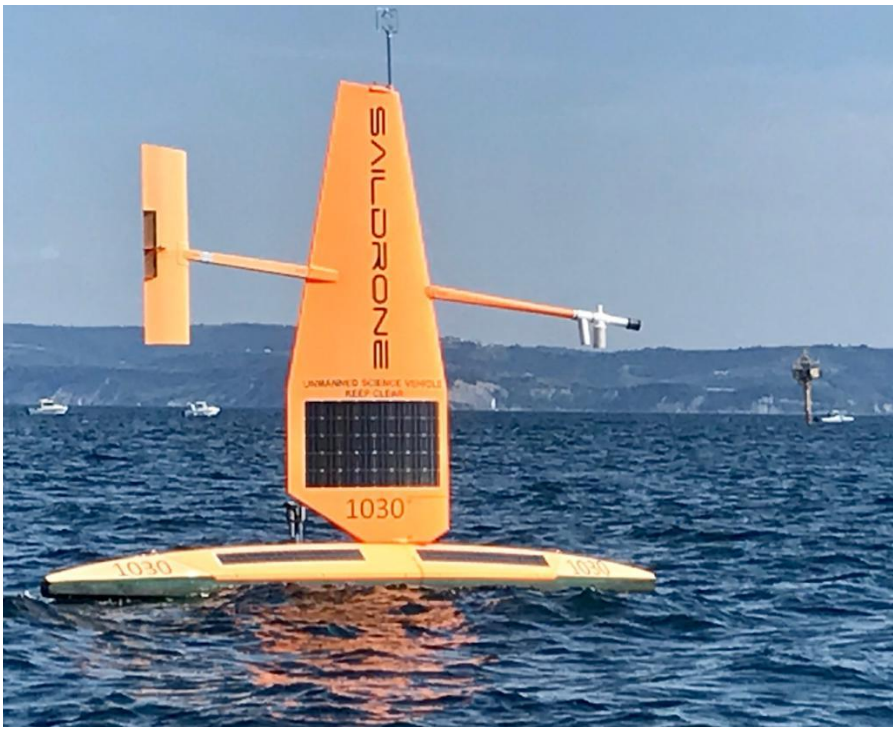
The ATL2MED mission - experiences and lessons learnt

Technical report



SD-1030 and the Paloma station in the Bay of Trieste (photo: ARPA-FVG)

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Contents

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Introduction

The ATL2MED mission was a joint effort between a group of European institutions/projects and the US company Saildrone, where two Autonomous Surface Vehicles (ASV) from Saildrone sailed from Cape Verde in the Atlantic Ocean to the Gulf of Trieste in the Mediterranean Sea. The mission started in October 2019 and ended in July 2020.

The ATL2MED mission was a result of a joint application from GEOMAR (DE) and ICOS-OTC (NO/UK), where two experiments were proposed: the first being eddy studies in the Canary Current upwelling system off West Africa and the second was the validation of CO_2 measurements at fixed ocean stations in the Atlantic Ocean and Mediterranean Sea. The mission was funded primarily from the US company PEAK 6 Invest, but also Saildrone and all involved institutions contributed to the experiments. During spring and summer 2019, more institutions joined in and thus more experiments were proposed. As the experiment started in October 2019, the following institutions and persons were involved:

- Integrated Carbon Observation System-Ocean Thematic Centre (ICOS-OTC): Ingunn Skjelvan
- GEOMAR Helmholtz Centre for Ocean Research Kiel (GEOMAR): Björn Fiedler
- Ocean Science Centre Mindelo (OSCM): Björn Fiedler
- Oceanic Platform of the Canary Islands (PLOCAN): Carlos Barrera
- University of Cádiz (UCA): Alfredo Izquierdo
- Instituto Hidrográfico (IH): Ines Martins, Joao Vitorino
- Balearic Islands Coastal Observing and Forecasting System (SOCIB): Mélanie Juza, Joaquín Tintoré
- Laboratoire Océanographique de Villefranche (LOV): Laurent Coppola (SU-CNRS)
- Consiglio Nazionale delle Ricerche - Istituto per lo studio degli impatti Antropici e Sostenibilità in ambiente marino (CNR-IAS): Roberto Bozzano, Sara Pensieri
- Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS): Vanessa Cardin, Michele Giani, Elena Mauri
- Consiglio nazionaledelle RIcerche - Istituto di scienze marine (CNR-ISMAR): Anna Luchetta, Carolina Cantoni

The ATL2MED mission represented the first monitoring experiments of such ASVs both in the Eastern Tropical North Atlantic (ETNA) and into the Mediterranean Sea. The mission lasted nine months covering all seasons with varying meteorological and oceanic conditions, ocean productivity, and maritime traffic. This report is an overview of experiences and lessons learnt, in order to provide guidance and support for similar missions in the future.

Area and aims

The study area for the ATL2MED mission extended from the ETNA area to the Gulf of Trieste in the northern Adriatic Sea in the Mediterranean Sea, crossing the Strait of Gibraltar, the Strait of Sicily and the Strait of Otranto, mainly covering the northern part of the western and central Mediterranean Sea (Figure 1). The ETNA area is characterized by the wind-driven and relatively cold Canary Current flowing southwards and generating numerous eddies along the West African coast. The heavily trafficked Strait of Gibraltar connects the Atlantic Ocean to the Mediterranean Sea and is the place where the surface currents are in general strong and density driven with tidal influence on top. The Mediterranean Sea is characterised by a basin wide anticlockwise circulation, with numerous cyclonic and anticyclonic eddies populating the entire basin as well as three areas of deep-water formation (the north-western Mediterranean, the Adriatic Sea, and the Aegean Sea).

The aim of the ATL2MED was multiple: to study eddies in the Canary Current upwelling system off West Africa in conjunction with a vessel-based research expedition (RV Meteor M160) and to validate the CO_2 measurements at the fixed ocean stations Cape Verde Ocean Observatory (CVOO), the French DYFAMED station, and the Italian stations W1M3A, E2M3A, Miramare, and Paloma. In addition, hydrographic measurements were compared at the ESTOC ocean station off the Canary Islands and at the Monizee Faro oceanic buoy off Portugal. At the Balearic Islands, mesoscale activity studies were performed including shelf-slope and eddy monitoring as well as tracing a tagged turtle. In addition, comparison between instruments along two glider sections (Nice-Calvi and at E2M3A) were performed.

Saildrone characteristics

The US company Saildrone designs, manufactures and operates a fleet of ASVs (drones; SDs) which are more and more used by the scientific community for oceanographic research: they are complementary to extend the capacity of observing systems (increase the space/time coverage), to observe hard-to-reach regions (e.g., cyclones, storms, ice) and allow the integration of multi-sensors with permanent communication in real time. The drones are 7 m long, 5 m high, 0.5 m wide, with a 2.5 m draft. They do not have an engine nor a propeller, and they are solely powered by the wind. They sail at an average speed of 3 knots (5.6 km/h) through the water using a rigid wing that acts as a sail. They carry no pollutants, no fuel, emit no discharge, and as sailing vehicles, make no noise. The sailing route is controlled by the pilots from the Saildrone controlling centre in California, USA.

During the ATL2MED mission the two drones (SD-1030 and SD-1053) carried loads of various scientific instruments, and in this report, we will focus on the oceanographic sensors included in Table 1. For both SDs, temperature (T), salinity (S), dissolved oxygen (O_2), and chlorophyll-a (Chl-a) have been measured using both Sea-Bird and RBR instruments: 1) SBE37-ODO sensors with conductivity electrode and pumping system coupled with an SBE63 optode and a WET labs Eco Triplet sensor, 2) RBR CTD and O_2 sensors with RBR Chl-a fluorometer. In addition to these sensors, the drone SD-1030 contained ADCP, pCO_2 and pH instruments, and the drone SD-1053 was equipped with an echosounder. RBR sensors have been installed on the drones with the intention to assess their capability to perform measurements on the ASV.

Table 1: Description of the oceanic sensors used during the ATL2MED mission.

SD	Sensors	Serial number	Calibration date	Depth (m)	Sampling rate
1030	SBE37-SMP-ODO	20981	30/06/2019	-0.5	12s on, 588s off
1030	WET Labs	5618	09/07/2019	-0.5	12s on, 48s off
1030	RBR (CTD/ODO/Chl-a)	40754	11/07/2019	-0.53	12s on, 48s off
1030	ADCP (Teledyne WHM300-I-UG1)	24672	NaN		Always on
1030	ASVCO2 (PMEL)	10	NaN	0.2	NaN
1030	pH (Durafet)	7736	NaN	-0.3	NaN
1053	SBE37-SMP-ODO	20782	05/05/2019	-0.5	12s on, 588s off
1053	WET Labs	5717	05/06/2019	-0.5	12s on, 48s off
1053	RBR (CTD/ODO/Chl-a	40749	20/06/2019	-0.53	12s on, 48s off
1053	Simrad EK80 WBTMiniEchosounder	266977	NaN	-1.9	NaN

Planned activity

The mission was originally planned to last for 174 days, starting from Mindelo in Cape Verde 1 November 2019 and ending in Trieste 23 April 2020. During Fall 2019, more institutions got involved and a joint mission plan and routes for ATL2MED were developed (Table 2).

Table 2: Legs and activities.

Leg	Activity
1	Transit Mindelo-CVOO
2	CVOO survey
3	CVOO Eddy search
4	Eddy Cross section (x2)
5	Eddy Grid pattern (x2)
6	Eddy Submesoscale Experiment (x2)
7	Transit from CVOO to ESTOC
8	ESTOC survey
9a	Transit form ESTOC to MONIZEE
9b	MONIZEE survey
9c	Sailing through Gibraltar Strait
9d	SOCIB survey
9e	Transit to French EEZ and LION for intercomparison
10a	LION survey
10b	Transit from LION via to ANTARES to DYFAMED for inter-comparison
11	DYFAMED/BOUSSOLE survey
12	Nice-Calvi glider section
13	Transit from French EEZ to W1M3A
14	W1M3A survey
15	Transit from W1M3A to Aeolian Islands
16	Aeolian Islands survey
17	Transit from Aeolian Islands to E2M3A
18	E2M3A survey
19	E2M3A glider section
20	Transit from E2M3A to PALOMA
21	PALOMA survey
22	Transit from PALOMA to Miramare
23	Miramare survey
24	Transit from Miramare to shore

Experiences

The two SDs were sent to the Canary Islands, where they were deployed from Puerto de Taliarte on 18 October 2019. The SDs sailed southwards and joined the eddy experiment west of Africa around 1 November 2019. Due to many unforeseen factors (in particular, hard atmospheric and oceanic conditions, pandemic situation and technical difficulties) the whole mission lasted 273 days until 17 July 2020 (Figure 1).

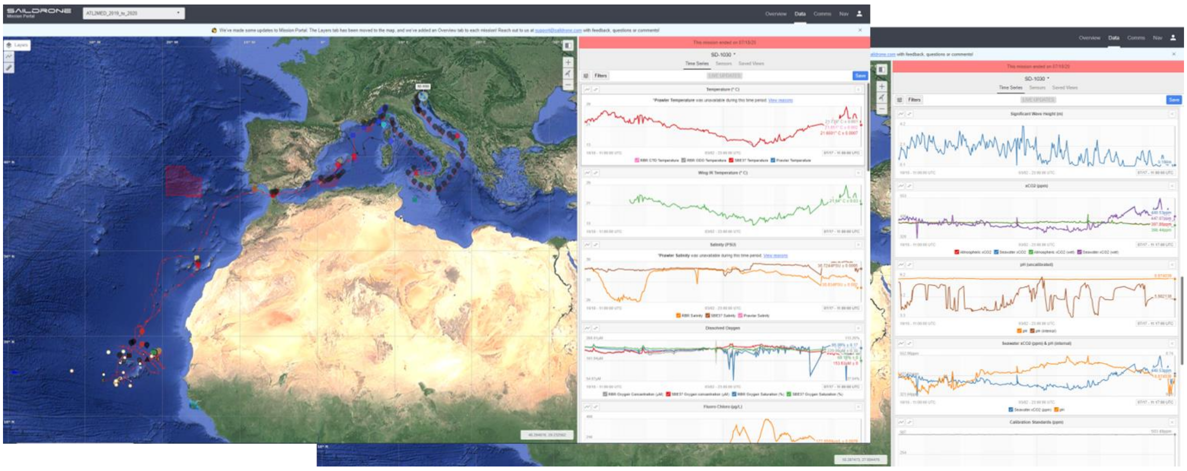

Figure 1: Screenshot from the Saildrone portal showing the full transect and some of the sensor data.

The activities were slightly modified due to primarily heavy biofouling at the drone's hull, Covid-19 pandemic restrictions, and instances with low winds and strong contrary winds. In particular SD-1053 had to undergo a complete refurbishment of the hull's anti-fouling coating in Cape Verde due to the faulty treatment back at the Saildrone facility in the US. The actual mission activities are presented in Table 3.

Table 3: Description of the activities of the two drones (SD-1030 and SD-1053) along the mission (modified from the Saildrone Portal).

Activity	Drone ID	Start (UTC)	End (UTC)	Partner
GEOMAR Adaptive Sampling	1053	01/11/2019 00:00	15/12/2019 10:59	GEOMAR
GEOMAR Adaptive Sampling	1030	01/11/2019 00:01	30/12/2019 17:00	GEOMAR
CVOO	1030	29/12/2019 00:00	30/12/2019 16:00	GEOMAR
ESTOC	1030	15/02/2020 06:01	17/02/2020 05:00	PLOCAN
MONIZEE	1053	24/02/2020 15.00	25/01/2020 20:00	IH

MONIZEE	1030	02/03/2020 22:00	03/03/2020 08:00	IH
SOCIB Adaptive Sampling	1053	17/03/2020 21:01	29/03/2020 10:00	SOCIB
SOCIB Adaptive Sampling	1030	19/03/2020 02:01	29/03/2020 17:00	SOCIB
LION	1053	01/04/2020 19:40	02/04/2020 09:00	LOV
LION	1030	01/04/2020 19:40	02/04/2020 13:00	LOV
ANTARES	1053	09/04/2020 17:00	10/04/2020 05:00	LOV
ANTARES	1030	09/04/2020 17:00	10/04/2020 05:00	LOV
Nice-Calvi Glider line	1053	20/04/2020 08:30	22/04/2020 21:00	LOV
DYFAMED	1053	22/04/2020 22:00	24/04/2020 00:30	LOV
DYFAMED	1030	23/04/2020 16:46	28/04/2020 19:30	LOV
W1M3A	1053	28/04/2020 18:30	02/05/2020 10:00	CNR-IAS
W1M3A	1030	29/04/2020 18:17	02/05/10:00	CNR-IAS
Aeolian survey	1030	20/05/2020 07:01	21/05/2020 03:00	OGS
Aeolian survey	1053	20/05/2020 07:01	21/05/2020 03:00	OGS
OGS Glider Line	1053	26/06/2020 04:00	29/06/2020 04:00	OGS
OGS Glider Line	1030	26/06/2020 15:00	29/06/2020 15:00	OGS
E2M3A	1053	29/06/2020 03:30	02/07/2020 21:00	OGS
E2M3A	1030	29/06/2020 15:30	02/07/2020 21:00	OGS
PALOMA	1053	15/07/2020 09:00	16/07/2020 09:00	CNR-ISMAR
PALOMA	1030	15/07/2020 11:30	16/07/2020 10:30	CNR-ISMAR
MIRAMARE	1053	16/07/2020 20:45	17/07/2020 13:45	OGS
MIRAMARE	1030	17/07/2020 00:30	17/07/2020 13:45	OGS

Table 4: A summary of the issues met by the different partners and in the different EEZs.

Section	Start date	End date	Duration	Comment
Cape Verde and GEOMAR (leg 1-7)	31/10/2019	05/01/2020 (SD-1030) 18/01/2020 (SD-1053)	66 days (SD-1030) 79 days (SD-1053)	Slow speed due to substantial fouling on SD-1053, which were removed in Mindelo. Co-located measurements with RV Meteor M160 expedition and SV3 Wave Glider equipped with biogeochemical sensors. Discrete samples for O_2, DIC, TA, Chl-a, and S were collected
Spanish EEZ (leg 7-9a)	16/01/2020 (SD-1030) 27/01/2020 (SD-1053)			SD-1030 slowed due to nylon line tied to bow, removed and biofouling removed from hull
Portuguese EEZ (leg 9a-b)		06/03/2020		
Strait of Gibraltar (leg 9c)	06/03/2020	06/03/2020	1 day	Delay in passage due to opposite (flood, westward) tidal currents and boiling waters at Camarinal Sill (west entrance of the Strait). Several moments with risk of collision at the mouth of the Bay of Algeciras
Spanish EEZ (leg 9d-e)	06/03/2020	01/04/2020	27 days	Severe atmospheric and oceanic conditions entering the Mediterranean. SDs arrived at the SOCIB study area on 17 March. Wiper arm on fluorometer not activated until 26 March, electrical problem with wind sensor of SD-1030 since 26 March, differences in measurements between sensors as well as between SDs (particularly for salinity), point experiment with RV in Cabrera cancelled due to Covid-19
French EEZ (leg 9e-13)	01/04/2020	28/04/2020	28 days	Issue with fouling on SD-1030 and data drifts (S, O_2, Chl-a)
Italian EEZ (leg 13-16)	29/04/2020 (SD-1030) 28/04/2020 (SD-1053)	07/06/2020	40 days	Biofouling on SD-1053 removed on 7 May in Imperia (Italy), both SDs were towed on 26 May to Cefalù (Sicily) where they anchored for 11 days, due to low wind and sailing problems, biofouling removed during this stay
Italian EEZ (leg 17-24)	07/06/2020	17/07/2020	42 days	Issue with fouling on SD-1030, RBR salinity sensor out of range, both O_2 and Chl-a sensors differed between SBE and RBR, the glider mission was shortened

O_2=dissolved oxygen; DIC=Dissolved Inorganic Carbon; TA=Total Alkalinity; Chl-a=chlorophyll-a; S=salinity.

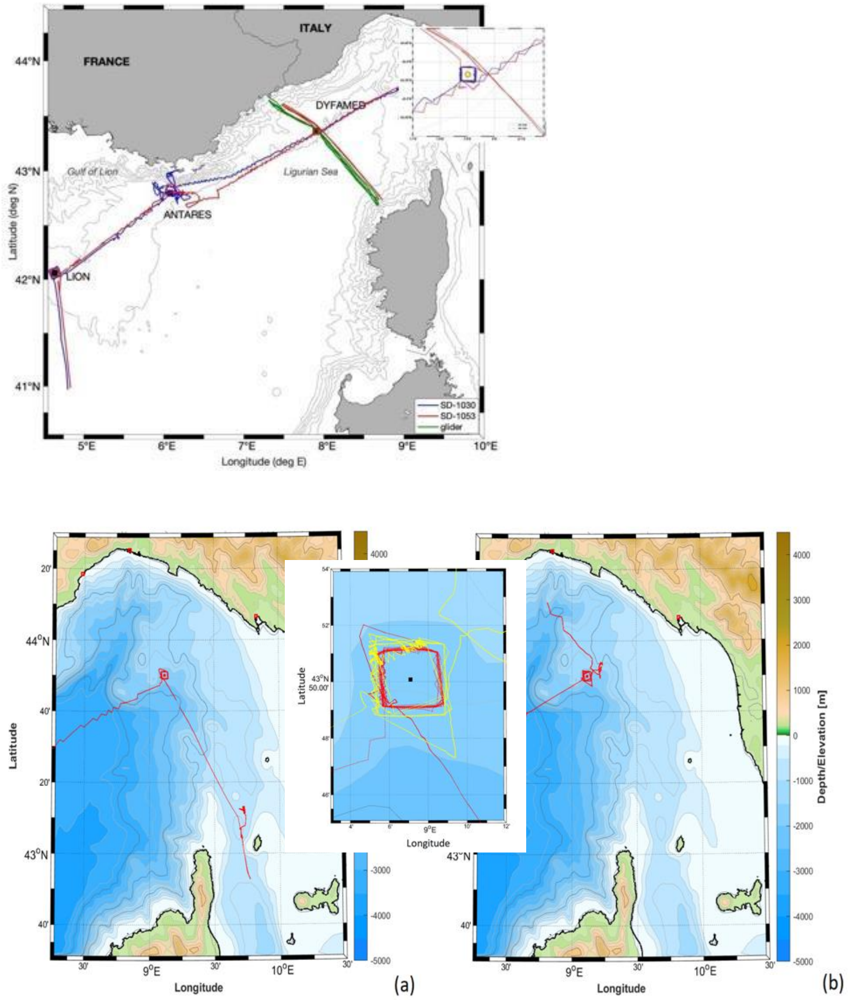

Figure 2a: Example of tracks for SD-1030 and SD-1053 in French (upper panel) and Italian (lower panel) waters in the North-western Mediterranean from April to early May 2020. Path of SD-1030 (red line) and SD-1053 (yellow line) around the DYFAMED and W1M3A sites.

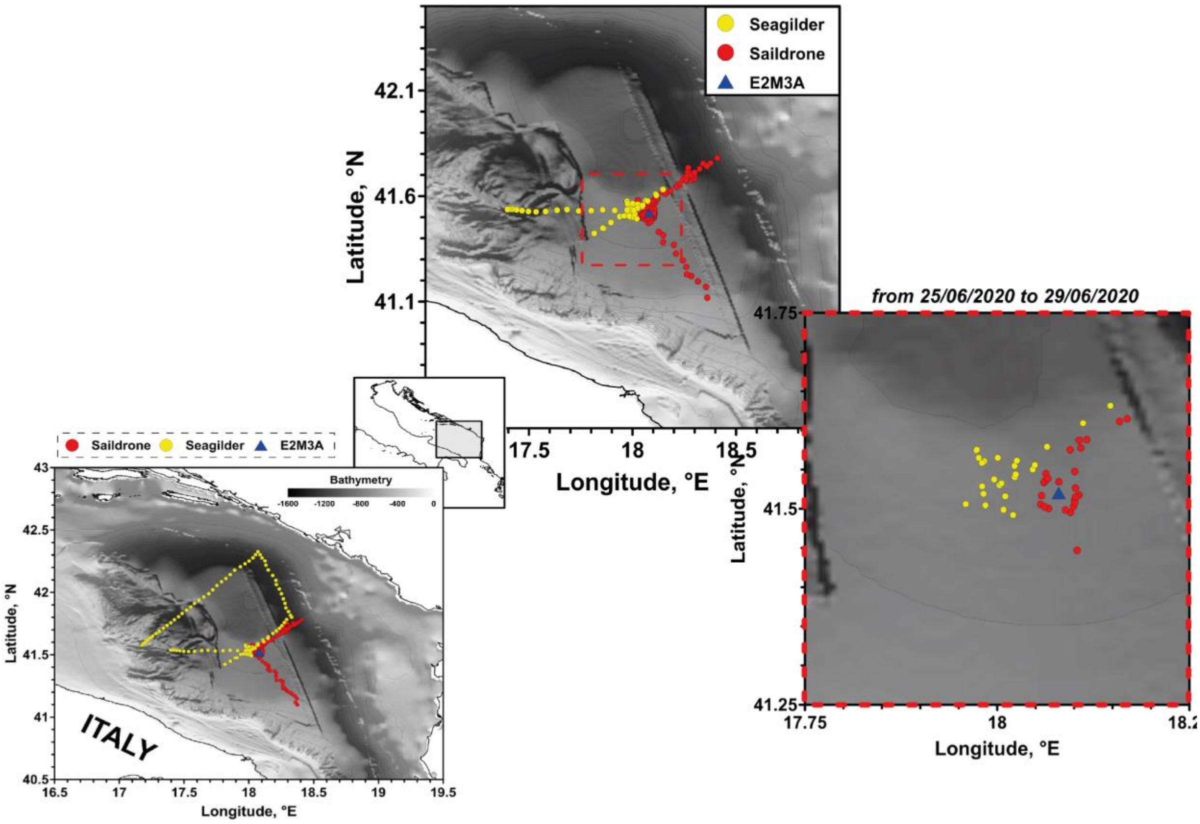

Figure 2b: The multiplatform sampling in the area of the Southern Adriatic Sea (Italian and Croatian waters) during the last week of June 2020: seaglider (yellow dots), saildrone (SD) (red dots), and the triangle shows the location of the E2M3A fixed buoy.

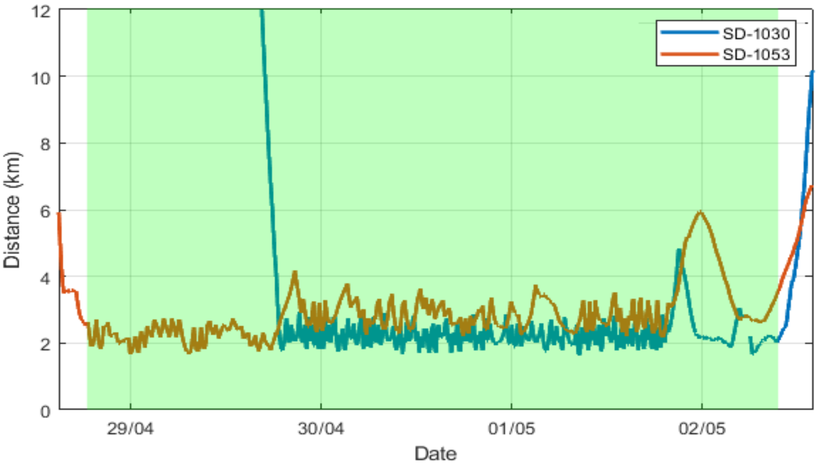

Figure 3: Nominal distance of the two SDs from W1M3A site.

More details of the issues faced during the mission

Biofouling

During the mission, there were four visits to shore for cleaning/repainting: at Cape Verde (SD-1053), at the Canary Islands (SD-1030), in French EEZ of the Ligurian Sea (SD-1030), in Italian EEZ of the Ligurian Sea (SD-1053), and Sicily (SD-1030).

After its entrance to the French EEZ, the SD-1030 had some serious difficulties with the rudder, likely due to biofouling. The SD was not able to move, and this situation delayed the mission plan. Despite the Covis-19 lockdown, this drone was rapidly recovered by a ship, near the Hyeres Islands. After two days of maintenance and cleaning in Porquerolles, the SD-1030 continued to the DYFAMED site. The bio-fouling problem made the vehicle unmaneuverable for several days, which caused problems for the French military authorities in the area at the time. Fortunately, the maritime traffic was low because of the containment set up in France.

In Italian waters, the two SDs arrived at the W1M3A site 28 and 29 April 2020. The SD-1053 experienced major manoeuvring problems due to biofouling. While SD-1030 stayed at a fixed position north of Capraia island, a first attempt was made to direct SD-1053 towards Genoa for the maintenance. However, due to difficulties in manoeuvring the SD, it was decided to let it follow with the current heading for Imperia. On 8 May, a rubber dinghy reached the SD, which was serviced by divers. Afterwards, the SD-1053 headed towards Capraia to be unified with SD-1030 and start the joint voyage towards southern Italy. In the Sicily area, wind conditions were very light, preventing the SDs from continuing their prescribed mission plan. Due to the situation, both drones were towed to a local marina waiting for the wind to strengthen. During the stay both drones were cleaned of biofouling and fishing gear was removed from the SD-1053.

Figure 4: SDs in Cefalù, where they stayed anchored due to low wind speed and where also biofouling and fishing gears were removed from the drone’s hull.

11 days later, when the wind strengthened, the two SDs were able to set sail and head to the

south Adriatic Sea. No further cleaning of sensors or hulls was performed until the end of the mission (Trieste on 17 July).

Communication with Saildrone

The technical support from Saildrone controlling centre was efficient. The good support (including on Sunday and night-hours) was essential for the adaptive sampling experiment (e.g., eddy and turtle tracking) but also in complicated areas (e.g., Strait of Gibraltar). Occasionally, there was a lack of warning/information from Saildrone about technical failures. Furthermore, the recommendations from Saildrone about which sensor to trust was not very clear.

Both drones (SD-1030 and SD-1053) shared a unique AIS (Automatic Identification System) identifier, thus, it was not possible to get the real position of both SDs at the same time. This was a major problem when the drones didn’t travel together or when they were separated to accomplish the maintenance operations. This caused some confusion and made it difficult for the naval authorities to position the SDs in real time in the EEZs, especially near the coast and in ZONEX when operating naval ships during military exercises for Spanish, French and Italian EEZ.

A particular time-consuming issue was the continuous delay with respect to the initially conceived timetable. This produced quite a few problems, especially during the stay in Italian waters being the last country, leading to a continuous request for extension of permits to the competent authorities. The arrival of the SDs in Trieste in the middle of the summer season and the subsequent monitoring in the Gulf of Trieste alerted the harbour master's office requesting additional safety guarantees for navigation.

Crossing the Strait of Gibraltar

The first unmanned passage of the Strait of Gibraltar was one of the remarkable achievements of the mission. It took place on 6 March 2020 with the authorisation and support of the Hydrographic Navy Institute, Tarifa Maritime Rescue Coordination Center (SASEMAR) and the SDs were escorted by the University of Cádiz (UCA) oceanographic vessel UCADIZ. The meeting between the two SDs and the UCADIZ was scheduled at 08:00 local time at the western entrance of the Strait, north of the traffic separation scheme as the crossing was planned through the northern inshore traffic zone for safety reasons. Despite the favourable west winds, the current velocity at Camarinal Sill was opposite with nearly 3 knots and boiling waters at the surface, arresting the SDs until flood flow slackened by 12:00 (local time) causing an overall delay of around 4 hours in the crossing. After passing the Camarinal Sill, with favourable winds and ebb tide, the two drones sailed at a speed more than 10 knots. The second dangerous location was crossing the mouth of the heavily trafficked Bay of Algeciras, where the course of entering/exiting ships is perpendicular to that of the Strait passage. At this point, although the Tarifa Traffic Control provided periodical warnings about the drone’s crossing, there were several episodes of potential danger. These were caused by the convergence of ships’ routes towards the mouth of the bay of Algeciras, the different positions of the SDs when tracked by only one AIS, and the difficulties/unwillingness of large ships to manoeuvre away from colliding course with the SDs (Figure 5). Direct intervention of UCADIZ and a master remote piloting was needed to escape some very dangerous situations. Lessons learnt from the crossing were: 1) local oceanographic conditions in dynamically complex environments (e.g., straits, estuaries) where tidal currents may limit the SD wind propulsion should be taken into account; 2) individual AIS identification would ease the SD positioning to avoid collision courses; 3) in heavy trafficked areas it is mandatory to have an escorting vessel.

Figure 5: The drones crossing the heavily trafficked Strait of Gibraltar (photo: Alfredo Izquierdo, UCA).

Inter-comparison between SD sensors and other platforms: oceanographic measurements

Table 5a: Offsets between SD sensors (SD-1030) and measurements at the stations. The offset has been calculated as follows: (mean value of station considered as close to the reference) - (mean value of SD). Usually, SD sensors underestimate the reference values.

			SD-1030 sensors									
Platforms (sampling depth)	**Area**	**Date**	**Temperature SBE37 °C**	**Temperature RBR °C**	**Salinity SBE37**	**Salinity RBR**	**O_2 SBE63 µmol/L**	**O_2 RBR µmol/L**	**Chl-a WetLabs µg/L**	**Chl-a RBR µg/L**	**pCO_2 ASVCO2 µatm**	**Platform details**
CVOO	Atlantic Ocean	20 Nov 3-4 Dec 2019									15 17	Wave glider Lagrangian surface drifter
SOCIB		17-31 March 2020			> -0.3							gliders - profiling - mooring
ODAS buoy	Gulf of Lion, Ligurian Sea	1-19 April 2020			-0.05	-2.16						buoy
DYFAMED	Ligurian Sea	28 April 2020									15-20 @13 °C	CARIOCA sensor
W1M3A (-1 m)	Ligurian Sea	29 April- 2 May 2020	-0.006 °C	-0.005 °C	-	-	-	-	-	-	12.6-23.2 @13 °C	SBE56
E2M3A (-1.7 m)	South Adriatic	25 June-3 July 2020	0.216	0.216	-0.21	-4.61	-32.5	-42	-	-	9 ± 7.5 @13 °C	SBE37-ODO; CO2-Pro ProOceanus
Seaglider (-0.5 m CTD; -1 m O_2; -0.7 m Chl-a)	South Adriatic	25 June- 30 June 2020	0.063 °C	0.055	-0.17	-4.61	-54	-63	0.41	183		SBE GPCTD, Aanderaa Optode 4330, WetLabs BBFL2IRB
Paloma (-0.5 m)	North Atlantic	15 July 2020	0.077	0.091	0.18	5.70	-	-	-	-	-	SBE 37 from small boat moored to station
Paloma (-3 m)	North Adriatic	15 July 2020	-0.061	-0.054	0.20	5.74	30	125	-	-	10-30 @13 °C	SBE37-ODO, Contros HydroC-CO2
Paloma (-3 m)	North Adriatic	15 July 2020	-	-	-	-	35	-5	-	-	14-19 @13 °C	Winker O_2 samples, pCO_2 calculated from pH_T and TA samples
Miramare (-0.5 m)	North Adriatic	17 July 2020	-0.085	-0.035	0.28	6.14	66.25	-3.25	-3.83	-226.12	13 – 14 @13 °C	Winkler O_2, pCO_2 calculated from pH_T and TA samples, SBE19
Miramare (- 2 m)	North Adriatic	17 July 2020	-0.117	-0.072	0.238	6.293	66.333	-3.167	-3.770	-226.06	6 - 14 @13 °C	Winkler O_2, pCO_2 calculated from pH_T and TA samples, SBE19, SBE37-ODO, ProOceanus

Table 5b: Offsets between SD sensors (SD-1053) and measurements at the stations. The offset has been calculated as follows: (mean value of station considered as close to the reference) - (mean value of SD). Usually, SD sensors underestimate the reference values.

			SD-1053 sensors								
Platforms (sampling depth)	**Area**	**Date**	**Temperature SBE37 °C**	**Temperature RBR °C**	**Salinity SBE37**	**Salinity RBR**	**O_2 SBE63 µmol/L**	**O_2 RBR µmol/L**	**Chl-a WetLabs µg/L**	**Chl-a RBR µg/L**	**Platform details**
SOCIB		17-31 March 2020			-0.40						gliders - profiling - mooring
LION	Gulf of Lion, Ligurian Sea	1-19 April 2020			-0.83	-3.15					ODAS buoy
Nice-Calvi glider	Ligurian Sea	20-23 April 2020					-28.8	-195.4			Slocum glider adjusted
W1M3A (-1 m)	Ligurian Sea	28 April- 1 May 2020	-0.026	-0.014	-	-	-	-	-	-	SBE56
E2M3A (-1.7 m)	South Adriatic	25 June-3 July 2020	0.138	0.115	-1.07	-1.33	-19	-44	-	-	SBE37-ODO; CO2-Pro ProOceanus
Seaglider (-0.5 m CTD; -1 m O_2; -0.7 m Chl-a)	South Adriatic	25 June- 30 June 2020	0.063 °C	0.035	-1.02	-1.30	-44	-67	0.13	2.89	SBE GPCTD, Aanderaa Optode 4330, WetLabs BBFL2IRB
Paloma (-0.5 m)	North Adriatic	15 July 2020	0.090	0.116	1.02	1.89	-	-	-	-	SBE 37 from small boat moored to station
Paloma (-3 m)	North Adriatic	15 July 2020	-0.046	-0.026	1.04	1.92	145	79	-	-	SBE37-ODO
Paloma (-3 m)	North Adriatic	15 July 2020					141	70			Winker O_2 samples
Miramare (-0.5 m)	North Adriatic	17 July 2020	-0.205	-0.180	1.16	2.295	130.25	63.75	0.03	-159.27	Winkler O_2, pCO_2 calculated from pH_T and TA samples, SBE19
Miramare (- 2 m)	North Adriatic	17 July 2020	-0.238	-0.212	1.113	2.253	130.333	63.833	0.090	-159.20	Winkler O_2, pCO_2 calculated from pH_T and TA samples, SBE19, SBE37-ODO

Temperature

Data from RV Meteor M160 expedition show overall agreement between vessel-mounted and Saildrone-mounted temperature probes (0.003 °C lower than M160 measurements), although the study area with mesoscale eddies was characterized by (sub)mesoscale fronts (Figure 6). Comparison between SDs sensors and those of DYFAMED are shown in Figure 7.

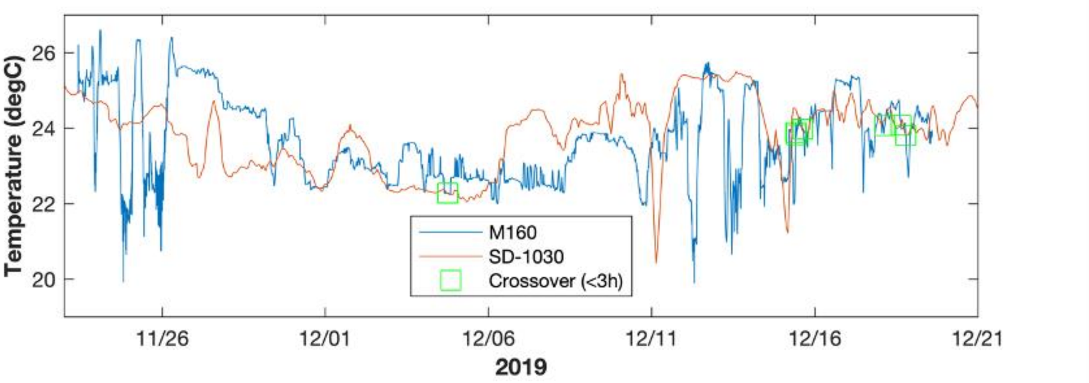

Figure 6: Comparison between SD-1030 and temperature measurements (Seabird Thermosalinograph, calibrated against calibrated CTD cast data) conducted during RV METEOR M160 expedition at a depth of 5 m. Crossovers between both platforms (within 3 hours) are highlighted as green squares.

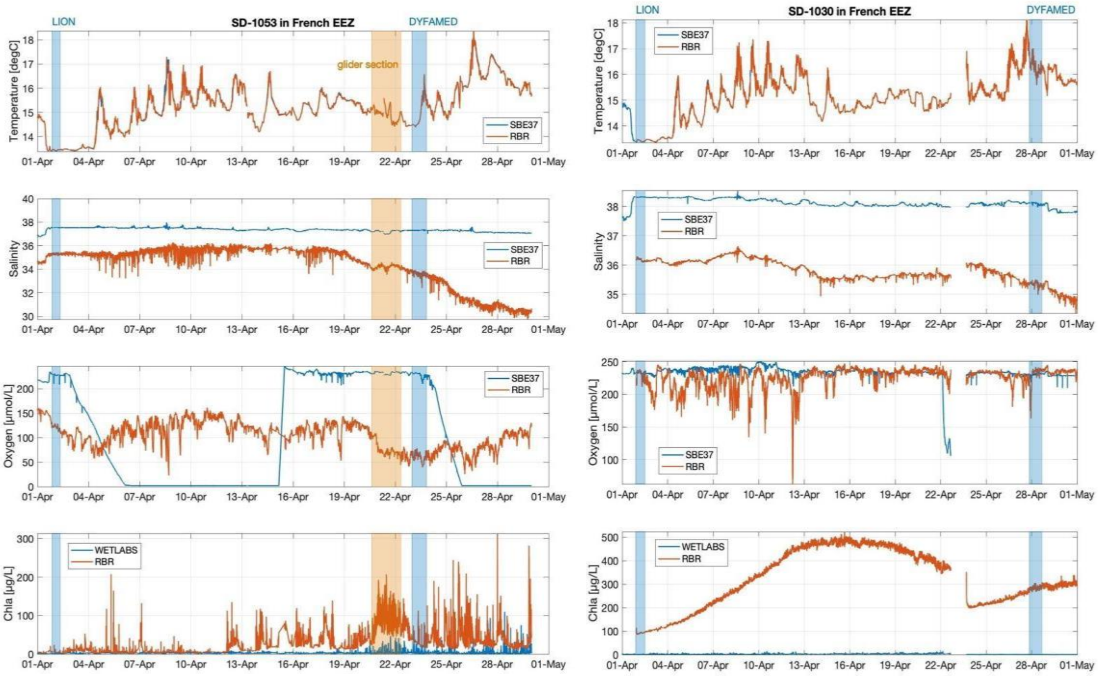

Figure 7: SD-1053 (right) and SD-1030 (left) oceanic time series during their passage in the French EEZ near the surface buoys (DYFAMED, LION) and glider section

At the W1M3A site (Figure 8), SBE37 and RBR thermistors on board the two drones were in very good agreement having a mean absolute bias of 0.0053 °C for SD-1030 and 0.0145 °C for SD-1053. The discrepancy among the thermistor on the W1M3A buoy and the sensors of the drones might be explained considering the nominal distance of the drones from the W1M3A site: SD-1030 was able to maintain a relatively short and regular distance from the buoy whereas SD-1053, due to the manoeuvring problems, wandered more around the target location.

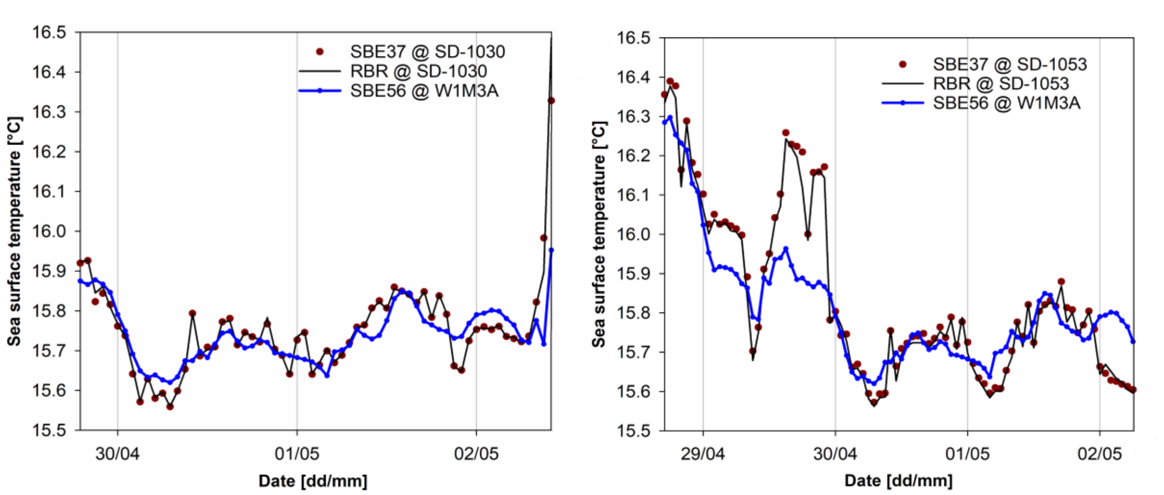

Figure 8: Comparison of sea surface temperature measured by an SBE56 thermistor deployed at 1 m depth on the W1M3A observatory and by the thermistors onboard the drones. Left: SD-1030, right: SD-1053.

Salinity

Regarding salinity, the drone SBE37 sensor seems to be more consistent with reality compared to the RBR sensor which presents too low values (2-4 units difference), see Table 5, Figure 7, 9 and 10. This difference was observed for both drones. For the SBE37 conductivity cells, an anti-fouling device is usually used but its effect is time limited. After a long use and especially in surface waters, where biofouling pressure is intense, a cell cleaning and anti-fouling device replacement is recommended.

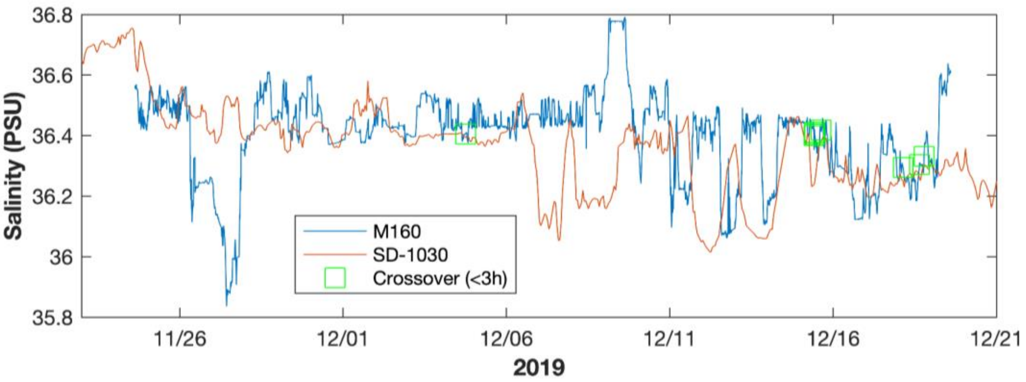

Fig 9: Comparison between SD-1030 and salinity measurements (Seabird Thermosalinograph, calibrated against calibrated CTD cast data) conducted during RV METEOR M160 expedition at a depth of 5 m. Crossovers between both platforms (within 3h) are highlighted as green squares.

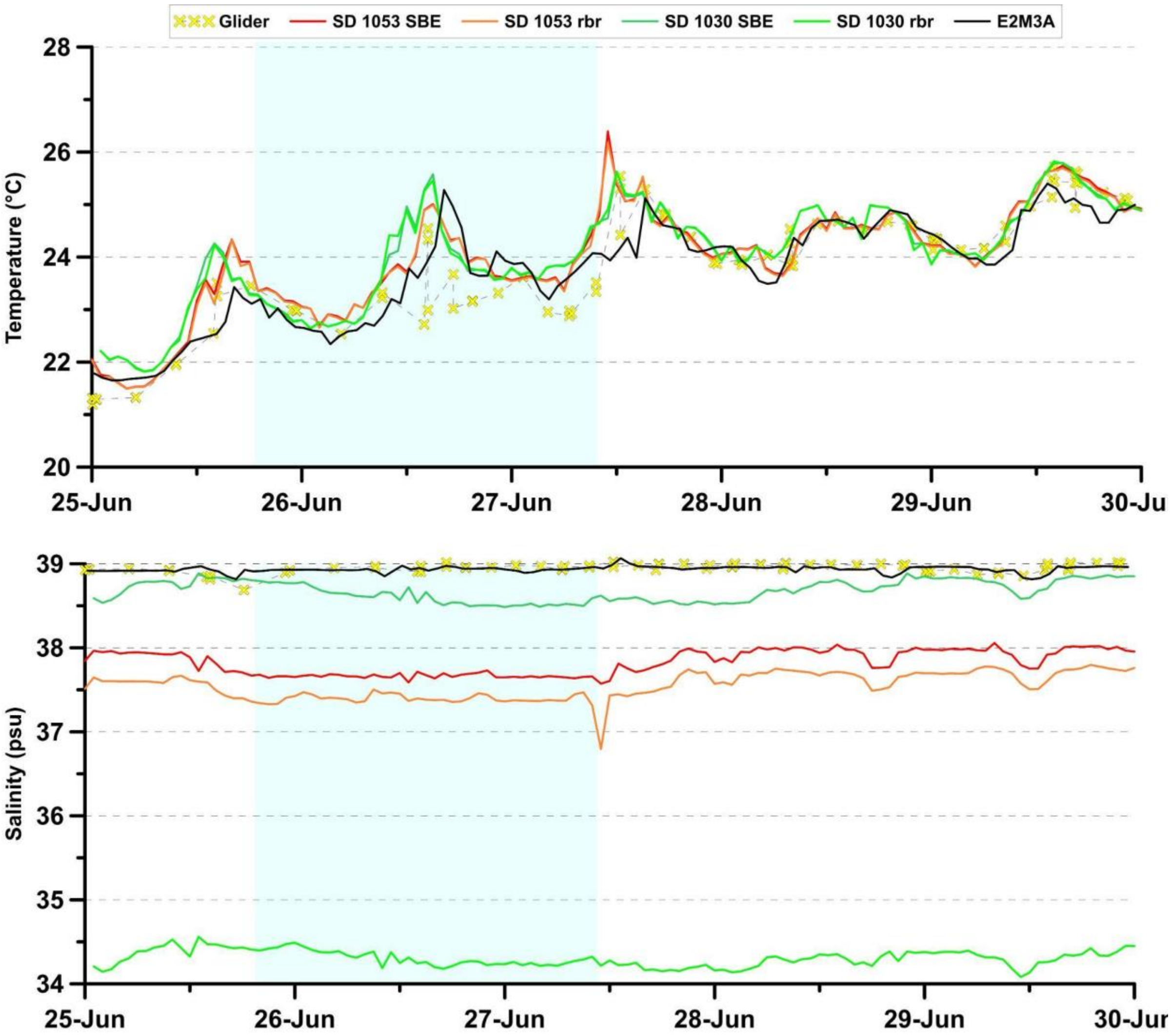

Figure 10: Multiplatform time series of temperature and salinity in the southern Adriatic Sea in the vicinity of the E2M3A site.The yellow dots are related to the measurements made with the glider, the black line is related to the E2M3A platform, while the other lines shows the records of the different sensors mounted on the two drones.

In general, as seen from Figure 10, the temperature data from the SDs, glider and fixed site in the southern Adriatic show the same trend while the salinity time series shows a different pattern between the different sensors. The salinity of the glider coincides with that of the E2M3A site and there is a relatively small difference between these data and the salinity measured by the SD-1030 SBE. In contrast, a major mismatch is observed between the glider and E2M3A salinities and those of the SD-1053 SBE, SD-1053 RBR and SD-1030 RBR. The shaded area indicates the period when the drones were farthest from the buoy.

Dissolved oxygen (O_2)

For SD-1053, the SBE and RBR sensors (both optodes) do not match (Figure 7). The RBR sensor presents quite low values for surface measurement at this season, and one possible explanation of this could be the integration of the RBR O_2 sensor inside the ship keel where dead water could accelerate the sensor fouling. The SBE63 seems to be more realistic between 16 April to 23 April 2020 (Figure 7). The rest of the time the optode shows signs of weakness with a rapid decrease of concentrations. This issue could be due to biofouling or foil damage.

Chl-a (Wet labs)

For both drones, RBR Chl-a sensors presented a serious issue regarding the fouling effect on fluorometer cells. For the Wet Labs sensor, we observed large spikes issues and an offset. In surface water during April 2020, the glider shows Chl-a maximum concentrations (from ECO-FLBBCD puck) around 1 µg/L along the Nice-Calvi section (Figure 7). Furthermore, the wiper arm was not activated until 26 March 2020, which accelerated the biofouling.

pCO_2

For SD-1030, the ASVCO2 system worked well from start to end. Some suspicious data occurred around 7 November 2019 near Cape Verde, however, no explanation was found for this and the data were flagged suspicious. The pCO_2 sensor was checked prior to the mission and during the mission, a non-zero standard gas was frequently used to calibrate the seawater measurements. Measurements off West Africa were concerted with a multi-platform eddy survey which also involved RV Meteor (M160) with a General Oceanic (GO) pCO_2 measuring system, a SV3 Wave Glider with a Contros HydroC-CO2, and biogeochemical Argo Floats with pH sensors. Unfortunately, data quality of pCO_2 measurements from M160 (GO system) is poor due to electrical problems during the cruise. Hence, only discrete samples for DIC and TA were converted to pCO_2 (using Mehrbach et al., 1973, refitted by Dickson & Millero, 1987) for comparison with the SD-1030 measurements. Measurements for pCO_2 from the HydroC sensor (deployed on a Wave Glider as well as on an Lagrangian surface drifter at 10 m depth) were pre- and post-deployment calibrated at the Contros facility following Fietzek et al. (2015). The comparison of SD-1030 $p\mathrm{CO}_2$ data with the Wave Glider and drifter measurements show an offset of 15 (Wave Glider) and 17 µatm (Drifter), respectively (see Figure 11).

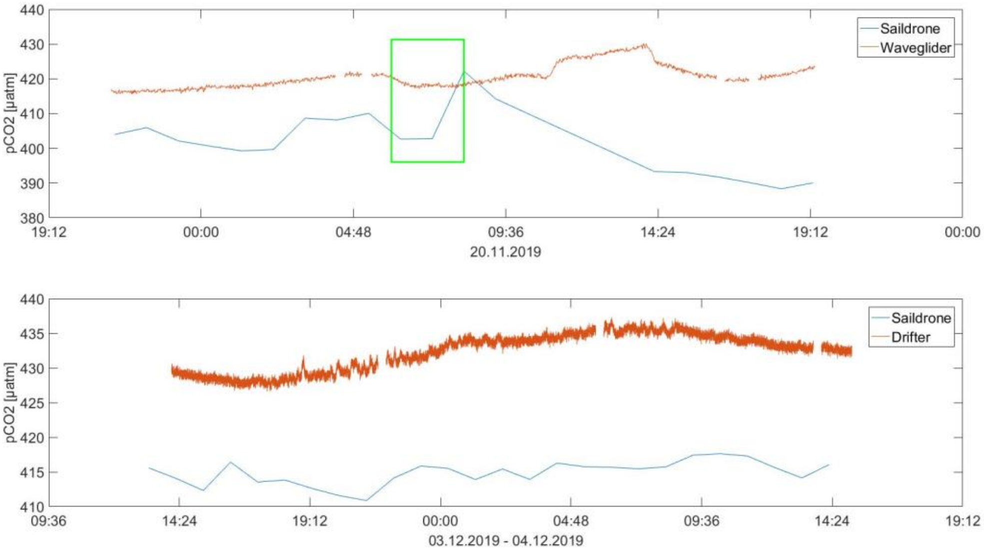

Figure 11: Comparison of *p*CO_2 measured by Contros HydroC CO2 sensor mounted either on an SV3 Wave Glider (upper) or on the surface drifter (lower) with measurements conducted on the SD-1030. Co-located measurements were carried out within 7 (Wave Glider) and 3 nautical miles (Drifter), respectively.

At W1M3A, the pCO_2 analyser (CO2-Pro CV) was deployed in July 2019 at 6 m depth and with a measuring frequency of 2/hr. Due to Covid-19 lockdown, neither maintenance of the sensor nor collection of discrete water samples for validation were performed at the station prior to the arrival of the two SDs. Despite of the lack of maintenance of the W1M3A pCO_2 sensor, a constant offset of -18.078 ± 2.764 µatm was found when comparing the temperature normalized (13 °C) pCO_2 from SD-1030 and W1M3A, where the SD pCO_2 was the lowest (Figure 12).

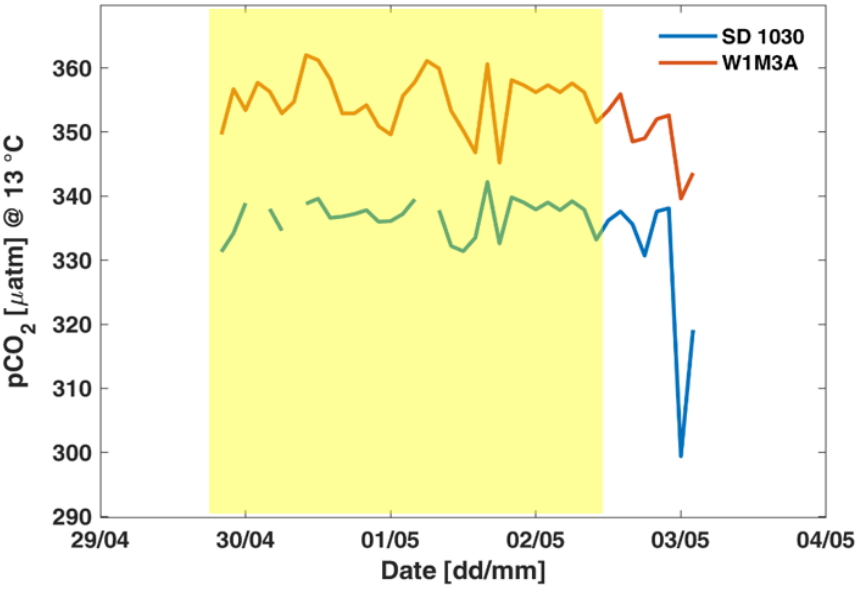

Figure 12: Comparison of pCO_2 measured by the Pro Oceanus CO2-Pro CV deployed at 6 m depth on the W1M3A observatory and the ASVCO2 onboard the SD-1030 normalized at 13 °C Yellow shaded area indicates the periods in which the saildrone 1030 was near the W1M3A observatory.

pH

For SD-1030, the pH Durafet sensor worked for only a short period of time. Then, the internal pH probe stopped working. Also, the pH temperature sensor at the SD-1030 was out of order. The external pH probe worked during the whole mission, but the pH sensor was not calibrated prior to deployment. Furthermore, only a few discrete pH data were available for comparison, partly due to Covid-19 lockdown, and thus, the pH data have not been examined further. For future experiments, an improved version of the pH Durafet sensor should be calibrated prior to deployment, and a large number of discrete samples should be collected for validation over the full length of experiment.

Inter-comparison between SD sensors and other platforms: meteorological measurements

Air temperature sensor

The air temperature sensors of both SDs worked well during the whole time of the mission. Nevertheless, they showed higher values if compared with the data coming from the fixed platform E2M3A. The excursion between night and day temperatures are smaller than those observed by the buoy but still all sensors perfectly catch the daily signal and the increased temperature trend of the spring to summer season.

Atmospheric pressure sensor

The atmospheric pressure sensors of both drones (SD-1030 and SD-1053) are correlated and worked during the whole mission. However, the comparison of the drone’s records and the data from the E2M3A reveal a constant offset of about 14 mbar (Figure 13). This offset might be connected to the fact that the pressure sensors at E2M3A have been deployed without being calibrated for more than a couple of years.

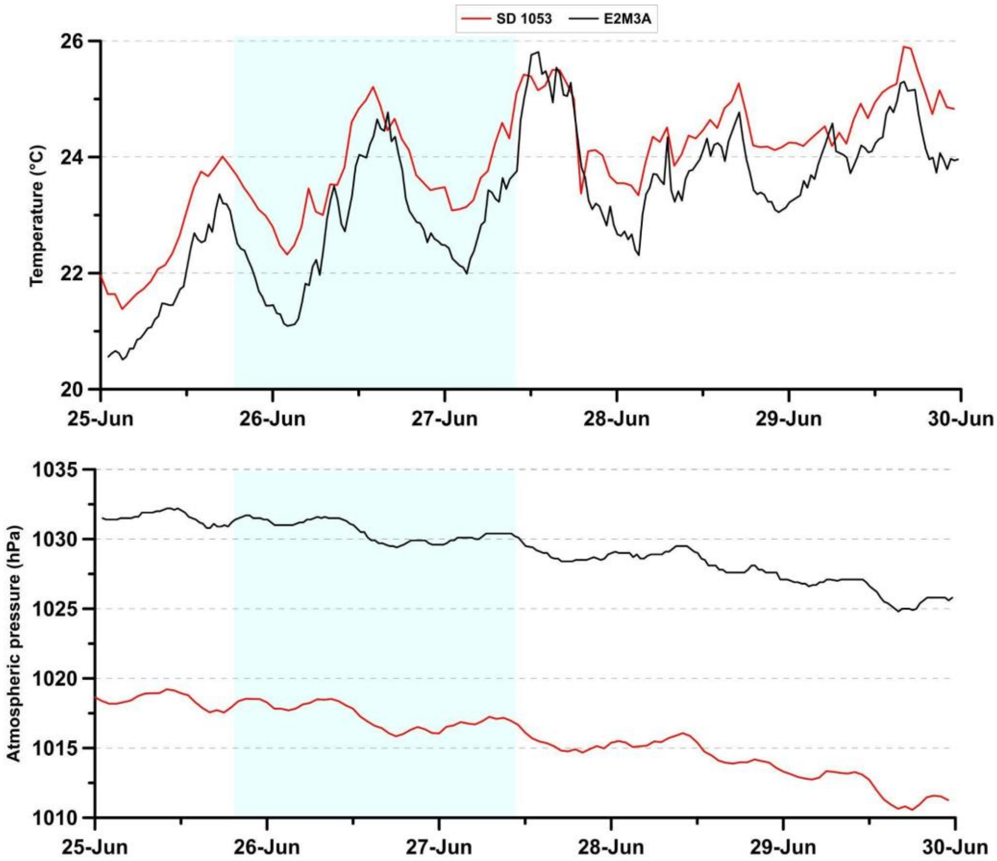

Figure 13: Comparison of air temperature and atmospheric pressure measured by SD-1053 and the E2M3A buoy. Shaded area indicates the period when the drones were furthest from the buoy.

Wind sensor (SD-1030)

The SD-1030 experienced electrical problems with the wind sensor from 26 March 2020 and onwards.

Conclusions and recommendations

The ATL2MED mission lasted for 273 days, which was longer than planned primarily due to challenges with heavy biofouling at the drone's hull, Covid-19 pandemic restrictions, low winds, and strong contrary winds. The experiment clearly shows some of the challenges faced when this type of surface vehicle is part of long-term missions. The sensors installed on the vehicles always remain in the surface layer and are exposed for biofouling, which can be particularly impacting in relatively warm waters of the Mediterranean Sea, and not only during summer. Thus, the feasibility of the mission can be debated.

This type of vehicles has great advantages to carry out long missions autonomously, they perform multi-variable and high-resolution sampling, they are environment friendly platforms, and they continue to collect data despite Covid-19 restriction affecting the rest of the world. Despite all of this, the possibility of collecting data of scientifically usable quality seems to depend on the one hand on the adoption of structural changes in the installation of some sensors and on the other hand on performing of periodic cleaning of both the hull, to ensure the necessary manoeuvrability and navigation precision, and the instruments.

In this report we have mentioned some key recommendations, which are: 1) more frequent cleaning of hull and sensors; 2) ensure that the SD sensors are mounted correctly to sample open water; and 3) necessity to more frequently collect discrete samples for validation of the SD dataset quality.

The RBR sensor package had serious issues regarding the biofouling effect. After a long route, since November 2019 in Cape Verde, this situation was expected. However, the SBE37 sensors seem to be more reliable and robust regarding biofouling, but a regular sensor cleaning procedure is necessary using special devices or human interventions during the SD deployment.

The anti-fouling system (cell cleaning and anti-fouling device replacement) and its frequency should be established according to the area (e.g., considering the high biofouling in the Mediterranean in summer). It is essential to take into account the ocean properties of the monitoring area and elaborate suitable planning prior to the mission start.

Finally, the capability of the Saildrone vehicles as tools for validating other types of measuring devices (e.g.,fixed stations, mobile platforms or ships) strongly depends on several conditions such as distance from the other platforms, depth of fixed station measurements, environmental conditions and status of the sensors.

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