

Replies to Topic Editor

We would like to thank also the topic editor for the additional comments that helped further improve the manuscript. We give our response to his comments:

Comments to the Second version of the manuscript: “An integrated open-coastal biogeochemistry, ecosystem and biodiversity observatory of the Eastern Mediterranean. The Cretan Sea component of POSEIDON system” from Petihakis et al.

The manuscript has been improved by the authors following the suggestions and correction of the three referees. I suggest just a few changes before being published.

General Comments:

Although the authors claimed I can't see the reduction of the 40% of section 2, which from my point of view it is still too long. It leads to diverting the reader's attention from the true content of the article.

Reply 1:

The information provided concerning the reduction of Section 2 by approximately 40% was correct (i.e. 39% from 2594 words in first version to 1584 words in the second version). We have further reduced the length of this section to approximately 50% (i.e. 49% from 2594 words in first version to 1330 words in the current version). We consider a further reduction will have a negative impact, as it will not allow to keep showing the particularities of the Cretan Sea (similarities, dissimilarities within the wider Eastern and entire Mediterranean Sea) in relation to the importance of implementing and sustaining an integrated OS in this area, and the benefits to the community beyond the specific area.

Other parts of the ms have been modified and/or reduced but not well integrated leading to a fragmentation of the reading. One possibility, which I propose, is to unify points 4.1 and 4.3 which refer directly to the observations made on the fixed platform (by slightly modifying the title), regardless of the type of parameter, so as to incorporate everything into one.

Reply 2: We have merged 4.1. and 4.3 to a single section with modified title, as suggested.

Minor comments:

Page 5 Line 35: “In 2017, an extended upgrade and renewal of POSEIDON buoy network monitoring parts and components and their supporting hardware was realized with the implementation of an integrated marine monitoring program funded by the EEA Financial Mechanism 2009-2014. *How was done this extended upgrade in 2017 with 2009-2014 funds?*”

Reply 3 : The call's name was EEA Financial Mechanism 2009-2014 and it was implemented in 2017 (due to several administrative delays).

Page 7 Line 19: replace *Lagrangian*

Page 7 Line 33: *Southern Adriatic*

Page 9 Line 15-17: non-easy to read, please change in: “The system was reactivated in 2012 for a few years until the end of 2014. Recently, since mid-2017 it has been running continuously with an upgrade to also provide also O₂, CO₂ and pH measurements”

Page 9 line 22: change displays for depicts

Page 9 line 23: That need *further* investigation

Page 11 line 5: “Specialized personnel is the *main* component for smooth *and* continuous

functioning of any multiplatform-multidisciplinary observatory”

Page 11 line 13: replace of with in

Page 11 line 28-29: add “proved *to be a* powerful”

Page 14 line 31: in-situ

Reply 4 : All above minor comments were made.

The font size in figure 4 is too small and we recommend enlarging it to make the graph more visible.

Reply 5 : The font size in figure 4 was enlarged.

Besides to the above adjustments requested by the Topic Editor, we checked again the manuscript for typos, missing co-authors, terminology and updates of data in tables.

Finally figure 7 was updated based on the latest (accepted) version of the manuscript by Potiris et al. (in the same issue).

An integrated open-coastal biogeochemistry, ecosystem and biodiversity observatory of the Eastern Mediterranean. The Cretan Sea component of POSEIDON system.

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Abstract. There is a general scarcity of oceanic observations that concurrently examine air-sea interactions, coastal-open ocean processes, physical-biogeochemical (BGC) processes, in appropriate spatiotemporal scales, and under continuous, long-term data acquisition schemes. In the Mediterranean Sea, the resulting knowledge gaps and observing challenges increase, due to its oligotrophic character, especially in the eastern part of the basin. The oligotrophic open Cretan Sea's biogeochemistry is considered to be representative of a greater Mediterranean area up to 10⁶ km², and understanding its features may be useful on even larger oceanic scales, since the Mediterranean Sea has been considered a miniature model of the global ocean. The spatiotemporal coverage of BGC observations in the Cretan Sea has progressively increased over the last decades, especially since the creation of the POSEIDON observing system, which has adopted a multiplatform-multivariable approach, supporting BGC data acquisition. The current POSEIDON system's status includes open and coastal sea fixed platforms, a Ferrybox (FB) system, and Bio-Argo autonomous floats, that deliver remotely fluorescence as a proxy of Chlorophyll-a (Chl-a), O₂, pH and pCO₂ data, as well as BGC-related physical variables. Since 2010, the list has been further expanded to other BGC (nutrients, vertical particulate matter fluxes), ecosystem and biodiversity (from viruses up to zooplankton) variables, thanks to the addition of sediment traps, frequent Research Vessel (R/V) visits for seawater-plankton sampling, and of an Acoustic Doppler Current Profiler (ADCP) delivering information on macrozooplankton-micronekton vertical migration (in the epi-, mesopelagic layer). Gliders and drifters are the new, currently under integration to the existing system, platforms, supporting BGC monitoring. Land-based facilities, such as data centers, technical support infrastructures, calibration laboratory, mesocosms, support and give added value to the observatory. The data gathered from these platforms are used to improve the quality of the BGC-ecosystem model predictions, which have recently incorporated atmospheric nutrient deposition processes and assimilation of satellite Chl-a data. Besides addressing open scientific questions at regional and international level, examples of which are presented, the observatory provides user-oriented services to marine policy-makers and the society, and is a technological test bed for new and/or cost-efficient BGC sensor technology and marine equipment. It is part of European and international observing programs, playing key role in regional data handling and participating in harmonization and best practices procedures. Future expansion plans consider the evolving scientific and society priorities, balanced with sustainable management.

1 International need for observatories

Oceans are complex dynamic systems embracing various physical, chemical and biological processes interacting on a wide range of time and space scales. The increasing anthropogenic pressures add another layer of complexity to their study. Ocean observatories are long-term infrastructures dedicated to multiple in situ observations (from air-sea interface to the bottom ocean and the water column), which are maintained over long timescales, with adequate temporal resolution, and are designed to address interdisciplinary objectives over wide spatiotemporal scales. The observatory concept created by scientific needs is driven today by societal needs to understand the connections between ocean processes and society (Ruhl et al., 2011), with the necessity for continued long-term ocean observation also recognized politically by the international community by the United Nations Conference on Sustainable Development at Rio+20 (Cicin-Sain et al., 2011). At the European level, the coordinating bodies (European Marine Board - EMB, and European Global Ocean Observing System - EuroGOOS) of the European observatories, besides addressing specific scientific questions, come also to address Europe's societal and policy demands for sustainable use of the seas, ecosystem-based management, and establishment of environmental status indicators, as expressed by the EU's Marine Strategy Framework Directive (MSFD).

Biogeochemical-ecosystem research is a key component in ocean observatories. The International Geosphere-Biosphere Programme (IGBP) (led by the Intergovernmental Oceanographic Commission - IOC of UNESCO), since its first projects (JGOFS - Joint Global Ocean Flux Study) as well as with its current ones (IMBER - Integrated Marine Biosphere Research) has realized that key biogeochemical variables and ecosystems must also be systematically and long-term observed, in order to study marine biogeochemical cycles and their interactions with the ecosystems, at the seasonal and decadal scale, as well as in short-term episodic events (www.imber.info).

Biogeochemical-ecosystem long-term data are, however, available only from few locations worldwide (Karl, 2010) and scarcity increases when considering only open (deep) ocean observatories (Ruhl et al., 2011). The European Marine Board (EMB) has published a position paper on critical challenges of deep-sea research, stressing that a current limitation of observatories is that they mainly monitor almost exclusively abiotic variables (Rogers et al., 2015).

2 A strategic location to study the unknowns of the Eastern Mediterranean

The Mediterranean Sea also "suffers" by this scarcity of observatories, especially with an open ocean component. Although long term time-series of physical, chemical and plankton ecosystem variables exist in several shallow (<200 m) coastal sites (<10 n.m. offshore) (e.g. Goffredo and Dubinsky, 2014), few offshore and deep ocean (>1000 m) biogeochemical observatories exist in the Mediterranean (Ruhl et al., 2011; www.eurosites.info). This leaves several questions for its physical and biogeochemical status unanswered, including among others: processes occurring in intermediate and deep layers, variability of the stock of nutrients, biological pump functioning, mesopelagic community structure, multiple stressor impact on ecosystem functioning (Malanotte-Rizzoli et al., 2014).

In the open Eastern Mediterranean Sea numerous studies of biogeochemical processes have been focused on various spatial scales (large to meso-scale), however these studies were seasonal and only two covered an annual cycle [Cretan Sea (Tselepidis and Polychronaki, 2000) and Cilician Basin (Eker-Develi et al., 2006)].

The Cretan Sea biogeochemical – ecosystem observatory presented here, comes to fill the above gap.

5 This observatory is located in the most voluminous and deep (2500 m) basin of the Aegean Sea, giving the opportunity to study not only properties limited to the specific area, but also the characteristics of the open Eastern Mediterranean basin. In fact, the open Cretan Sea's biogeochemistry has been estimated that it represents an area in the Eastern Mediterranean varying from 0.6 to 1.6×10^6 km² (Fig. 1) depending on the biogeochemical variable (see variables in Henson et al., 2016). Understanding Cretan's seas' features may be useful on larger oceanic
10 scales, since the Mediterranean Sea has been considered a “miniature ocean” that can be used as a model to anticipate the response of the global ocean to various kinds of pressures (Bethoux et al., 1999). These Cretan Sea features, presented below, underline the strategic location of the observatory.

2.1 Coupling of biogeochemistry with circulation patterns

The Cretan Sea plays an important role in the dynamics of the Eastern Mediterranean circulation and has
15 been considered as heat, salt, and dissolved oxygen reservoir; ~~since with~~ high temperature (>14 °C) ~~and~~ salinity (>38.9) ~~and dissolved oxygen concentrations (>4.3 mL/L) were detected~~ in its intermediate and deep layers. It is also the poorer in nutrients and richer in oxygen (>4.3 mL/L), among the principal basins of the Mediterranean Sea (e.g. Souvermezoglou and Krasakopoulou, 2000; www.mongoos.eu/data-center).

The Cretan Sea is an area of intermediate and/or deep-water formation, dominated by multiple scale
20 circulation patterns and intense mesoscale variability (e.g. Georgopoulos et al., 2000). Such areas of water formation are key locations for monitoring of the Mediterranean biogeochemical functioning (Malanotte-Rizzoli et al., 2014). ~~The wintertime convective mixing of the water column and the exchanges of water and mass (diluted, suspended or near-bed) with the adjacent Levantine and Ionian Seas through the straits of the Cretan Arc, make the Cretan Sea the poorer in nutrients and the richer in oxygen, among the principal basins of the Mediterranean~~
25 ~~Sea (Souvermezoglou and Krasakopoulou, 2000).~~

In the late 1980s - early 1990s, the Cretan Sea has become the major contributor of deep/bottom, warmer, more saline water to the Eastern Mediterranean (review by Laskaratos et al., 1999 and references therein), ~~which is considered to be part of a salinity driven alternating mechanism of the Eastern Mediterranean;~~ (Theocharis et al., 2014). This transition known as the Eastern Mediterranean Transient (EMT) alternated dramatically the
30 physical and biogeochemical properties at the intermediate and deep layers of the whole basin (Roether et al., 2007, among others). Data collected from different platforms in the Cretan Sea during the 2000s present evidence of gradually increasing salinity in the intermediate and deep intermediate layers after the middle of the decade. From late 2000s to early 2010s, dense water formation conditions have been identified showing that the basin is
35 ~~in the process of~~ slowly returning to the state of the late pre-EMT period (Velaoras et al., 2014; Cardin et al., 2015).

The deep-water mass formation in the Cretan Sea has the potential to transfer CO₂ into the deep layers. However, there is a sparseness of carbonate system data, i.e. total inorganic carbon (C_T), total alkalinity (A_T), pH and pCO₂ in the wider Eastern Mediterranean, ~~despite an increasing effort to study these properties in the last decade,~~ s to understand its role as source or sink of CO₂ (González-Dávila et al. 2016; Sisma-Ventura et al., 2016)

and the existing A_T -S relationships for the Mediterranean do not reproduce efficiently the A_T levels observed in the Aegean Sea (Krasakopoulou et al., 2015). ~~(Sisma-Ventura et al., 2016). González Dávila et al. (2016) based on one year pH records in Outer Saronikos Gulf, reported that the area was acting as a source of CO₂. The few recent in situ measurements of A_T in the Cretan Sea suggest that the existing A_T -S relationships for the~~
5 ~~Mediterranean do not reproduce efficiently the A_T levels usually observed in the Aegean Sea (Krasakopoulou et al., 2015).~~

The significant variability in the circulation patterns (e.g. Korres et al., 2014) and the strong coupling with the biogeochemical processes in the Cretan Sea (Tselepidis and Polychronaki, 2000) has made evident that sparse spatial and temporal observations are prone to misrepresentation of the underlying dynamics.

10 2.2 Oligotrophy, primary production, plankton stock and biodiversity hot spots

The Eastern Mediterranean Basin (including the Cretan Sea) is considered to be an ultra-oligotrophic system, in terms of both Chl-a concentration (D'Ortenzio and Ribera d'Alcala, 2009) and primary productivity ~~and Chl-a concentration, compared to the rest of the Mediterranean and to other oceans~~ (Siokou-Frangou et al., 2010 and references therein). ~~Based on a division of the Mediterranean in bioprovinces (as derived from SeaWiFS~~
15 ~~Chl-a), the South-Central and Eastern Mediterranean (including the Cretan Sea) are clustered together within 60% of the total Mediterranean area and are generally characterized by oligotrophic conditions (D'Ortenzio and Ribera d'Alcala, 2009)~~ The dominance of the multivorous food web ~~(herbivorous and microbial grazing modes having similar roles)~~ in the Cretan Sea (Siokou-Frangou et al., 2002), is a dissimilarity with most areas of the Mediterranean Sea where the microbial food web generally dominates (Siokou-Frangou et al., 2010 and references
20 therein).

The Mediterranean Sea also constitutes a hot spot of biodiversity with a uniquely high percentage of endemic species (Coll et al., 2010 and references therein). However, biodiversity studies are still limited in the Mediterranean both for benthos (Danovaro et al., 2010) and plankton, ~~with the studies of the latter being mainly limited to the epipelagic layer~~ (Siokou-Frangou et al., 2010). In addition, the Eastern Mediterranean is more
25 subject to change by the invasion of alien species in combination with warming (Coll et al., 2010), ~~due to the connection with the Red Sea~~. All the above make clear the interest of studying the biodiversity of the open Cretan Sea.

2.3 Biological pump efficiency at mid and deep waters

The inhabitants of the deep sea play an important role in determining the depths to which carbon is
30 exported, a role mainly played by microbes and zooplankton (review by Turner, 2015). The lack of data from midwater depths severely limits our ability to quantify the efficiency of the biological pump (Robinson et al., 2010). ~~Although in the western-eastern part of Mediterranean there have been several studies on less is known on deep living zooplankton, much less is known for the Eastern Mediterranean~~ (review by Saiz et al., 2014).

In the Cretan Sea, deep water mesozooplankton has occasionally been studied (Siokou et al., 2013) and
35 the vertical flux of zooplankton faecal pellets quantified (Wassman et al., 2000). In this area, macrozooplankton vertical migration appears to occur at diel and seasonal scale down to 500 m ~~as suggested by ADCP measurements~~ (Potiris et al., this issue). Since zooplankton vertical migration may constitute an important active vertical flux

increasing the biological pump's efficiency (review by Frangoulis et al., 2005), ~~the role of this vertical migration~~its role in the Cretan Sea pump needs exploration.

2.4 Basin to global anthropogenic impact

Although it is clear that human activities have modified the biogeochemical cycles of nutrients ~~in~~
5 ~~terrestrial and aquatic ecosystems~~ (Galloway et al., 2008), the understanding of the marine ecosystems' response to ~~atmospheric and terrestrial input~~these variations is limited. The Eastern Mediterranean is characterized by an anomalous N:P ratio ranging from 25 to 28, significantly higher than the normal oceanic Redfield ratio (16:1) (Kress, 2003). In this basin, atmospheric deposition is believed to be the main source of nutrients in the euphotic zone of the open sea, other than the vertical mixing of water during winter (Christodoulaki et al., 2013 and
10 references therein), but the exact contribution to the balance of nutrients and the resulting impact on the productivity remains uncertain (Duce et al., 2008).

~~Furthermore, vertical mixing in the Mediterranean Sea is an important mechanism for the fertilization of the surface waters during the mixing period of the water column. Under global warming, a higher surface temperature would result in~~ a stronger stratification of the water column (Barale et al., 2008) ~~thus could~~
15 ~~increasing~~ the importance of the external sources of nutrients like atmospheric deposition. However, thermal instability in the atmosphere, ~~occasionally induced by air pollution~~, could lead to strong convective events in the atmosphere that could also increase the vertical mixing in the water column, bringing ~~up limiting~~ nutrients ~~like P to support the phytoplankton growth~~ (Christodoulaki et al., 2016).

Besides atmospheric deposition, a large part of the Mediterranean coasts host areas with coastal water
20 contamination occurring by pollutants (EEA, 2006) and changes on the quality and quantity of river inputs (Ludwig et al., 2009).

The Cretan Sea, ~~based on a delineation of the Mediterranean basins~~ according to ~~the its~~ river discharges, is qualified as having open ocean characteristics (Ludwig et al., 2009 and references therein). However, river discharges only do not allow to fully support the assumption that this area receives only basin to global scale
25 anthropogenic impact. In fact, it has still to be verified against other poorly known open ocean anthropogenic activities in this area, such as fisheries (including deep ecosystems exploitation), maritime transport and noise.

3 Aims and mission

The Cretan Sea Observatory, is the most biogeochemistry/ecosystem oriented, multiplatform subsystem of POSEIDON. POSEIDON (www.poseidon.hcmr.gr) is an observatory research infrastructure of the Eastern
30 Mediterranean basin, for the monitoring and forecasting of the marine environment, supporting the efforts of the international and local community and replying to the needs and gaps of science, technology and society (Perivoliotis et al., 2018). It was developed in three phases under the funding of EEA Financial Mechanism (85%) and Greek National funds (15%): POSEIDON-I (1997-2000), a first-generation buoy monitoring network with operational centre, forecasting system, and relevant human resources; POSEIDON-II (2005-2008) a system
35 upgrade and expansion; and finally POSEIDON-III (2009-2011) a deep sea observing capacity expansion. During the period 2011 to 2017 they were no major upgrades and the system was partly supported by EU and National Projects. In 2017, an extended upgrade and renewal of POSEIDON buoy network monitoring parts and

components and their supporting hardware was realized with the implementation of an integrated marine monitoring program funded by the EEA Financial Mechanism 2009-2014. The POSEIDON's biogeochemistry-ecosystem observational component aims, mainly achieved via its most oriented biogeochemistry-ecosystem oriented subsystem of the Cretan Sea, are presented below.

- 5 A. The **scientific objectives** coming out from the international (Ruhl, 2011; IMBER, 2005, 2010; NRC, 2011), European (EGMRI, 2013) as well as national scientific projects, are to provide scientific knowledge and support on the study of:
- 10 a. ocean mechanisms, including their interactions and spatiotemporal variability (duration, occurrence, match-mismatches). The currently examined mechanisms are: solubility and biological pump, transformation and transfer of matter (fluxes within food webs and in-out of ocean interfaces), and ocean-atmosphere interactions (heat, dust, CO₂).
 - 15 b. food web structure (stock, functional groups, microbial loop, size spectra) and biodiversity related variables (number of species present and their temporal variability), in order to help understand species interaction with food web functioning and biogeochemical cycling.
 - 20 c. the sensitivity of biodiversity and the variability of ocean mechanisms in relation to combined natural forcing factors and anthropogenic pressures. The current pressures considered, are those induced by warming (temperature, circulation, stratification, wind mixing, extreme-episodic events), ocean acidification (carbonate chemistry), nutrient dynamics (stoichiometry, dust deposition) and oxygen concentration. Other pressures and feedback effects planned to be considered in the future studies of the observatory are presented in the Sect. 8.
- B. The **Management aims** based on the experience acquired by POSEIDON team and international management recommendations (NRC, 2011; Karl, 2010; Ruhl et al., 2011) are:
- 25 a. Sustainability through prioritization and cost-effective management. This aim guides the expansion of the number and of the spatiotemporal coverage of the variables studied (see Sect. 7)
 - 30 b. Integration of disciplines, platforms and analysis methods, by bridging various measurement scales and methodologies as well as through a step-by-step integration of an increasing number of different biogeochemical platforms (see Sect. 4), variables and analysis methods (see Sect. 5)
 - c. Maintain a quality controlled biogeochemical-ecosystem database, with reduced data delivery time and expanded accessibility (see Sect. 6)
 - 35 d. Support ecosystem model validation for improved ecosystem forecasting and management
 - e. Provide a technology test bed for new biogeochemical sensors
 - f. Maintain collaboration through strong networking with similar observatories for common strategy, complementary tasks, protocol standardisation, and transfer of knowledge (see Sect. 4)
- C. Provide services to marine **policy-makers and the society**, while adaptation to the evolving needs is ensured by a feedback mechanism put in place. POSEIDON is being developed in accordance to the policy frameworks suggested by IOC/GOOS, EuroGOOS, the Mediterranean Operational Network for the Global Ocean Observing System (MonGOOS) and the Group on Earth Observations (GEO). The achievement of these objectives is made through collaboration with scientists from other disciplines including social scientists, and in communication with policy makers and the wider public. Within this framework the
- 40 observatory aims to:

- a. Provide policy makers with sound scientific knowledge to assist in making informed decisions. The observatory provides several MSFD descriptors (D1: Biological Diversity, D2: Commercial Fish, D3: Food web, D4: Hydrological conditions) and tests indicators of ecosystem health status.
- b. Promote understanding of anthropogenic impact on the ocean systems, and at the same time the dependence on them.
- c. Provide products to the end user through the POSEIDON operational biogeochemistry and ecosystem modelling tools.

A balance between the operational and research character of the infrastructure is maintained through the integration of methodologies and tools developed in relevant EU initiatives and projects. In parallel, the objectives are adapted based on new science and society goals and future scopes are considered in the strategic plan (see Sect. 8).

4 Components-Platforms

The present (2017) status of the Cretan Sea's coastal-open ocean biogeochemistry, ecosystem and biodiversity observatory includes: a) an open sea fixed platform with a multi-sensor array, b) a coastal fixed platform with a multi-sensor array, c) open sea sediment traps, d) an open sea ADCP e) open sea sampling through regular R/V visits, f) coastal sampling through regular R/V visits and g) a Ferrybox (FB) (Fig. 1, Fig. 2). It is complemented by land-based HCMR facilities (laboratories, mesocosms, calibration room) located on the island of Crete. The Cretan Sea Observatory platforms are integrated within a wider area network of Eulerian and Lagrangian (Bio-Argo floats) BGC platforms. Remote sensing (satellite) and BGC-ecosystem modelling products are used for the validation of measurements and vice versa. Last, but not least, comes the experienced multitasking personnel with significant experience in all aspects of the system.

We describe below these components via an historical evolution describing the progressive introduction of several platforms operating in long-term, and their development towards a more biogeochemical-ecosystem orientation.

4.1 Fixed platforms. From physics to biogeochemistry and to zooplankton vertical migration

In the framework of EuroGOOS, a multi-national effort to develop an integrated operational monitoring and forecasting system for the Mediterranean Sea took place under the Mediterranean Forecasting System (MFS) project (Pinardi and Flemming, 1998). During the Pilot Phase of the Project (1998-2001), a significant element of the designed observing systems was the Mediterranean Moored Multi-sensor Array (M3A) deployed in the open Cretan Sea, a prototype observatory that was designed to form the basis of a permanent network of moored stations for continuous recording of open-ocean conditions in the Mediterranean Sea (Nittis et al., 2003). From the eight planned stations in the Mediterranean, the E1-M3A was the prototype, the first open ocean buoy deployed in the Mediterranean in January 2000, followed by two other M3A stations in the Southern Adriatic (E2) and Ligurian Sea (W1) a few years later (Fig. 1).

The nowadays called POSEIDON E1-M3A buoy (WMO 61277) is the founder component of the Cretan Sea Observatory. The current configuration was designed and built during the second phase of POSEIDON. The mooring is located about 24 nautical miles north of the island of Crete at a depth of 1400 m (Fig. 1, Fig. 3), and

is currently the most developed physical-biogeochemical observing site of the POSEIDON system (Petihakis et al., 2007). Biogeochemical sensors currently deployed on the buoy are O₂, fluorescence (Chl-a), pCO₂ and pH (described in detail in Sect. 5). It is considered a reference point for monitoring open ocean biogeochemical processes (including air-sea interactions) of the Eastern Mediterranean and part of the operational oceanography observing system developments supporting the MSFD implementation in the Mediterranean Sea (Pinardi et al., 2009). Consolidating on the long experience of physical variables monitoring, the objective of the observatory has been expanded to include regular monitoring of the epipelagic ecosystem and the associated biogeochemistry (see Sect. 4.2).

Next to the E1-M3A buoy location, a fixed position ADCP was first deployed in 2000 for a period of one year. This 75 kHz ADCP placed at 600 m looking upward, allowed to study currents at multiple depths and gave indication of the presence of vertical migration of scatterers, probably large zooplankton (Cardin et al., 2003). Acknowledging the importance of this particular mechanism in the modulation of the ecosystem, in 2012 the ADCP was redeployed (depth ~500 m), and it provided data to analyse the vertical migration patterns (at diel and seasonal scale) of large zooplankton from 400 m to the surface (Fig. 7; Potiris et al., this issue).

In 2016, the Cretan Sea Observatory was expanded with a second fixed platform, the Heraklion Coastal Buoy (HCB) (Fig. 1, Fig. 3). This Oceanor Seawatch buoy, coupled with the existing infrastructures (open sea buoy, Ferrybox, R/V missions, Bio-Argos) in the area, opens possibilities to study the interaction of coastal with open sea processes (e.g. wave dynamics, exchanges of matter, extreme events spatial extend).

Since 2017 two more POSEIDON buoys outside the Cretan Sea, also provide biogeochemical data (O₂, Chl-a). These two similar to E1-M3A, Oceanor Wavescan buoys are deployed in the N. Aegean and Ionian waters. The buoy placed between Athos peninsula and the island of Lemnos (AB) (Fig. 1), monitors an area affected (e.g. with increased productivity) by the Black Sea water entering the North Aegean through the Dardanelles straits, which plays a significant role modulating the thermohaline characteristics and dynamics of the whole Aegean Sea, including the Cretan Sea (e.g. Korres et al., 2014). The Pylos site (PB) in the SE Ionian is a crossroad where intermediate and deep-water masses meet. The site is located on the pathway of the Aegean Sea dense water that travels to the north along the western coast of Greece. These three buoys (E1-M3A, AB and PB) providing meteorological, physical, and biogeochemical data in different areas, have allowed comparison of trends of physical variables (such as temporal increasing trend in temperature, see Fig. 4) and may allow the future comparison of biogeochemical variables in different levels of oligotrophy.

4.2 Water column sampling and sediment traps (R/V cruises). From occasional high spatial resolution snapshots to sustained temporal coverage

The biogeochemistry of the Cretan Sea has been studied approximately every 2 to 5 years since the 80's by in situ sampling using R/V's in the framework of different research programs (e.g. POEM, PELAGOS, CINCS, MATER, SESAME, PELAGIAL). However, having a wide spatial coverage, most of the cruises were at the best made at seasonal scale (generally at mid-spring and early-autumn). In addition, there was a large sampling gap between 1999 and 2005 (Fig. 5) while only from 1993 to 1995, during the CINCS project, high frequency (bi-monthly) samplings were performed (Danovaro et al., 2000; Psarra et al., 2000; Tselepides and Polychronaki, 2000; Van Wambeke et al., 2000). Parallel to this, sediment traps were also deployed in the Cretan Sea during the CINCS project 1994-1995 (Stavrakakis et al., 2000) and MATTER project 1997-1998 (Lykousis et al., 2002).

A major contribution towards the implementation of a long term biogeochemical monitoring based on regular R/V visits was made in 2010, when the Institute of Oceanography of HCMR initiated a continuous sampling program at the POSEIDON E1-M3A site (Fig. 5). Initially it included conductivity-temperature-depth (CTD) casts and seawater/plankton sampling providing multiple variables (e.g. T, S and Chl-a shown in Fig. 6). Latter on (2011) it was complemented with two sediment traps, and a year later (2012) with an acoustic Doppler current profiler (ADCP) (see Sect. 4.13). Since 2016 CTD casts and seawater/plankton sampling are also performed at monthly frequency next to the coastal fixed platform HCB. These initiatives are maintained until present (2018).

4.3—ADCP. From currents to zooplankton vertical migration

~~A fixed position ADCP was first deployed next to the E1-M3A buoy location in 2000 for a period of one year. This 75 kHz ADCP placed at 600 m looking upward, allowed to study currents at multiple depths and gave indication of the presence of vertical migration of scatterers, probably large zooplankton (Cardin et al., 2003). Acknowledging the importance of this particular mechanism in the modulation of the ecosystem, in 2012 the ADCP was redeployed (depth ~500 m), and it provided data to analyse the vertical migration patterns (at diel and seasonal scale) of large zooplankton from 400 m to the surface (Fig. 7; Potiris et al., this issue).~~

4.5.4.3 Ferrybox. From temperature and salinity to carbonate system

A Ferrybox system operated for the first time in the Mediterranean, on the route connecting the ports of Piraeus (Athens) and Heraklion (Fig. 1), for one year between 2003 and 2004 within the framework of the EU-funded project Ferry-Box. This fully automated, flow-through system included sensors for underway measurement of temperature, salinity, fluorescence and turbidity. High frequency measurements took place every night, and the data were delivered in Near Real Time (NRT). ~~The system was reactivated in 2012 for a few years until the end of 2014. Recently, since mid-2017 it has been running continuously with an upgrade to provide also O₂, CO₂ and pH measurements. The system was reactivated in 2012 and operates since then (with a gap from late 2014 to mid 2017), with an upgrade to provide also measurements of O₂, CO₂ and pH.~~ The FB has been proven a helpful tool in the study of water circulation (e.g. modified Black Sea Water flowing in the Aegean Sea), in particular when assimilated into prognostic numerical circulation models to improve their accuracy (Korres et al., 2014). For surface Chl-a validation/calibration, a comparison of FB's fluorescence with satellite data as well as nearsurface measurements of Chl-a (by discrete water sampling) from nearby R/V cruises is a powerful multi-tool. An example of a first comparison of FB and satellite data from 2017, ~~displays depicts~~ higher values by both platforms in the Saronikos Gulf (Fig. 8) and opens questions that need further investigation. First, the comparison denotes differences between the two platforms which could most probably be due to differences in the time of acquisition (night time FB versus daytime Satellite means), the spatial acquisition (FB data from 3 m depth versus Satellite sea-surface 1 km horizontal resolution data) and/or sensing-data processing method. In addition, it denotes differences within FB data acquired in the Saronikos Gulf, depending on the direction of the vessel (mainly related to sensor adaptation time after FB reinitialisation).

4.64.4 BioArgo floats

During 2012 the Greek Argo infrastructure was launched as a component of the POSEIDON observing system, with the aim to purchase and deploy 25 ARGO floats (www.greekargo.gr), further contributing to the international ARGO community efforts to monitor the Eastern Mediterranean region. In 2016, five of the 15 Greek deployed floats were Bio-Argos (equipped with O₂ sensor). It is worth noticing that in the Aegean Sea the ARGO recordings are largely based on POSEIDON floats.

4.74.5 Gliders

Two SeaExplorer gliders were added in 2017 to the monitoring platforms of the POSEIDON system. The two gliders will be gradually integrated to the operational network of the system with the ultimate objective of establishing at least two endurance lines in the Aegean and Ionian Seas. In the Cretan Sea, the continuous monitoring that has started in late 2017 through an endurance line (example of first results shown in Fig. 9) is expected to contribute to the further knowledge of the seasonal variability of the flow field, collecting also evidences of the intermediate or deep-water formation events that are known to occur in the area.

The gliders' T/S profiles, collected during a 6-month period, will be used in Observing Systems Experiments (OSE) to assess the impact of the continuous monitoring of the Cretan Sea to the hydrodynamic modelling of the Aegean Sea, as the former plays a significant role in water masses exchanges with the Eastern Levantine basin, through the east and west Cretan Straits. It is interesting to see that the sea-surface height distribution as derived from satellite altimetry (Fig. 9a) is reasonably consistent with the vertical temperature and salinity structures depicted in Figure 9b -9c. In fact, as the glider transverses from west to east, the elongated anticyclonic eddy structure located to the north of Crete at approximately 23.8°E - 24.8°E (Fig. 9a) displays a noticeable deepening of the isothermals and isohalines, as revealed by the measured profiles that goes down to 300 m depth. It is expected that the introduction of these glider measured profiles to the Aegean Sea dynamics, through data assimilation system, will act synergistically with the satellite altimetry trivially assimilated into the system.

4.84.6 Biogeochemical Modelling

Forecasting tools are centrally placed in the POSEIDON system, with a number of state-of-the-art weather, wind waves, ocean circulation and marine ecosystem numerical models, initialization and data assimilation schemes providing 5-days ahead information on daily basis regarding the atmospheric (Papadopoulos et al., 2002), sea state (Korres et al., 2011) and hydrodynamic conditions (Korres et al., 2010) in the Aegean/Ionian Seas and in the Mediterranean. Currently, the POSEIDON modelling group is providing the wave forecasting products of the Copernicus Marine Environment Monitoring Service (CMEMS) for the Mediterranean Sea in the framework of MED-MFC.

The POSEIDON ecosystem simulation tool is one of the first developed in the Mediterranean, producing daily forecasts for a range of ecosystem variables for the whole basin. The Cretan Sea has been a test site for the implementation of the biogeochemical European Regional Seas Ecosystem Model (ERSEM, Baretta-Bekker et al., 1995), since it is the only offshore site in Greece in which the ecosystem has been systematically observed, providing a very successful test bed for model development (Petihakis et al., 2002; Triantafyllou et al.,

2003a, b, c; Hoteit et al., 2004). Data from POSEIDON buoys such as E1-M3A have been extensively used for model validation/calibration and testing of model parameterization techniques adopted in the operational POSEIDON models. Although the assimilation of these data directly in the model forecasts would have a relatively limited effect, given their small spatial coverage, they are of paramount importance for the development and testing of data assimilation schemes, as well as in the analysis of specific processes and the underlying dynamics of the system. General calibration – validation activities are applied to the operational models, as data from the observatory are used in conjunction with experiments (e.g. mesocosms, see Sect. 4.98), for the analysis and modelling of specific processes, such as the microbial functioning, the effect of the atmospheric deposition (Christodoulaki et al., 2013; Tsiaras et al., 2017) or for the assimilation algorithms of sea ~~colour~~ color data in BGC models (Kalaroni et al., 2016).

4.94.7 Personnel. From separate specialists to multitask collaborators

Specialized personnel is the ~~major-main~~ component for a smooth, ~~and~~ continuous functioning of any multiplatform-multidisciplinary observatory. Since its beginning, POSEIDON invested in the necessary human resources, namely a dedicated group of scientists and engineers that operate, maintain and upgrade the system on a full-time basis. Over the last years as the number and complexity of platforms significantly grow and as the inflow of data increased, the knowledge level of personnel became more demanding. Balancing these demands with personnel shortage, due to budgetary constraints, led not only technicians but also scientists to have multifunctional duties that “...may involve aspects of a bosun, chemical safety officer, satellite communications specialist, network administrator and electronics technicians” (NRC, 2011). In addition, despite the need of specialists of each domain remained, it appeared necessary to share the basics ~~of-in~~ each domain among several persons (e.g. 3 having knowledge of buoy maintenance-deployment, 5 of seawater sampling, 3 of CTD cast data processing, etc). Through active communication and with the support of various EU projects (JERICO, FixO3, JERICO-NEXT, EMSODEV, EMSOLINK) the personnel acquired precious experience by strong collaboration, continuous education and exchange of knowledge-experience with personnel of similar observatories.

4.104.8 ~~Land based support facilities~~

Sensor maintenance and analysis of discrete samples are not the only reasons for having several land-based facilities located nearby the observatory. Other land-based infrastructures such as calibration room, micro- and mesocosms, meteorological stations, and atmospheric deposition station, provide added value to the observatory.

The Poseidon calibration lab (based in Heraklion) accommodates the regularly scheduled calibration of sensors, considering the local environmental conditions (e.g. for conductivity sensors high salinity and for Chl-a sensors low concentration and native phytoplankton species). The lab is equipped with a specially designed large calibration tank and several smaller fiberglass tanks. Several reference sensors and equipment allow calibration of temperature, conductivity, fluorescence (Chl-a), turbidity and dissolved oxygen sensors. It has been proved ~~to~~ ~~be~~ a powerful tool for the calibration of sensors deployed in the wider Mediterranean Sea (Pensieri et al., 2016). In particular, calibrations of fluorometers and turbidity sensors are especially important in the Mediterranean, and

more so in the Eastern part, since primary production is significantly lower compared to most other areas in the world where such sensors are operating (Bozzano et al., 2013).

Microcosm laboratory facilities allow performing experiments on the physiology of a specific species or group of organisms of the Cretan Sea. In addition, the land-based mesocosm facilities at Crete (www.cretacosmos.eu), part of the MESOAQUA network of European mesocosm facilities, allow to better explore specific biogeochemical processes in connection with food-web functioning occurring within the Cretan Sea oligotrophic ecosystem.

Finally, the “Finokalia” atmospheric deposition monitoring site of the University of Crete located on the island of Crete (www.finokalia.chemistry.uoc.gr) is among the few atmospheric stations located along the coasts of the Eastern Mediterranean, with the particularity of being representative background station for atmospheric observations in the area (Kanakidou et al., 2011). The proximity of Finokalia monitoring station with the Cretan Sea Observatory offers a unique coupling of observing locations to study the impact of atmospheric deposition in the Mediterranean Sea (e.g. Kouvarakis et al., 2001).

4.114.9 Connection with European and international observatories

A regional observatory can reach a higher potential when it belongs to a wide network of observatories (Ruhl et al., 2011). Ocean observation at global scale is implemented through the international program GOOS (Global Ocean Observing System) executed by the Intergovernmental Oceanographic Commission (IOC) under the auspices of UNESCO (www.ioc-goos.org/), aiming to inform scientists, policymakers and society (Karl, 2010). GOOS is a global network of ships, buoys (fixed and drifting), subsurface floats, tide gauges and satellites that collect real time data on the physical state as well as the biogeochemical profile of the world's oceans for three critical themes: climate, ocean health, and real-time services.

At the European level, the EMB and EuroGOOS (www.eurogoos.org) have joined forces towards a truly integrated and sustained European Ocean Observing System (EOOS) as suggested by the Ostend Declaration (EurOCEAN 2010 Conference) and described in the EMB position paper “Navigating the Future IV” (EMB 2013).

For the open ocean, the OceanSITES project, an integral part of GOOS, facilitates international coordination of time-series at fixed locations (www.oceansites.org). The E1-M3A buoy of the Cretan Sea Observatory is part of the global network OceanSITES, via its European contribution (EuroSITES and former EMSO ERIC), which established integration between the fixed-point deep ocean observing systems around Europe. A strong and direct collaboration is established with scientists from observatories operating in the Mediterranean focusing on open ocean biogeochemistry (DYFAMED, W1-M3A and E2-M3A) (Fig. 1) as well on the atmospheric deposition monitoring (Finokalia). The open-ocean observatory of the Cretan Sea has been expanded with a multi-platform coastal component (including coastal buoy and Ferrybox) in the framework of JERICO-NEXT project in an attempt to characterize the timing, intensity, and fate of organic matter and the coupling of offshore with coastal processes.

5 Biogeochemical, ecosystem variables

The complexity of ocean environment has led the international scientific community (e.g. GOOS Expert Panels) to identify essential ocean variables based on their relevance, feasibility and cost effectiveness (www.goosocean.org). For comparison and consistency, it is also crucial for local observing systems to be an integral part of a wider network of observatories. The choice of variables and protocols used at the Cretan Sea Observatory are aiming to follow international relevance, best practices, inter-comparable methodologies and are evolving towards more simplified and cost-effective sensing/sampling/analysis. The Cretan Sea Observatory's biogeochemical variables, associated platforms and their spatiotemporal coverage are summarized in Fig. 10, and detailed in the Sect. 5.1 and 5.2.

5.1 Biogeochemical Sensors

Table 1 presents the BGC and associated variables measured by sensors on the various platforms of POSEIDON. The operation protocol for these sensors follows international best practices for standardized methods, regarding checking and maintaining sensor accuracy, on demand manufacturer calibration, regular lab calibrations (Coppola et al., 2016) and comparisons with relevant in situ data. Sensors are replaced approximately every 10 years. Pre-deployment lab calibrations for dissolved oxygen (DO), turbidity and Chl-a (fluorescence) sensors are performed in the POSEIDON calibration lab (described in Sect. 4.98). In situ comparisons ("field calibrations") are made for DO, pH and Chl-a (fluorescence) sensors, by comparison with casts made with a reference CTD (regularly calibrated) and with discrete samples taken at the depth of deployment of the sensors.

5.2 Adaptations of biogeochemical sampling and analytical (lab) methodology

Seawater and plankton samples are taken regularly in the vicinity of the fixed biogeochemical platforms and on-board the FB. In addition, samples of sinking particulate matter are collected with sediment traps. The variables studied and the lab methods used for analysing these samples are summarized in tables 2 and 3.

Water-plankton sampling is made using either a) a large (62_m) or medium (23_m) R/V, or b) a small R/V (RIB boat). The small R/V offers the opportunity of maintaining long time series at a lower cost, is easier to schedule, and is twice as fast as the larger vessels (allowing thus quick storage and analysis of samples at the land facilities). Overall, experience acquired up to now showed the small R/V to be the most frequently used vessel. HCMR has therefore invested to grow up its capabilities (e.g. new winch allowing casts much deeper than 1000 m – Fig. 11).

During the R/V visits in the area of the fixed biogeochemical platforms the order of sampling is always CTD-Niskin bottle casts followed by net tows. The vast majority of casts and net tows (>80% after 2010) were made between 09h00 and 14h00 (local time). The order of sampling, the sampling procedure and storing protocols follow the international recommendations described by Lorenzoni and Benway (2013) and remain consistent since 2010, with recording of cruise metadata (Cruise Summary Reports available at www.seadatanet.org). Adaptations of certain protocols have been made in certain cases, considering the open ocean oligotrophic conditions of the area. For example, zooplankton sampling was initially made with a single 200 µm mesh size net but soon it was changed into parallel two mesh-size nets (45 µm mesh size and 200 µm mesh size) tows. This was done due to the small size organisms found in the area, since combined data from several nets allows for a better estimation

of the mesozooplankton biomass (Frangoulis et al., 2016). In all cases, when a new method was introduced, a minimum one-year period of sampling-analysis using both old and new methods was applied, before moving exclusively to the new method (e.g. Chl-a by fluorescence and by HPLC where measured in parallel during 3 consecutive years).

5.3 Derived biogeochemical-ecosystem variables and model state variables

Any necessary unit conversion of physical and chemical oceanographic data for model validation, is generally straightforward. However, many biological variables expressed in biomass units are usually derived from the initial data with some conversion factor assumed. These conversions introduce biases that have to be carefully considered by biologists and modellers (Flynn, 2005; Frangoulis et al., 2010; Tsiaras et al., 2017). In the case of the Cretan Sea biogeochemical-ecosystem model, the choice of appropriate conversion factors from literature, that can be considered, is made by the data providers (biologists) in communication with modellers and is revised regularly.

Besides units' conversion, a provider-modeller communication is mandatory as the numerous measured biological variables often have no direct correspondence with the state variables of the operational biogeochemical model. Figure 12 summarizes the correspondence between measured variables and ERSEM model variables used by the POSEIDON team for the Cretan Sea. Most plankton groups measured (except bacteria and diatoms) do not have a direct correspondence with a model variable. To make such links several measured plankton groups have to be combined (e.g. *Prochlorococcus*, *Synechococcus*, picoeukaryotes), whereas others have to be split into subgroups based on their size (e.g. dinoflagellates >20 µm and <20 µm) and/or trophic functioning (e.g. autotrophic and heterotrophic nanoflagellates). Mixotrophs data field data were the most particular case, since they were split in four subgroups, creating an autotrophic and a heterotrophic subgroup to express mixotrophy (not represented in the model), which were subdivided again based on cell size (>20 µm and <20 µm). A model application using such field data grouping/splitting for validation can be found in Tsiaras et al. (2017). Planktonologists and the modellers of the observatory agreed that there is no rule of thumb, and model-field data correspondences should be adjusted according to the season and region.

6 Metadata and data handling

The POSEIDON database is set to include BGC and BGC-associated variables, either remotely sensed (pH, pCO₂, Chl-a, O₂, meteorological, T, S), or obtained from in-situ sampling (Chl-a, O₂, nutrients, plankton stock). The processing and the Quality Control procedures for the data collected from all the POSEIDON stations comply with the Copernicus Marine Environment Monitoring Service (CMEMS) In-Situ Thematic Assembly Center (INS-TAC) procedures, as HCMR is the regional data distribution node for the Mediterranean Sea. A number of quality control procedures for the validity of the data and a series of metadata correctness tests are applied before the release of the relevant data files. The data quality control process includes different routines for Near Real-Time (NRT) products and the Delayed Mode/Reprocessed Products.

The Near real Time quality control consists of a set of automatic tests according to the EuroGOOS Data Management, Exchange and Quality Working Group (DATA-MEQ) recommendations (<http://eurogoos.eu/data-management-exchange-quality-working-group-data-meq/>). These procedures are defined by variable, elaborated

in coherence with international agreements, in particular those adopted within SeaDataNet project (<https://www.seadatanet.org/Standards/Data-Quality-Control>) and they are applied by all the regional nodes of CMEMS ~~Insitu~~INS TAC on the NRT products in order to assure a minimum level of quality. Detailed information on the applied procedures can be found in the CMEMS INS TAC QC procedure manuals for temperature and salinity, currents and sea level (<http://dx.doi.org/10.13155/36230>), waves (<http://doi.org/10.13155/46607>), Chl-a (fluorescence), dissolved oxygen and nutrients (<http://doi.org/10.13155/36232>).

During the Delayed Mode/Reprocessed data analysis, procedures assessing the consistency of the data over a period of time are applied to the time series. The scientific validation includes statistical tests to check the consistency of the observations and climatological tests to highlight suspicious data that could not be detected by the automatic Quality Control processes. The resulted outliers are reassessed through visual inspection, a procedure that has an increased level of complexity on its implementation and highly relies on scientific expertise. Delayed Mode/Reprocessed products are available for temperature, salinity and waves, while the relevant product for Chl-a (fluorescence) and dissolved oxygen is under development.

Data can be visualized through the POSEIDON web-site (fixed platforms, Ferrybox) and the MonGOOS data portal (<http://www.mongoos.eu/data-center>, all platforms except sediment traps, ADCP), while the data are freely available to the public, the stakeholders and the scientific community, acknowledging the EC INSPIRE directive, in order to enable easy access to data and their reuse.

7 Management, governance and sustainable development

POSEIDON, and thus its subsystem of the Cretan Sea Observatory, has been managed up to now at institutional level by the HCMR Operational Oceanography Unit (i.e. POSEIDON team) which is subdivided in four components, three headed by scientists (observing, forecasting/modelling, data center) and one headed by an engineer (technical component). Within this management, the choice of infrastructures, sensors and thus BGC variables has been mainly driven by the participation in EU projects (e.g. JERICO, FixO3, JERICO-NEXT) which follow EU and International priorities. The recent emphasis given to biogeochemistry has been mainly the outcome of participation to JERICO and JERICO-NEXT. The latest project will allow to the Cretan Sea Observatory to integrate in the nearby future new biogeochemical variables by following the recent developments in sensors observing carbonate system variables, pollutants, phytoplankton and microbial diversity, toxic algae, etc.

In the near future the management/governance will move to a national level, as in 2018 the Hellenic Integrated Marine and Inland Observing Forecasting and Offshore Technology Systems Observing and Forecasting System (HIMIOFOTS), a national research marine observing infrastructure has been initiated. Within the HIMIOFOTS network a national management/governance is planned subdivided in (i) coordination team, (ii) operational and development team, (iii) scientific/technological committee and (iv) advisory team for infrastructure users. These boards will supervise the execution of the infrastructure's strategic plan, the scientific excellence, the technological development/innovation, the long-term sustainability, the good access to the infrastructure by national and international scientists, the outreach activities and the participation in large research international infrastructure networks.

A critical issue for any observatory is its sustainability. A continuous funding which will allow not only the day-to-day operations, but also the upgrade to the current state of the art technology is crucial. Unfortunately, in most cases marine observatories in Europe are developed through intermittent funding and national incentives. Likewise, the fixed platform of the Cretan Sea's observatory was founded through the FP6 EU Mediterranean Forecasting System Pilot Project (MFSP) followed by the POSEIDON project and the EFTA funds. Furthermore, some activities and developments have been funded in the framework of both EU and national projects (research and infrastructural), while in 2018 the observatory became part of the HIMIOFOTS, a research infrastructure part of the Greek Research Infrastructure road map.

In periods when funds are limited, it is important to have and maintain a baseline via prioritisation of the variables observed and platforms used. Such a plan must take into consideration, among other, the existing historical data sets, the international priorities and efforts and the specific scientific questions in the wider area (Eastern Mediterranean).

Despite some periods of low support, the multivariable-multiplatform approach and the resulting scientific production (>80 peer reviewed publications, >170 conference presentations, 7 PhD thesis) allowed the participation to various targeted research projects and thus the provision of funds through multiple sources. In addition, the long experience in the entire chain of operations and the particular conditions of the Eastern Mediterranean make the observatory an excellent test bed both for new technology and sampling methods.

8 Future scopes, expansion and vision

The future of the observatory is presented in a short-term strategy and a long-term vision.

1. The short-term strategy of the biogeochemical observatory follows the expansion vision of POSEIDON system which considers recommendations, guidelines and priorities defined in the national Research Infrastructure road map of observing systems (HIMIOFOTS), review papers (e.g. Claustre et al., 2010), EU goals directives (MSFD, H2020), and visions of European (EMB and EuroGOOS, e.g. EGMRI, 2013) and International coordinating bodies (Global Ocean Observing system - GOOS, and Global Climate Observing System - GCOS).

A main short-term goal is attaining a NRT character for the biogeochemical variables together with a further expansion of the recorded variables, with a greater focus in air-sea interaction. Based on the key variables recommended by the EU (EGMRI, 2013), priority is currently given to further integrate sensors of O₂, CO₂, pH and fluorescence (Chl-a). Nutrient sensing is expected to be the next to follow, although the low concentrations found in the Eastern Mediterranean constitute a strong technological challenge. HCMR plans to expand the ability to host such biogeochemical sensors (with NRT capability) to more of the existing POSEIDON platforms (e.g. buoys, Bio-Argos, gliders, drifters, Ferrybox) beyond the Cretan Sea, as done in 2017 with the addition of biogeochemical sensors to the NE Aegean and SE Ionian Sea buoy. In addition, a greater focus in the air-sea exchanges will be given. Finally, providing an operational status to the regular in situ sampling program is expected, following the experience gained and the standardisation of the procedures.

This strategy will give scientists the opportunity to study primary production, secondary (zooplankton) production, higher trophic level web structure, as well as feedback effects, such as the capacity to store CO₂, and the ecosystem's feedback on physics (light attenuation). In addition, the long-term time series data and the expanded NRT data delivery, proxy estimations, hazard mapping, and higher resolution predictions will benefit

numerous society users (local authorities, technical institutions, tourism industry, educational organizations, fisheries industry, environmental organizations, policy-makers etc).

2. The long-term vision considers further expanding the biogeochemical-ecosystems variables and spatiotemporal coverage of the observational system, including the capacity to perform deep biogeochemical observations, that will allow to resolve mechanisms that remain poorly known, like benthic-water column interactions, the functioning of mid-water and deep-water ecosystems, and the plankton vertical migration effect on active carbon flux.

Driven by other societal needs, supplementary underwater sensors will be considered. Once integrated in observing systems, these will offer scientists the potential to examine long term effects of additional pressures (e.g. thermal regime shift, contaminants including microplastics, noise, open ocean and deep ocean fishing, harvesting) and additional products to society (e.g. contaminants warning systems).

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Table 1: Current status of marine BGC and associated variables (T, S) measured from sensors in the POSEIDON platforms

Variable	Platform	Sensor	Sensor accuracy/sensitivity	Frequency of measurements
Temperature /Salinity	Buoys (E1-M3A, HCB, AB, PB)	SBE 16plus-IMP C-T-P SBE 37 IM C-T	$\pm 0.005\text{ }^{\circ}\text{C}$ / $\pm 0.0005\text{ S/m}$	180 min
	Ferrybox	Thermo-Salinometer SBE 45	$\pm 0.005\text{ }^{\circ}\text{C}$ / $\pm 0.0005\text{ S/m}$	1 min
	RV (CTD)	SBE 19+ OR SBE911	$\pm 0.005\text{ }^{\circ}\text{C}$ / $\pm 0.0005\text{ S/m}$	1 sec
	Glider	SBE GPCTD (Glider Payload CTD)	$\pm 0.002\text{ }^{\circ}\text{C}$ / $\pm 0.0003\text{ S/m}$	30 sec
Fluorescence (Chl-a)	Buoys (E1-M3A, AB, PB)	Wetlabs FLNTU	0.025 $\mu\text{g/L}$ Chl	180 min
	Ferrybox	Scufa II Turner Design	0.02 $\mu\text{g/L}$ Chl	1 min
	RV (CTD)	WET Labs ECO-AFL/FL 9 or Chelsea Aqua 3	0.025 $\mu\text{g/L}$ Chl	1 sec
Dissolved Oxygen	Buoys (E1-M3A, AB, PB)	SBE43 / SBE 63/ Aanderaa Optode	$\pm 2\%$ / $\pm 2\%$ / $\pm 5\%$	180 min
	Ferrybox	Aanderaa O optode	$\pm 5\%$	1 min
	Bio-Argos	Aanderaa O optode	$\pm 5\%$	1 min
	RV (CTD)	SBE 43	$\pm 2\%$	1 sec
	Glider	SBE 43F	$\pm 2\%$	30 sec
Turbidity	RV (CTD)	WET Labs ECO FLNTU	0.013 NTU	1 sec
PAR/Irradiance	RV (CTD)	Biospherical/Licor	N/A	1 sec
pH	Buoy (E1-M3A)	Sensor LabpH	$\pm 0.005\text{ pH units}$	180 min
	Ferrybox	Meinsberg probe	$\pm 0.3\text{ pH units}$	1 min
pCO ₂	Ferrybox	ControsCO2	$\pm 0.5\%$	1 min
	Buoy (E1-M3A)	Pro-Oceanus	2 ppm	180 min
ADCP (backscattering)	Buoy (E1-M3A)	Teledyne RDI 75kHz	$\pm 1\%$	180 min

Table 2: Variables measured from discrete bottle and net samples at high frequency (monthly). Method ranking from Lorenzoni and Benway (2013).

Variable	Platform	Analytical method	Method Ranking	Accuracy
NO ₃ +NO ₂ , Si(OH) ₄	E1-M3A, HCB	Manual Spectrophotometric	Acceptable	<3% <4%
PO ₄	E1-M3A, HCB	Magnesium-induced co-precipitation	Best	<2%
Total Chl-a	E1-M3A, HCB	Fluorescence and HPLC	Best	NA
Other Phytopigments	E1-M3A, HCB	HPLC	Best	NA
Viruses and Bacteria	E1-M3A	Flow cytometry	Best	NA
Picophytoplankton	E1-M3A	Flow cytometry	Best	NA
Nanophytoplankton	E1-M3A, HCB	Microscopy (UV + blue light excitation)	Best	NA
Other nanoplankton	E1-M3A, HCB	Inverted microscopy	NA	NA
Microphytoplankton	E1-M3A, HCB	Inverted microscopy	Best	NA
Ciliates	E1-M3A	Inverted epifluorescence microscope (blue light excitation)	NA	NA
Zooplankton	E1-M3A, HCB	45µm and 200 µm nets, Scanning & Image analysis	Best	NA

Table 3: Variables measured from discrete bottle samples at low frequency (6 to 24 months) and from sediment traps (integrating 15 days). Method ranking from Lorenzoni and Benway (2013). +traps : measurement from both water column samples and from particulate matter in sediment traps. FB: Ferrybox.

Variable	Platform	Analytical method	Method Ranking	Accuracy
Dis. Oxygen	E1-M3A, HCB	Winkler (against CTD sensor)	Best	<0.02 mL/L
A _T	E1-M3A, FB	Potentiometric titration (Closed cell)	Best	<0.1%
DIC	E1-M3A, FB	Coulometric determination	Best	<0.1%
TEP	E1-M3A	Colorimetric determination	NA	<11%
POC/ PN	E1-M3A (+ traps)	High Temperature Combustion via Elemental Analyzer	Good	<3.5% / <2.5%
DOC or TOC	E1-M3A	High Temperature Combustion	Best	<3%
TDN	E1-M3A	Persulfate Oxidation	Good	<5%
DOP	E1-M3A	Persulfate Oxidation	Best	<5%
Primary production	E1-M3A	¹⁴ C. Fractional day incubations scaled to daily rates	Acceptable	NA
Bacterial production	E1-M3A	³ H-labelled leucine method	Best	NA

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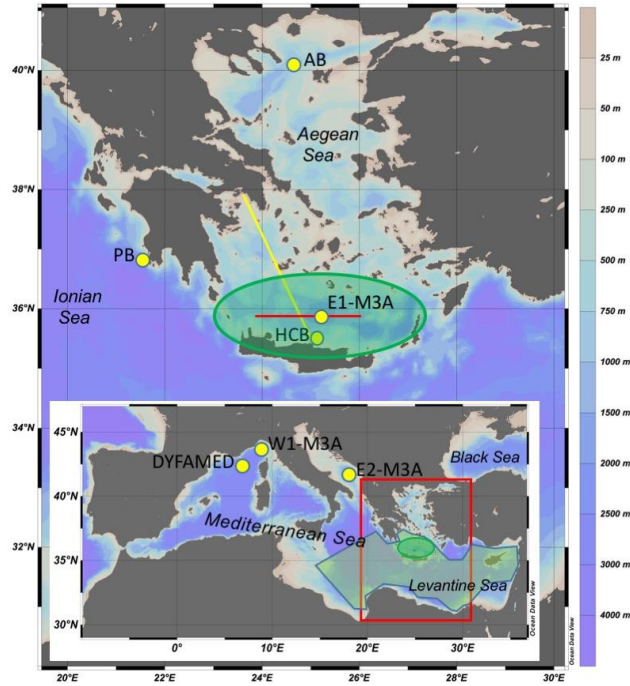


Figure 1: Map of showing the location of the Cretan Sea (green ellipse) and all POSEIDON system BGC fixed platforms (yellow dots, see Sect. 4.1), glider endurance line (red line, see Sect. 4.65) and Ferrybox (yellow line, see Sect. 4.43). Inset map shows location within the Mediterranean Sea (red square), location of other BGC fixed platforms (from www.oceansites.org) and E1-M3A spatial footprint (green area) for Chl-a using satellite observations (redrawn after Henson et al., 2016). The E1-M3A location includes in addition to the BGC fixed platform, an ADCP and sediment traps.

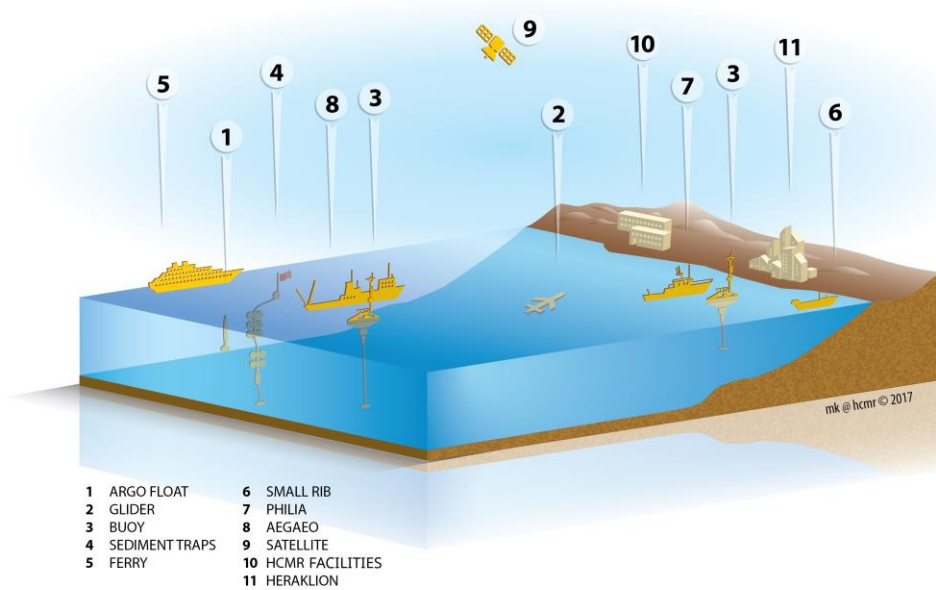


Figure 2: Platforms of the Cretan Sea biogeochemical-ecosystem observatory.

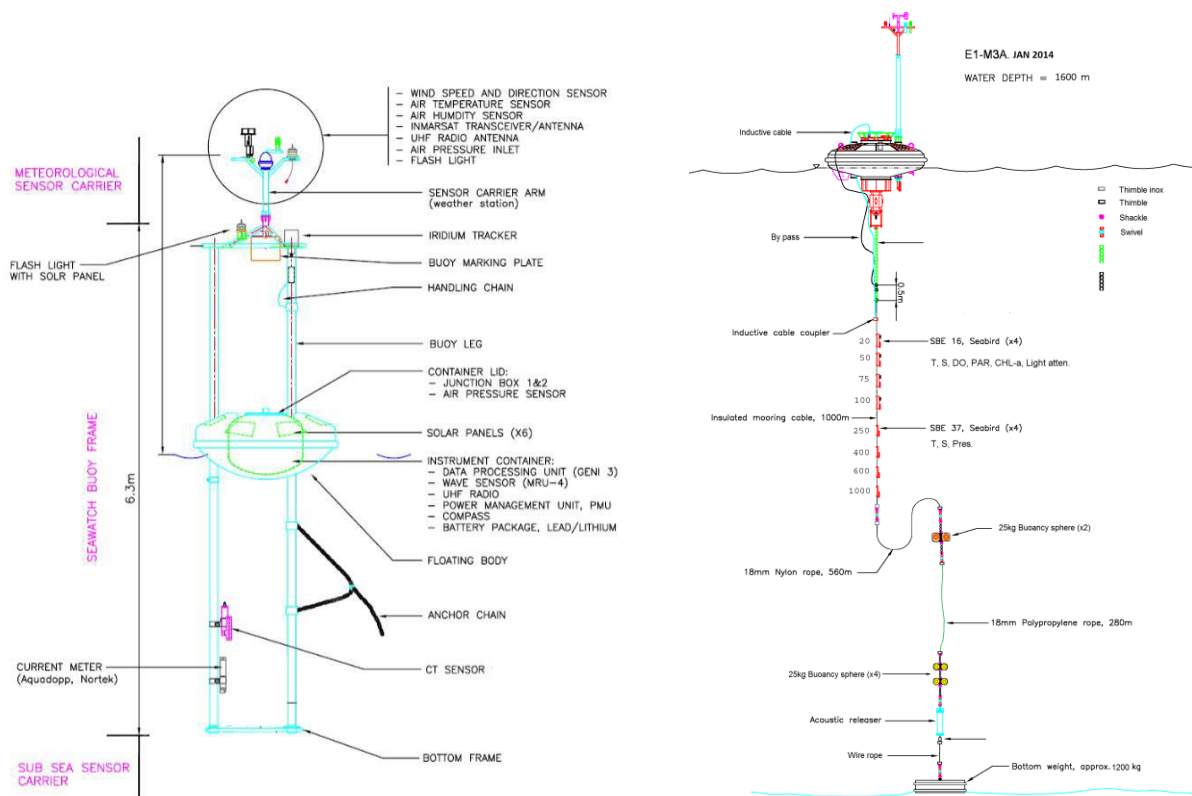
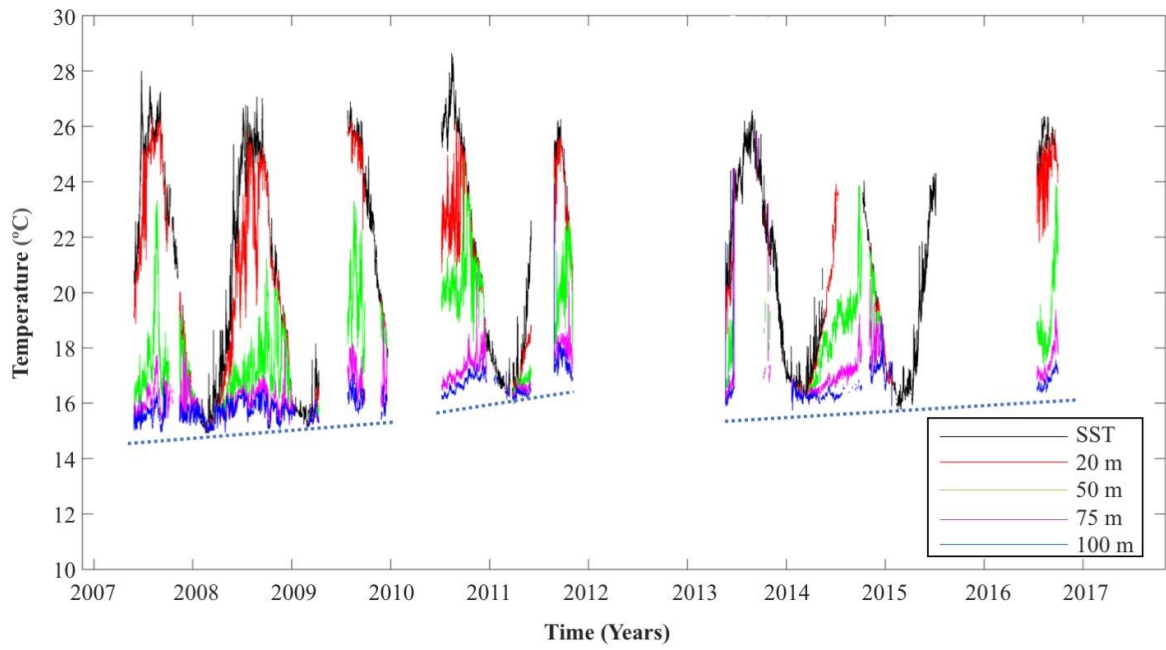
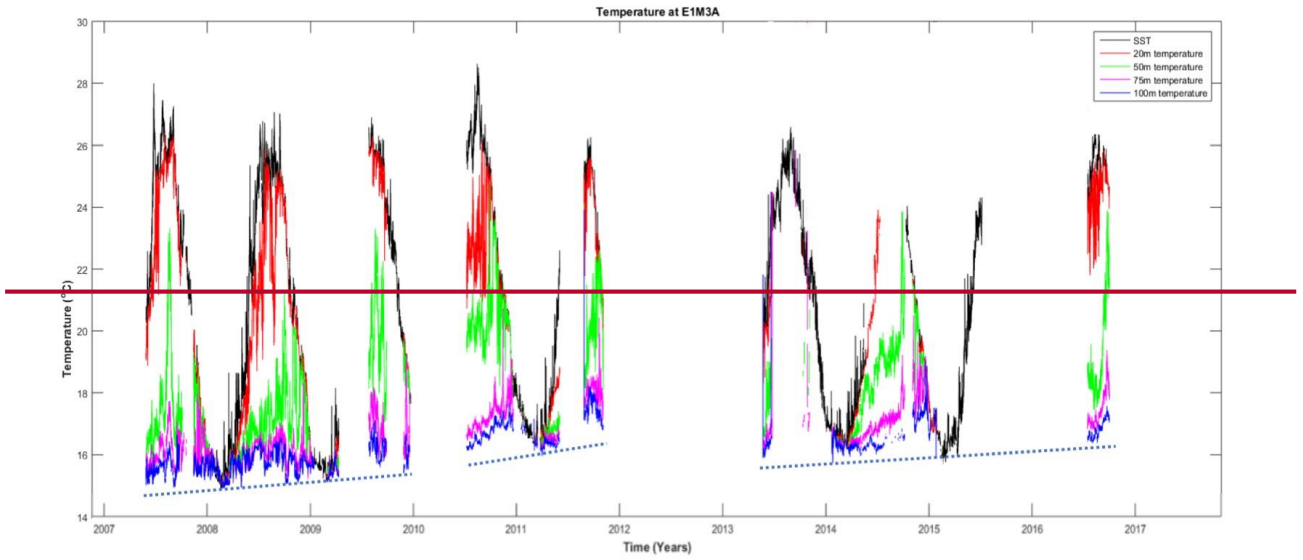


Figure 3: Coastal (left) and open sea (right) fixed platforms configuration with scheme of payload



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Figure 4: Temperature recordings at the E1-M3A buoy from 2007 to 2017.

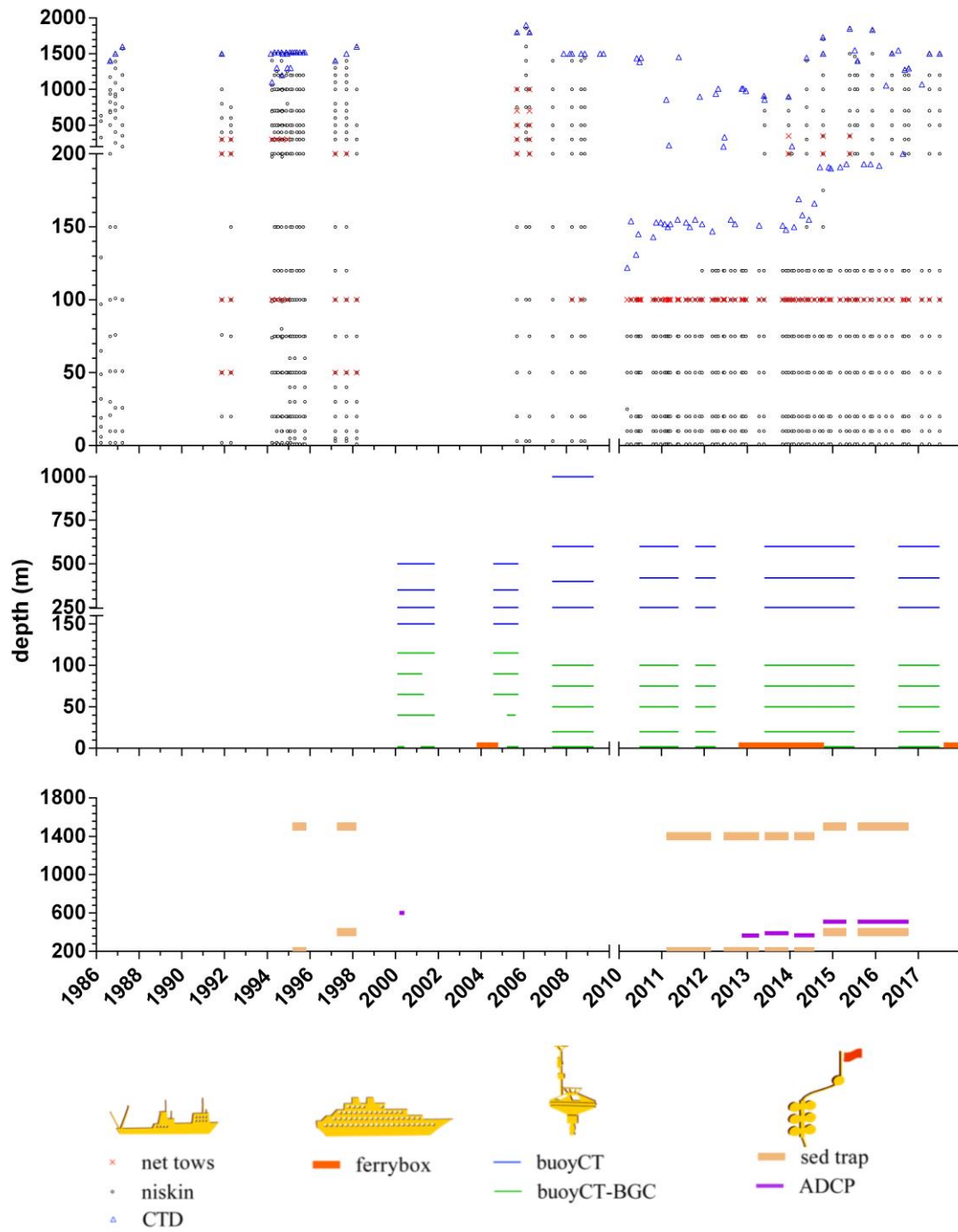


Figure 5: Periods of operation of the different platforms located in the open Cretan Sea (historical metadata within a circle of 20 nautical miles radius around the position of E1-M3A; exclusion of metadata made within 10 nautical miles from a coast). Before 2010 the metadata listed may not be exhaustive. CTD casts and net tows were made from the surface to the depth shown in the figure. Ferrybox entry point is located at 3 m depth. BGC: O₂ and/or fluorescence sensors. CT: conductivity and temperature.

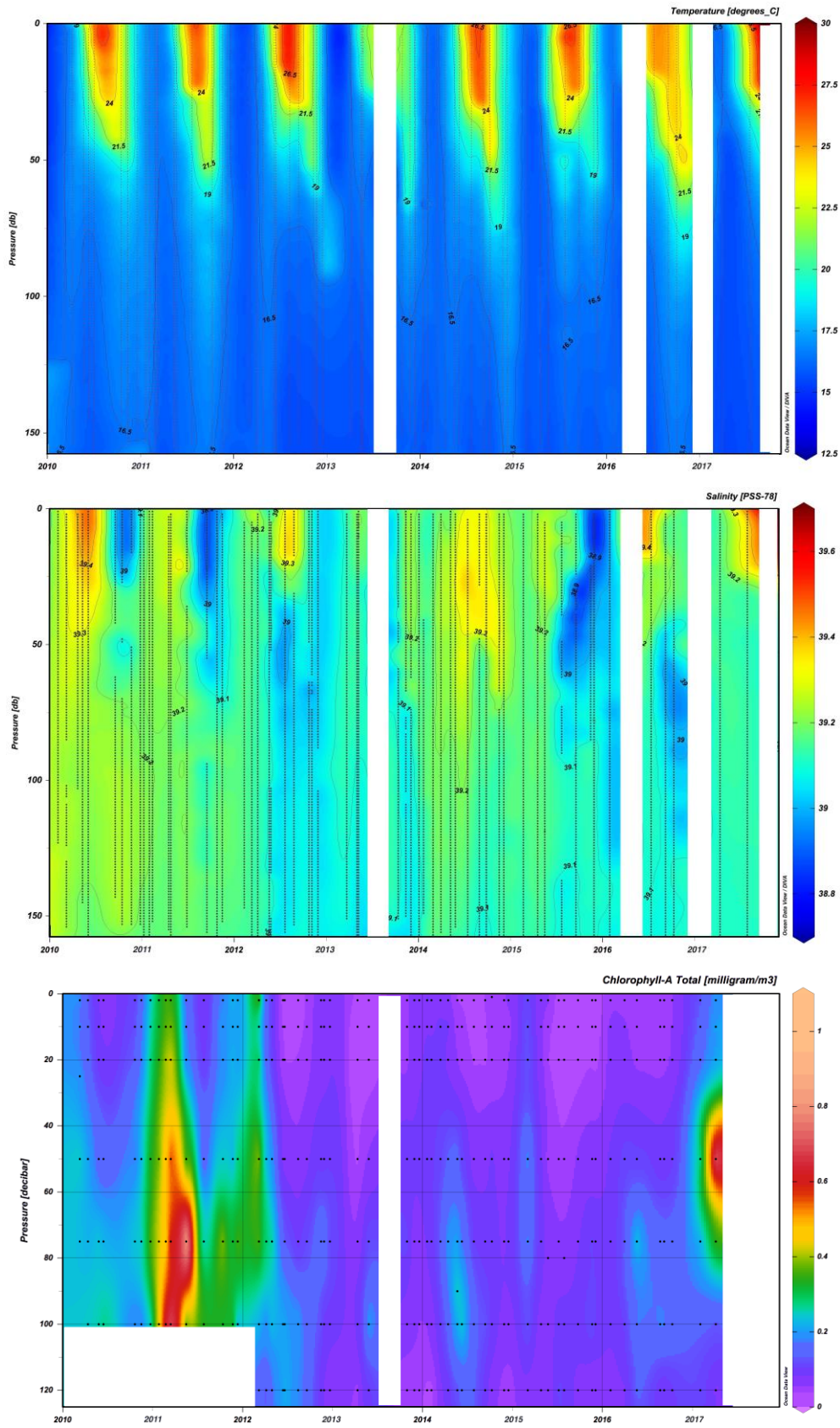
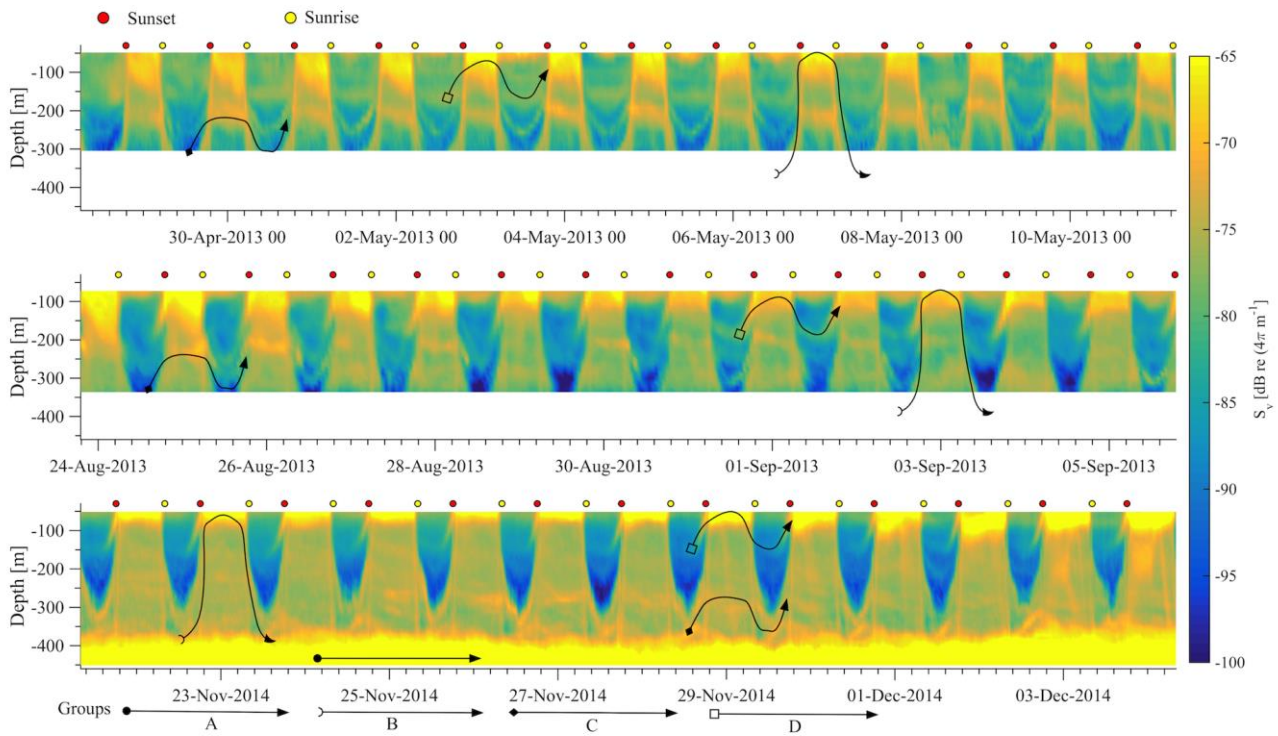
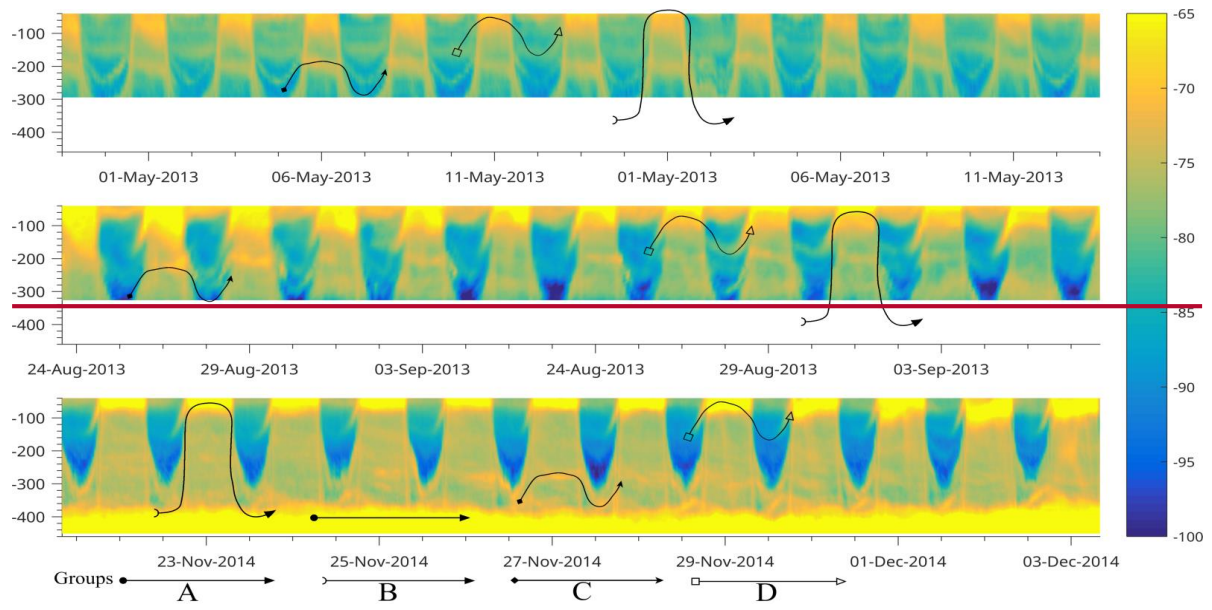
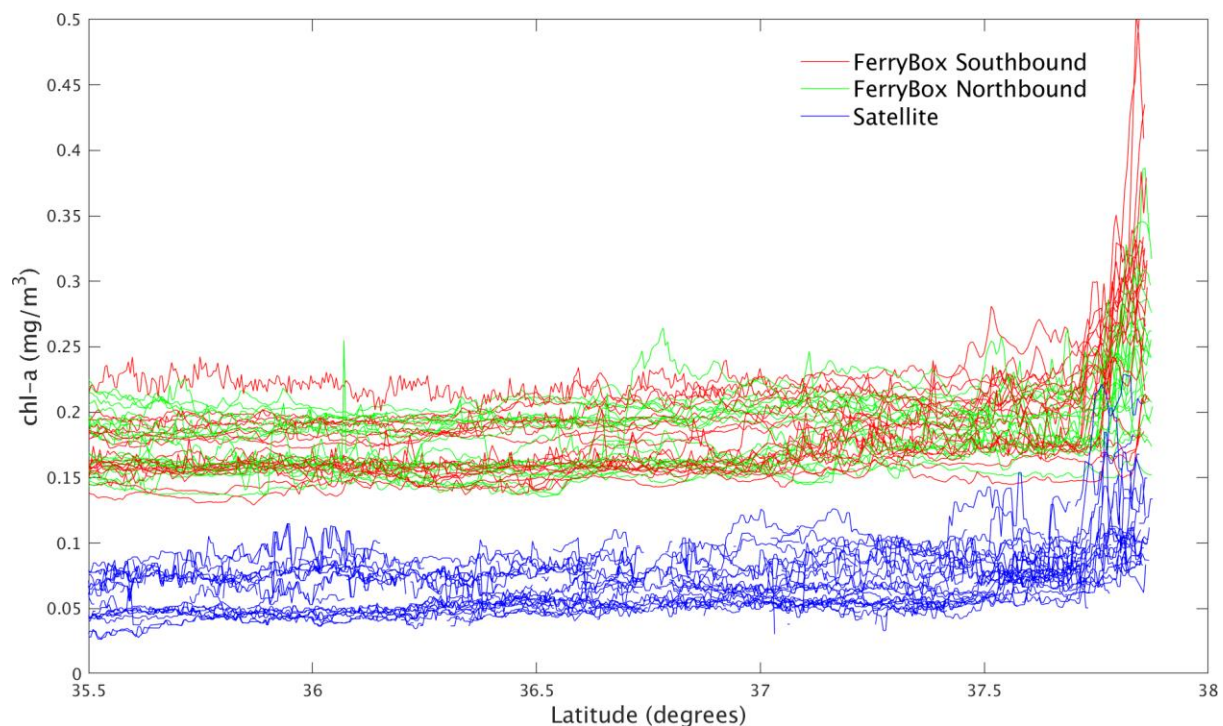


Figure 6: Vertical distribution of temperature, salinity (CTD casts) and total Chl-a (fluorometric analysis of seawater from bottle sampling) from 2010 to 2017 at the POSEIDON E1-M3A location.



5 **Figure 7: Backscatter coefficient S_v from the 75 kHz ADCP placed at the POSEIDON E1-M3A location. Hand-drawn trails are attributed to different groups of zooplanktonic and micro-nectonic organisms (from Potiris et al., this issue).**



5 **Figure 8: Comparison of POSEIDON Ferrybox's fluorescence data with satellite ocean colour data over a selected period (October 2017 to January 2018). FB data are separated depending on the direction of the vessel (green lines: southward towards Heraklion, red lines: northward towards Piraeus). Satellite data were obtained from the OCEANCOLOUR_MED_CHL_L3_REP_OBSERVATIONS_009_073 product available at <http://marine.copernicus.eu/services-portfolio/access-to-products/>**

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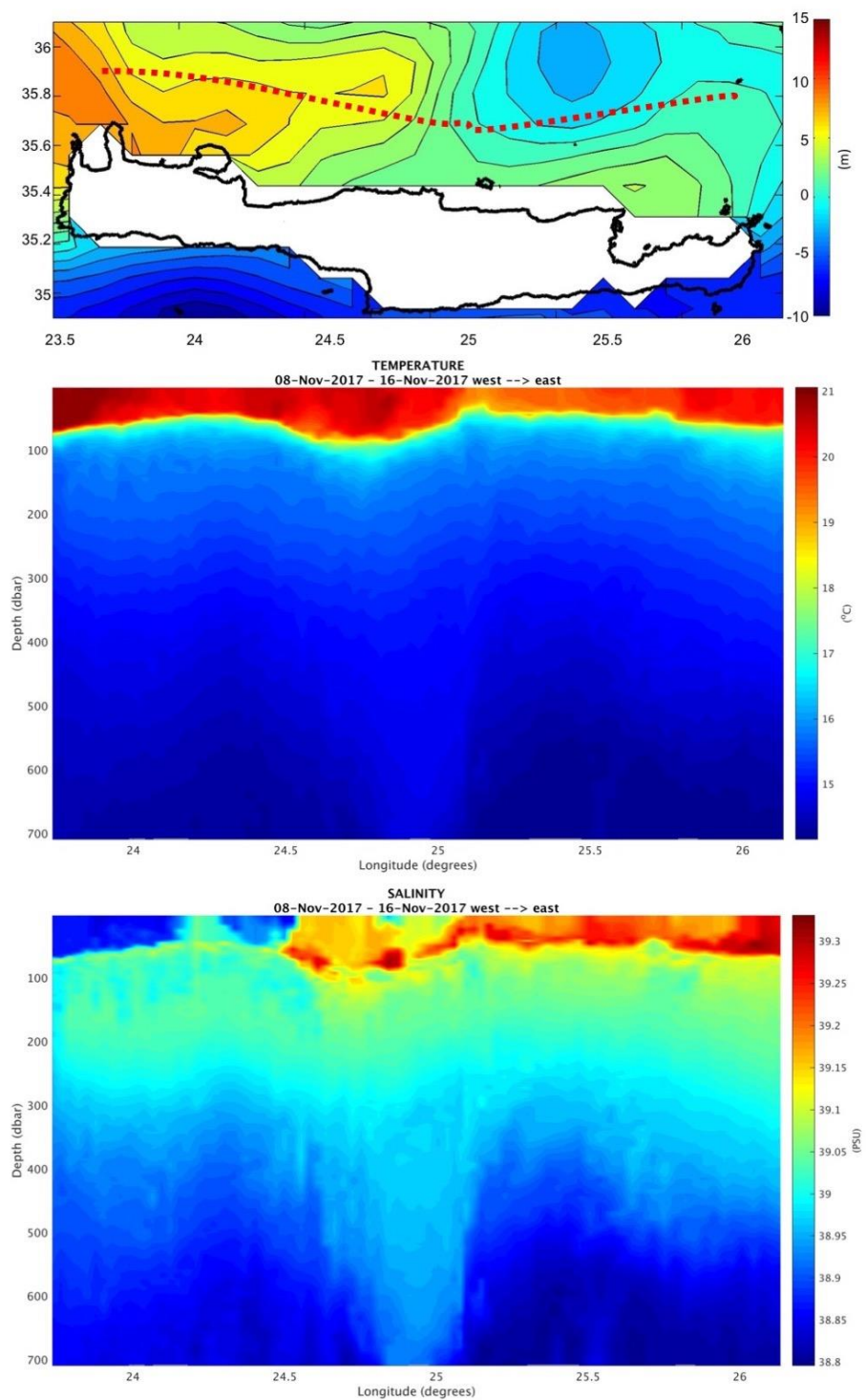


Figure 9: Sea-surface height (top panel) derived from satellite altimetry in the Cretan Sea in November 2017, in
 5 comparison to the vertical distribution of temperature (middle panel) and salinity (bottom panel) obtained by the glider
 along a west-east transect (red dotted line in top panel).

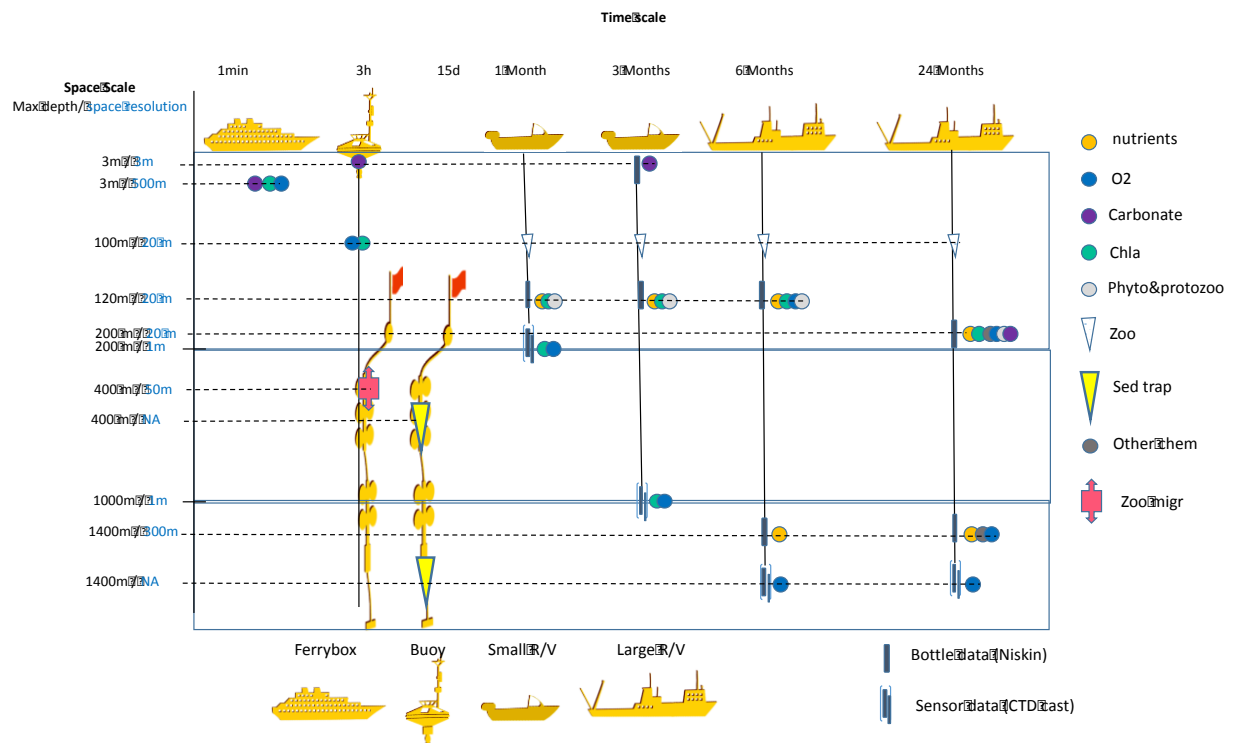


Figure 10: Time and space resolution of biogeochemical data acquisition by the different platforms of the observatory. The list of variables can be found in tables 1 to 3. Space resolution is vertical except in the case of Ferrybox. Carbonate: pH, pCO₂ or C_T&A_T, Other chem: other chemical variables, Sed trap: sediment trap, Phyto & protozoo: phytoplankton and protozoans; zoo: metazoans (collected with nets), Zoo migr: ADCP backscatter data for zooplankton migration.

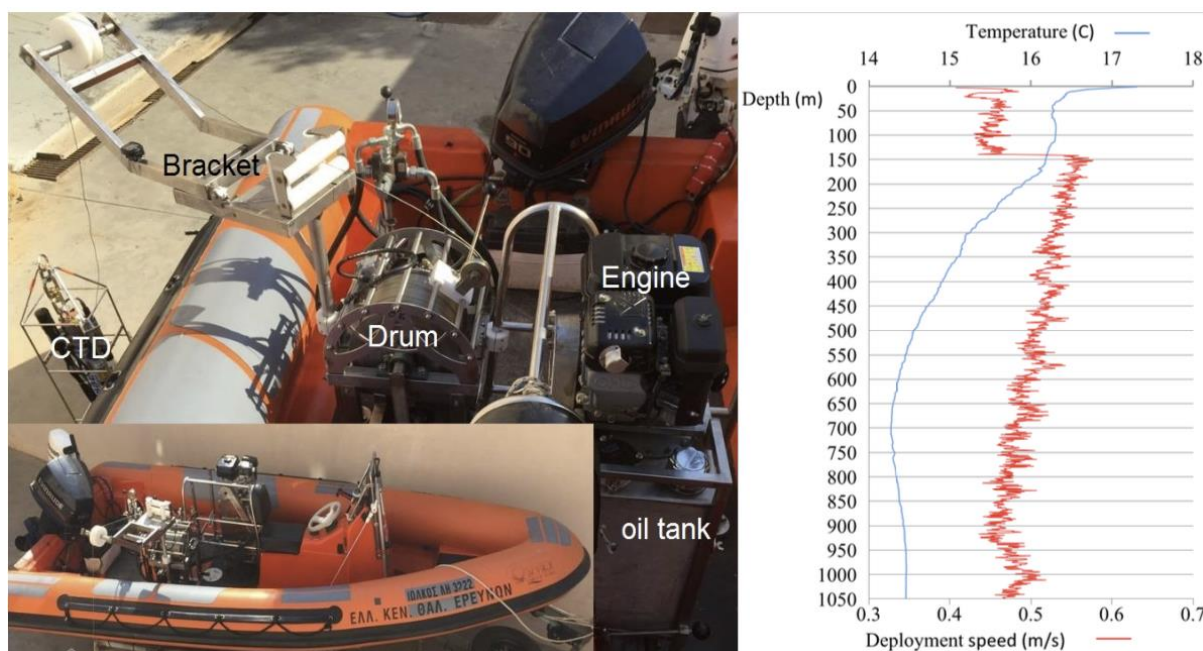


Figure 11: Left: Hydraulic winch positioned on a small RIB allowing casts >1000 m (Pettas et al., 2015); Right: Temperature and deployment speed against depth from a CTD cast made using the hydraulic winch. Deployment speed decrease above 150m was made in order for the CTD to respond better to rapid environment changes like thermocline.

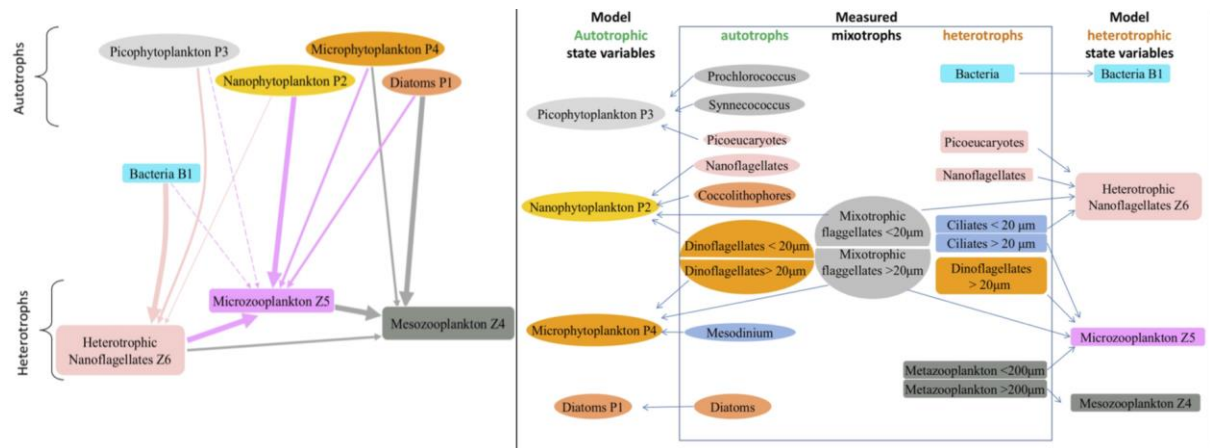


Figure 12: ERSEM model's food web structure (left) and correspondence between model variables and measured variables at the Cretan Sea Observatory (right)