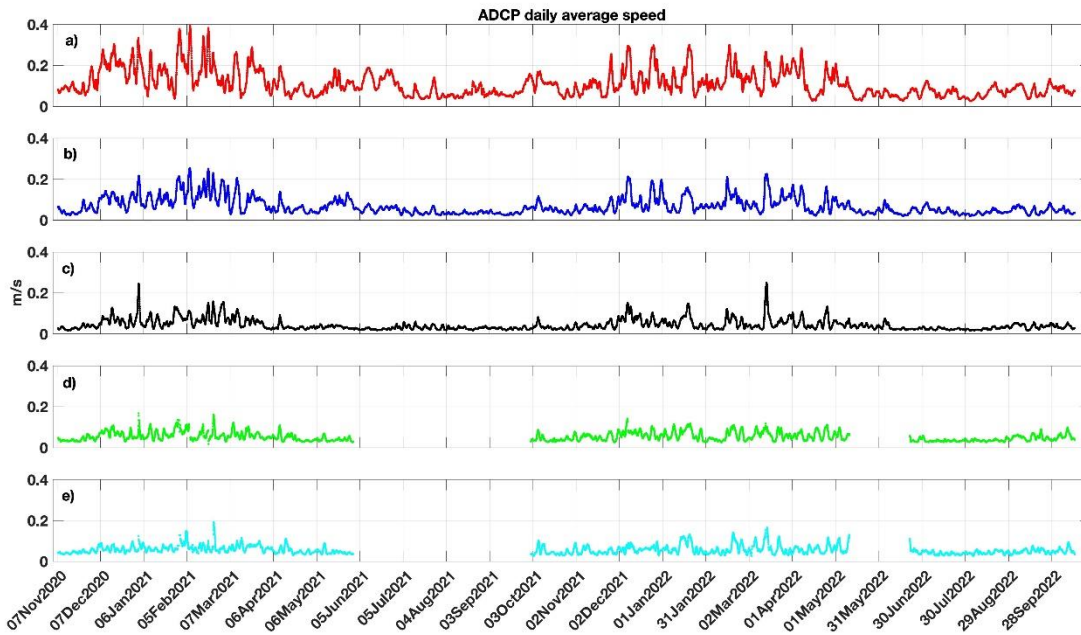



Figure 8: Time series of the current speed (m/s) in the 5 different layers assumed in the analysis by applying a daily average smoothing (UL: Upper Layer; UIL: Upper Intermediate Layer; IL: Intermediate Layer; LIL: Lower Intermediate Layer; BL: Bottom Layer).

290

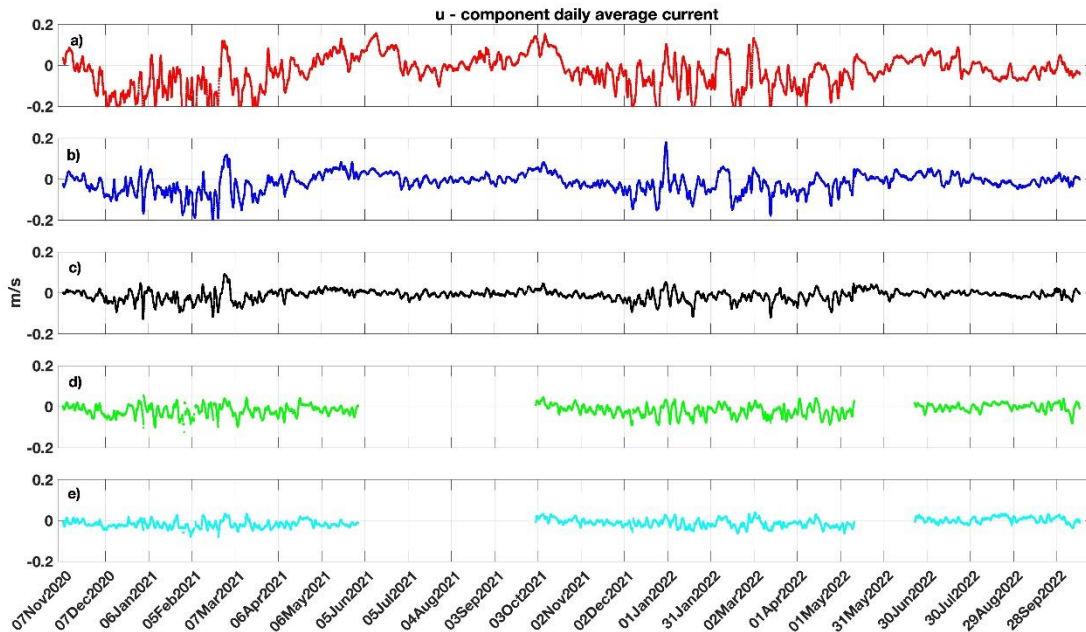



Figure 9: Time series of the East component of the current speed (m/s) in the 5 different layers assumed in the analysis by applying a daily average smoothing (UL: Upper Layer; UIL: Upper Intermediate Layer; IL: Intermediate Layer; LIL: Lower Intermediate Layer; BL: Bottom Layer).

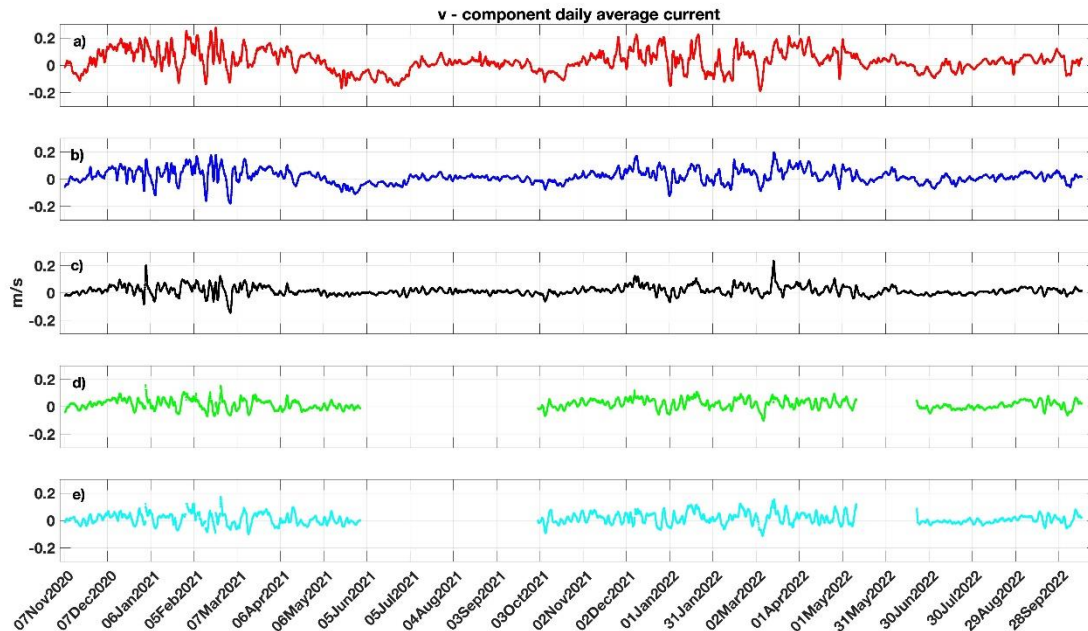



Figure 10: Time series of the of the North component of the current speed (m/s) in the 5 different layers assumed in the analysis by applying a daily average smoothing (UL: Upper Layer; UIL: Upper Intermediate Layer; IL: Intermediate Layer; LIL: Lower Intermediate Layer; BL: Bottom Layer).

4. Conclusions

This paper presents the results of the first 2 years data acquired on the Levante Canyon Mooring conducted in the Eastern Ligurian Sea, throughout the installation in 2020 of a mooring line placed in a canyon area at about 600 m depth, characterised by the presence of cold-water living corals. This activity was realised thanks to a multidisciplinary framework, where some of major national research centres (CNR-ISMAR, DLTM, ENEA, IIM and INGV) cooperate under the coordination of the DLTM.

The LCM, equipped with two ADCP, three CTD probes and a sediment trap, provides valuable and original hydrodynamic and thermohaline measurements along the water column (approximately from 50 m depth up to the bottom) in a deep canyon site. The LCM initiative can represent an innovative regional Centre where members can calibrate, compare and test instrumentations or share tools favouring a sustainable technological development in the marine and maritime transport sectors. Furthermore, it can link with the various regional monitoring systems already in existence in both the Tyrrhenian and Ligurian Sea regions, contributing to create a regional network of experimental marine stations. This will meet national and international demand for the protection of the marine environment and its potential for innovation and growth (Marine Strategy and Blue Growth). Its data can nourish studies about human impact on coastal and port areas to stimulate the implementation of European directives and/or national/regional laws (e.g., ecosystem approach and environmental status evaluation).

Analysed data extended from 2020 to 2022 and are characterised by seasonal cycle in the first hundred metres of the water column with strong vertical mixing during autumn and winter against water column stratification in spring and summer. This was also stressed by Picco et al. (2010) in their work on the Ligurian Sea, where they described a vertical thermal structure in the upper thermocline characterised by a high variability during winter, related to the presence of the Ligurian front, the occurrence of internal waves and the wind mixing.

The time series covers the period of summer 2022, characterised by the exceptional heat wave interesting the central and north-western part of the Mediterranean. In this period the ESA-funded project CAREHeat (https://eo4society.esa.int/projects/careheat/) reports that the Ligurian Sea was particularly affected as the peak of the heat wave reached its surface waters in late July, with temperatures of five degrees above average, and, despite a slight drop in temperatures at the end of August, the heat wave was still evident in the measurements of September. From the temperature data in the LCM site, this heat wave is not so evident in the upper layer, where the temperatures are lower than those of summer 2021, whereas a slightly positive increasing is recorded for the lower CTD records.

From a hydrological point of view, water mass distribution resulting from the T-S diagrams in the LCM site is coherent with previous evidence in the Ligurian Sea: the canyon area is characterised by the presence of two main water masses: 1) Surface water of Atlantic origin (Atlantic Water, AW; upper 150 m), well separated from the underlying intermediate water, and 2) the Levantine Intermediate Water (LIW) that occupies the layer between 200 m and 500-700 m of depth. This is something that should be accurately verified during next data recovery and probe calibrations, even if already previously documented by Prieur et al. (2020), as regards coastal and frontal zones of the Ligurian Sea.

The first 2-years' time-series is presented here, but further detailed studies and long-term series of geophysical and hydrological data are necessary to better understand the bottom dynamics, the seabed and water column interaction and the ecological conditions of valuable ecosystems in the Levante Canyon and in the Ligurian Sea more in general, a challenging area for geological, geophysical, oceanographic and ecological research.

5. Data availability

All data is made publicly available through https://www.seanoe.org/data/00810/92236/. The registered database DOI is https://doi.org/10.17882/92236 (Borghini, et al., 2022).

This paper describes in detail the temporal coverage of the dataset, which is constituted by quite continuous high temporal resolution time series of currents, temperature and salinity from November 2020 to October 2022. The adopted methodology about settings, data records and quality control procedures ensure compliance and consistency of the dataset. The dataset presented here ends in October 2022 but monitoring activities are still in progress and future data collected by this deep observatory will be added to an updated version of the repository at least every 2 years.

6. Author contribution

Conceptualization, T.C., Z.K. and M.Be.; Field measurements and data management, M.Bo., A.B., M.D., Z.K.; Data processing and analysis, T.C. and Z.K.; TC prepared the manuscript with contributions from all co-authors. All authors have read and agreed to the published version of the manuscript.

7. Competing interests

The authors declare that they have no conflict of interest.

8. Acknowledgements

The Levante Canyon Mooring is co-financed by DLTM through funding obtained from Regione Liguria (PAR-FSC 2007-2013 funds) and by institutional funds from CNR-ISMAR, ENEA, IIM, and INGV. The authors are deeply indebted to the Captain and the crew of the CNR R/V "Dallaporta" and MM "Leonardo" for continuous support during the whole measurement/deployment phases.

References

Astraldi, M. and Gasparini G.P.: Elements for a comparison between the Tyrrhenian and Ligurian coastal currents during spring, Il Nuovo Cimento, C, 8, 842-850, https://link.springer.com/article/10.1007/BF02558014, 1985.

Astraldi, M. and Gasparini, G.P.: Observation of pressure and wind fields over the Ligurian and Tyrrhenian Seas (West Mediterranean), Meteorl. Atmos. Phys., 35, 139–148, https://doi.org/10.1007/BF01026170, 1986.

Astraldi, M. and Gasparini, G. P.: The seasonal characteristics of the circulation in the north Mediterranean basin and their relationship with the atmospheric-climatic conditions, J. Geophys. Res., Oceans 97, no.C6, 9531-9540, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/92JC00114, 1992.

Berta, M., Corgnati, L., Magaldi, M. G., Griffa, A., Mantovani, C., Rubio, A., Reyes, E., and Mader, J.: Small scale ocean weather during an extreme wind event in the Ligurian Sea, in: Copernicus Marine Service Ocean State Report, Issue 4, J. Oper. Oceanogr., 13, 149–155, https://doi.org/10.1080/1755876X.2020.1785097, 2020.

Bordone, A., Ciuffardi, T., Delbono, I., Pannacciulli, F., Raiteri, G., Locritani, M., Muccini, F., Cocchi, L., Demarte, M., Ivaldi, R., Berta, M., Borghini, M., Vetrano, A., Caprino, G., Marini, D. and Schierano, E.: LabMare Coastal station: A shallow water cabled observatory in the Eastern Ligurian Sea, SEANOE, https://doi.org/10.17882/87643, 2022.

Borghini M., Bordone A., Ciuffardi T., Kokkini Z., Demarte M., Ivaldi R., Delbono I., Berta M., Locritani M., Vetrano A., Raiteri G., Muccini F., Pannacciulli F., Marini D. and Caprino G.: Moored current and temperature measurements in a

submarine canyon of the Eastern Ligurian Sea, November 2020-October 2022. SEANOE. https://doi.org/10.17882/92236, 2022.

Canals, M., Puig, P., De Madron, X.D., Heussner, S., Palanques, A. and Fabres, J., Flushing submarine canyons. Nature, 444, 354–357, https://www.nature.com/articles/nature05271, 2006.

Cattaneo Vietti, R., Albertelli, G., Aliani, S., Bava, S., Bavestrello, G., Benedetti Cecchi, L., Bianchi, C.N., Bozzo, E., Capello, M., Castellano, M., Cerrano, C., Chiantore, M., Corradi, N., Cocito, S., Cutroneo, L., Diviacco, G., Fabiano, M., Faimali, M., Ferrari, M., Gasparini, G.P., Locritani, M., Mangialajo, L., Marin, V., Moreno, M., Morri, C., Orsi Relini, L., Pane, L., Paoli, C., Petrillo, M., Povero, P., Pronzato, R., Relini, G., Santangelo, G., Tucci, S., Tunesi, L., Vacchi, M., Vassallo, P., Vezzulli, L. and Wurtz, M.: The Ligurian Sea: present status, problems and perspectives, Chemistry and Ecology 26(S 1):319–340. DOI: 10.1080/02757541003689845, 2010.

Ciuffardi, T., Napolitano, E., Iacono, R., Reseghetti, F., Raiteri and G., Bordone, A.: Analysis of surface circulation structures along a frequently repeated XBT transect crossing the Ligurian and Tyrrhenian Seas, Ocean Dyn. 66, 767–783, https://doi.org/10.1007/s10236-016-0954-y, 2016.

Ciuffardi, T., Berta, M., Bordone, A., Borghini, M., Celentano, P., Cocchi, L., De Fabritiis, L., Delbono, I., Delfanti, R., Demarte, M., Ivaldi, R., Kokkini, Z., Locritani, M., Marini, D., Marini, S., Muccini, F., Pannacciulli, F., Peirano, A., Raiteri, G., and Vetrano, A.: A new multidisciplinary observatory in the Eastern Ligurian Sea (NW Mediterranean Sea): a combination of deep-sea and coastal measurements, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-16533, https://doi.org/10.5194/egusphere-egu2020-16533, 2020.

Copernicus Marine In Situ Tac Data Management Team: Copernicus Marine In Situ NetCDF format manual, https://doi.org/10.13155/59938, 2021.

Crout R. L. and Conlee, D. T.: Quality Control of Minerals Management Service - Oil Company ADCP Data at NDBC: A Successful Partnership Implementation, OCEANS, 1-5, doi: 10.1109/OCEANS.2006.307072, 2006.

Delbono, I., Ivaldi, R., Pratellesi, M., Fanelli, E., Peirano, A., Cocito, S., Dialti, L. and Delfanti, R.: Seafloor morphology: nature of the seabed and the cold water corals of the Levante Canyon (eastern Ligurian Sea, NW Mediterranean), Geophys. Res. Abstr., 16, EGU 2014-14732, https://ui.adsabs.harvard.edu/abs/2014EGUGA..1614732D/abstract, 2014.

De Monte C., Locritani, M., Merlino, S., Ricci, L., Pistolesi, A. and Bronco, S.,: An In Situ Experiment to Evaluate the Aging and Degradation Phenomena Induced by Marine Environment Conditions on Commercial Plastic Granules, Polymers, 14, 1111. https://doi.org/10.3390/polym14061111, 2022.

Fanelli, E., Delbono, I., Ivaldi, R., Pratellesi, M., Cocito, S. and Peirano, A.: Cold-water coral Madrepora oculata in the eastern Ligurian Sea (NW Mediterranean): historical and recent findings. Aquatic Conservation: Mar. Freshw. Ecosyst., https://doi.org/10.1002/aqc.2751, 2017.

Fedele, G., Mauri, E., Notarstefano, G. and Poulain, P.M.: Characterization of the Atlantic Water and Levantine Intermediate Water in the Mediterranean Sea using 20 years of Argo data, Ocean Sci., 18, no. 1, 129-142, https://doi.org/10.5194/os-18-129-2022, 2022.

Iacono, R., Napolitano, E., Palma, M, Sannino, G.: The Tyrrhenian Sea Circulation: A Review of Recent Work. Sustainability,
405   13, 6371. https://doi.org/10.3390/su13116371, 2021.

Locritani, M., Chiappini, M., Chiarabini, R., Bruni, F., Ciccarelli, V., Natale, L. and De Pauli, R.: Hydrological and physical
characterization of Cinque Terre Marine Protected Area (Ligurian Sea) and evaluation of current velocity and direction by
AUV navigation tracks. OCEANS 2010 MTS/IEEE SEATTLE, Seattle, WA, 1-8, doi: 10.1109/OCEANS.2010.5664052,
2010.

410   Margirier, F., Testor, P., Heslop, E., Mallil, K., Bosse, A., Houpert, L., Mortier, L., Bouin, M.-N., Coppola, L., D'Ortenzio,
F., de Madron, X. D., Mourre, B., Prieur, L., Raimbault, P., and Taillandier, V.: Abrupt warming and salinification of
intermediate waters interplays with decline of deep convection in the Northwestern Mediterranean Sea, Sci. Rep.-UK,10,
20923, https://doi.org/10.1038/s41598-020-77859-5, 2020.

Picco, P., Cappelletti, A., Sparnocchia, S., Schiano, M.E., Pensieri, S. and Bozzano, R.: Upper layer current variability in the
415   Central Ligurian Sea, Ocean Sci. 6, no. 4, 825-836, https://doi.org/10.5194/os-6-825-2010, 2010.

Poulain, P.M., Mauri, E., Gerin, R., Chiggiato, J., Schroeder, K., Griffa, A., Borghini, M., Zambianchi, E., Falco, P., Testor,
P. and Mortier, L.: On the dynamics in the southeastern Ligurian Sea in summer 2010, Cont. Shelf Res., 196, 104083,
https://doi.org/10.1016/j.csr.2020.104083, 2020.

Pratellesi, M., Ivaldi, R., Delbono, I.: Dual use Hydrographic Surveys for Seabed Nature and Morphological Research.
420   Integrated Mapping of Seabed Features. Hydro International, 18 (7), 26-29, 2014.

Prieur, L., D'Ortenzio, F., Taillandier, V., and Testor, P.: The Mediterranean Sea in the Era of Global Change 1, chapter 3:
Physical Oceanography of the Ligurian Sea, John Wiley & Sons, Ltd. 10.1002/9781119706960.ch3, 2020.

Schroeder, K., Chiggiato, J., Haza, A.C., Griffa, A., Özgökmen, T.M., Zanasca, P, Molcard, A., Borghini, M., Poulain, P.M.,
Gerin, R., Zambianchi, E., Falco, P. and Trees, C.: Targeted Lagrangian sampling of submesoscale dispersion at a coastal
425   frontal zone, Geophys. Res. Lett., 39, L11608, doi:10.1029/2012GL051879, 2012.

Thurber, A.R., Swetman, A.K., Narayanaswamy, B.E., Jones D.O.B., Ingels J. and Hansman R.L.: Ecosystem function and
services provided by the deep sea. Biogeosciences, 11, 3941–3963, doi:10.5194/bg-11-3941-2014, 2014.

Tanhua, T., Pouliquen, S., Hausman, J., O'Brien, K., Bricher, P., de Bruin, T., Buck, Justin J. H., Burger, E.F., Carval, T.,
Casey Kenneth, S., Diggs, S., Giorgetti, A., Glaves, H., Harscoat, V., Kinkade, D., Muelbert, J. H., Novellino, A., Pfeil, B.,
430   Pulsifer, P. L., Van de Putte, A., Robinson, E., Schaap, D., Smirnov, A., Smith, N., Snowden, D., Spears, T., Stall, S., Tacoma,
M., Thijsse, P., Tronstad, S., Vandenberghe, T., Wengren, M., Wyborn, L. and Zhao, Z. Ocean FAIR Data Services. Front.
Mar. Sci., 6, doi:10.3389/fmars.2019.00440, 2019.

U.S. Integrated Ocean Observing System, Manual for Real-Time Quality Control of In-Situ Current Observations. Version
2.1. Silver Spring, MD, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean
435   Service, Integrated Ocean Observing System, 54, https://doi.org/10.25923/sqe9-e310, 2019.