

Replies to Reviewers

We would like to thank all three reviewers for their constructive comments that helped improve our manuscript.

Further we give our response to the comments:

Replies to Reviewer 1

General comments

The present manuscript aims to describe the current POSEIDON observing system (OS) in the East Mediterranean Sea which is based on multi-platforms and multi-parameters approach. The actual status of this OS is composed by coastal and open sea eulerian and lagrangian platforms (gliders, Argo floats, Ferrybox, moorings and buoys). This OS delivers variables which are essential to understand and predict the impacts of climate change and anthropogenic pressure on marine ecosystems in the Eastern Mediterranean Sea.

The manuscript is well written but some parts are missing and some parts should be re-organized.

The section 2 is too long and it should be reduced. The authors should do a rapid state of arts of the situation in the eastern basin and describe the main characteristics of the basin (why is it important to implement and sustain an integrated OS in this region).

Reply 1:

Section 2 was reduced by approximately 40%, with emphasis on the Eastern Mediterranean in relation to the importance of implementing and sustaining an integrated OS in this area.

In the section 3, the scientific questions, which are the backbone of each OS, should be detailed in the first part followed by the management aims and services.

Reply 2:

The requested change was made.

In the section 4, the personnel section should be moved after the section 4.9 otherwise this is confusing to see the personnel skills between the description of Ferrybox and Argo floats.

Reply 3:

The requested change was made.

In this section, there is no description of the POSEIDON buoys used for forecasting products. Why ?

Reply 4:

As a reply to this question in section 4.7 the following text was added (p.10 lines 32-37).

“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.”

After the data description in the section 5, a section on data analysis and data quality control is largely missing: How real-time data are managed ? Which protocols are used ? How the delayed mode data are adjusted ? Is there different correction levels (as for the remote sensing data) ? For example in Tables 1, 2 & 3, the authors should add some information on correction methods applied for each variables. In the same way, accuracy and measurements frequency should be added in these tables.

Reply 5:

The section 6 “Metadata and data handling” was rewritten to include the information requested. Accuracy was added in all tables. Frequency of measurements was added as a separate column in Table 1. In tables 2 and 3 frequency was described in the table title.

An additional section on the POSEIDON management and governance is missing too: who decide the choice of variables ? sensors ? how the new scientific needs are taken into account ? for example nowadays, global OS are focusing more and more on biological variables for marine ecosystems change (e.g. genomics). What is the vision of the POSEIDON group on this question ?

Reply 6:

The section 7, now entitled “Management, governance and sustainable development” was rewritten to include the information requested.

Regarding the scientific production, which is depending on the POSEIDON OS sustainability, how many publications, thesis, reports have been produced ? Any information regarding the DOI dataset statistics should be also included (at least on annex) to demonstrate the importance to maintain such OS.

Reply 7:

At the last paragraph of section 7 in p.16 line 4, the number of peer review publications, conference presentations and PhD thesis was added.

Finally, a description and figure on integrated results from the different POSEIDON components are missing. This should prove the necessity to implement an integrated and multi-variables OS but also it will stress what are the actual gaps and needs.

Reply 8:

Integrated results are now presented in the new figures 8 and 9, which are discussed in sections 4.4 and 4.6 respectively.

Ancillary comments

The word “parameter” is often over-interpreted. A distinction with variable should be addressed here. Parameters are not natural quantities, variables are. A variable is an entity that changes over time or depth: this what we are measuring. In general, parameters are "constants" that define a specific instance of a general equation that is based on variables. That’s why we used the term EOVS for Essential Oceanic Variables.

Reply 9:

We agree with the reviewer on the use of those two words. The term “parameter” was changed to “variable” when appropriate.

“Biochemical” should be changed to “biogeochemical”

Reply 10:

The change was made in the entire manuscript

Figure 1 Information is missing regarding the glider endurance lines, the Argo floats observation area, the sediment traps deployment, etc... A new figure should be proposed with the names of seas, straits, main countries, ...

Reply 11:

The glider endurance line was added in addition to the geographical location of other observatories requested by reviewer 2 (see reply 24). The sediment traps location is the same as the E1-M3A buoy (as described in section 4.2 and in the new modified legend of Figure 1). The Argo floats observation area was not added as it is highly variable. Names of seas cited in the manuscript were added in the figure. We believe adding names of countries too will complicate the figure and remove the focus from the observing systems.

Figure 3 This is not very clear and too small. It should be modified or removed

Reply 12:

The figure was modified by being split in subplots as suggested by reviewer 3 (see reply 51)

Figure 4 To better illustrate the physical and biogeochemical variabilities in this region, different time series should be shown here (not only TChl_a). For example, T, S, O₂, ...

Reply 13:

Temperature and salinity were also added to in the Figure (see new figure 6).

Figure 6 This figure does not bring anything. It should be at least merged with an ocean color remote sensing map or something else.

Reply 14:

Ocean color data were added as well as more and recent FB tracks (see new figure 8) as requested by reviewer 3. A description of the new figure was added in section 4.4

A figure on mooring dataset variability should be included too

Reply 15:

Mooring dataset variability is shown in the new figure 4

Replies to Reviewer 2

General aspects:

The manuscript written by Petihakis et al. describes the components part of the Cretan ecosystem observatory as the coastal and open sea buoys, ferry box, floats, gliders so as the land-based facilities and personnel capabilities. Special interest is given to biochemical measurements and ecosystem modelling. Finally, it gives an overview of future developments in the short term so as in the long one.

The manuscript (hereafter ms) is well written and easy to read. The part concerning the sustainability development is very well addressed, touching important aspects mandatory to maintain the system in the long run, key point of the Observing Systems.

MS deserves to be publishing; however some points I recommend to be reviewed and modified to improve it.

Main parts:

1. Part 2 (A strategic location to study the unknown of the Eastern Mediterranean) should be reduced because it is true that it gives a global idea of the area by touching different aspects but also that it is too discursive and dispersive as regards the real purpose of the ms. I should be synthesized the importance of the Observatory, the role in the East Med, and the benefits the community gains from it measurements. Please reduce the references, it is not a review paper and makes very difficult the read;

Reply 16:

This part was reduced. See Reply 1.

Approximately 25 references were also removed.

2. The Cretan Sea Observatory describes itself as a complex and articulated system. In this context and in MS it is difficult to place it in the Poseidon network. If this is the goal I suggest that the approach used be revised giving a meaning to part 3. The naming of the other two buoys (Pylos and the one in the Athos peninsula) without making any connection between them (Page 9, line 20-25) does not make much sense. Again in this framework, the future vision of the Cretan Sea system would be applied also to the other two buoys?

Reply 17: In the first paragraph section 3 the Cretan Sea Observatory was better defined, as a subsystem of the Poseidon network.

The last paragraph of section 4.1 p. 8 lines 13-24 was rewritten to show the connection between buoys.

A sentence was added in section 8 p. 16 lines 21-22 to show the vision concerning the Pylos and Athos Buoys.

3. I suggest moving 4.5 after Biochemical Modelling to keep a logical thread in the description of the system components (types of instruments and then personal and support facilities).

Reply 18:

The requested change was made.

Please provide the scheme of the payload of both coastal and open sea buoy.

Reply 19:

A new figure (Figure 3) was added showing the scheme of the payload of both coastal and open sea buoy.

Specific aspects:

1. Page 8 line 10: please provides some MSFD descriptors as example (useful for those not familiar with the argument)

Reply 20:

Some MSFD descriptors were added as an example (p.7 lines 2-3).

2. Page 9 line 3: change in ... followed by two other M3A stations in the southern Adriatic (E2) and Ligurian Sea (W1).... This will help to connect this two other sites with what is said in 4.10

Reply 21:

The requested change was made (p.7 lines 33-34).

3. Page 10 line 18-20: Please rephrase the sentence for better understanding

Reply 22:

The sentence was rephrased (p.9 lines 15-17).

4. Page 11 (Section 4.7): are any measurements done yet? please indicate an estimate time for the start of the monitoring program

Reply 23:

Time of the start of the Glider program was added in the text (p.10 line 5), and a new related figure (Fig. 9) was added. The Glider endurance line was added in Figure 1.

5. Page 13 line 4: the geographical location of the three observatories should

be indicated to give more information to the reader.

Reply 24:

The geographical location of the three observatories was added in Figure 1

6. Title 5.2 is not really representative of the section

Reply 25:

The title was modified to be more representative of the section

References:

Please review the reference part since many of them are missing in the text or are in the text and not cited.

Page 3 line 20/28/30 misspelling Theocharis et.al

Correct Cardin et al. 2014 to 2015 in the reference section

Page 4 line 23: Correct Kress et al.2003 to Kress (2003)

Page 5 line 16/line 18: Siokou et al. 2010 ? or Siokou-Frangou et al.2010 or reference is missing?

Page 5 line 39: Turner, 2015? Year does not agree with the reference which state 2002?

Misspelling or different paper?

Page 6 line 10: Frangoulis et al. 2005 or 2004? not agree text and reference part Page 6 line 25:

EEA 2015? ---2006???

Page 7 line 26: Ruhl 2001?

Page 9 line 8: Petihakis et al. 2006 --- I'm not sure if Ocean Science Discussion paper can be cited

Page 11 line 26: Baretta et al or Baretta-Bekker?

Missing:

Mentioned in the text and not in the references: Lascaratos et al. 1999

Theoharis et al. 2009

Pitta and Giannakourou, 2000

Ruhl 2001

Hoteit et al. 2004

In the references but not in the text: Balopoulos and Collins, 1999 Danovaro et al. 2004

Krom et al. 2004

Mihalopoulos et al. 1997

Reply 26:

References were checked and corrected

Replies to Reviewer 3

The manuscript proposed by G. Petihakis et al. aims giving a detailed overview of the POSEIDON observing system. The article introduces this observing system for the Eastern Mediterranean sea. Following this aim, no specific scientific question is addressed in the manuscript but it is more dedicated to the description of the POSEIDON objectives and

components. The manuscript is well written and describes briefly each components of the network, including links with ongoing European and international initiatives on Ocean Observing Systems. A specific focus also appears on the representativeness of the Cretan Sea to monitor Eastern Mediterranean Sea.

As general comments, I suggest that the manuscript would benefit from some illustrations/examples of POSEIDON recent measurements. There are very few examples in the manuscript and it doesn't highlight the potential of such observing system.

Reply 27:

New figures were added including recent measurements: Figure 4, Figure 6, Figure 8, Figure 9

Furthermore, authors take care of showing the interest of this observatory in this region. It would be interesting to mention how past measurements have contributed to the scientific knowledge of processes in the region.

Reply 28:

An example of contribution of past measurements is shown in the new Figure 4

As the paper aimed to be published in Ocean Science with a wide reading audience, it would be important to be more explicit in acronyms as a lot of projects, initiatives, programs are mentioned in the manuscript. As I'm familiar with this community, I can follow the ideas but for a reader less familiar with those initiatives, it can be difficult to follow in some parts.

Reply 29:

All acronyms were checked as to be cited full the first time

Considering the limited needed improvements included in general and specific comments, I recommend this paper for potential publication after minor revisions more related to illustrating more the paper contents.

Specific comments

Abstract

p. 1 / first sentence – The first sentence is mixing as the same kind of “object” processes (air-sea interactions and coastal-open ocean) and parameters. It would be more accurate if authors mentions either processes (physical and biogeochemical) or parameters.

Reply 30:

The sentence was rephrased (p.1 lines 12-14)

p. 1 / l. 22 – Bio-Argo systems are not measuring Chlorophyll concentrations but fluorescence. I recommend using the latest parameter in the text.

Reply 31:

The sentence was adapted to specify that, for Bio-Argo and other sensors, fluorescence is measured as a proxy of Chlorophyll-a (p.1 lines 23-24).

1. International need for observations

p. 2 / l. 11 – EuroGOOS is the first example of the acronyms or notations not defined in the manuscript (as for example and without classification: CT, AT, GCOS, HCMR, NRT, POEM, PELAGOS, ...).

Reply 32:

See Reply 29

2. A strategic location to study the unknowns of the eastern Mediterranean

p. 3 / l. 9 – “... depending on the parameter”. I did not understand to which parameter the author is referring to.

Reply 33:

The sentence was rephrased (p.3 lines 8-9).

3. Aims and mission

p. 7 / l. 4 – The reference to Perivoliotis EuroGOOS extended abstract is misleading as it sounds as if it is describing the same content as the present paper. Please consider referring to this abstract for more specific points.

Reply 34:

A sentence was added at the beginning of section 3 (p. 5 lines 26-27) to distinguish the CS observatory as a subsystem of POSEIDON system thus specifying that the reference Perivoliotis et al. includes the CSO subsystem.

p. 7 / l. 6 – 9 – Reading this part, we wonder about the POSEIDON activity between 2011 and 2017. We understand a bit more in the following sections but it is possible to be more explicit at this stage on this temporal gap ?

Reply 35:

A sentence was added (p. 5 lines 33-35) to specify activities between 2011 and 2017.

p. 7 / l. 29-35 – This “b” topic sounds to me included in “a” topic. Please consider rephrasing those scientific objectives to be more explicit.

Reply 36:

The topics “a” and “b” were rephrased.

4.4 Ferrybox

p. 10 / l. 14-24 – The figure given for FerryBox does not highlight the long term FB activity. Please consider a figure including more track (and recent) for example to illustrate those platforms.

Reply 37:
See Reply 14

4.7 Gliders

p. 11 / l. 10-15 – A figure showing glider tracks and data would support this subsection in the manuscript.

Reply 38:
See Reply 23

5.3 Derived biochemical-ecosystem parameters and model state variables

p. 14 / l. 24 – The figure 9 seems very interesting but there is a lack of explanation in the manuscript. Please consider adding more information on this figure or if you consider that it would need too much details, you can consider removing this figure and replacing by model results examples.

Reply 39:
More information concerning the figure 12 (ex figure 9) was added in section 5.3 p.14 lines 8-14

6. Metadata and data handling

p. 15 / l. 1 – Are ADCP and sediment traps available on a different portal ?

Reply 40:
Unfortunately, ADCP and sediment trap data are not available yet, something that we are working and hope it will be solved in the near future.

Minor and technical corrections

1. International need for observations

p. 2 / l.5 – “ocean bottom” could be replace by “bottom ocean”

Reply 41:
The replacement was made.

p. 2 / l.15 and l.22 – In the manuscript, both terms are used: “biochemical” and “biogeochemical”. Even if those terms are used often without distinction, this is not the same definition. Please, consider to be more homogeneous in the whole manuscript.

Reply 42:
See Reply 10

p. 2 / l. 24 – Authors cite “recently” for a study from 2015. Please consider rephrasing the introduction of the sentence.

Reply 43:

The sentence was rephrased. In addition, the term “recently” was removed in most locations in the text as the year was kept only.

2.1 Coupling of biochemistry with circulation patterns

p. 3 / l. 34 – To keep the paper understood for the next century, I would suggest to use “1970s” instead of “70s”.

Reply 44:

The term “70s” no longer exists as the corresponding phrase was removed due to the requested reduction of section 2.

2.4 Basin to global anthropogenic impact

p. 6 / l. 25 – The reference to EEA is 2006 and not 2015 in the reference list. Please double check the reference.

Reply 45:

The reference was checked and corrected

4. Components-Platforms

p. 8 / l. 20-31 – A reference to the map in Figure 1 is missing in this section introduction.

Reply 46:

A reference to Figure 1 was made in this section

Tables

Table 1

+ pCO₂ and ADCP are missing in the list.

Reply 47:

pCO₂ and ADCP were added in the Table 1

+ Please consider adding the sampling frequency range for each parameter.

Reply 48:

The sampling frequency of each parameter was added in Table 1

+ The sensor replacement frequency would also benefit readers interested in managing an observing system.

Reply 49:

The sensor replacement frequency was added in section 5.1

Figures

Figure 1

- + The figure 1 is a key figure for the paper. I think that a green less dark to highlight the are would help to see other system locations.
- + Please add a depth scale/colorbar

Reply 50:

The requested changes were made

Figure 3

- + this figure is tricky to read. Please consider splitting in 4 subplots (cruises, FB, buoy, sed trap
- + ADCP) for clarity.

Reply 51:

The figure was split in 3 subplots (cruises, buoy+FB, sed trap+ADCP)

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-and~~ biogeochemical (BGC) ~~processesparameters~~, 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-~~multivariablemultiparameter~~ 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 ~~variablesparameters~~. Since 2010, the list has been further expanded to other BGC (nutrients, vertical particulate matter fluxes), ecosystem and biodiversity (from viruses up to zooplankton) ~~variablesparameters~~, 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 ~~ocean~~-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 -~~and~~ 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~~Biochemical-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~~parameters 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~~Recently 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~~parameters exist in several shallow (<200 m) coastal sites (<10 n.m. offshore) (e.g. Berline et al., 2012; Eker-Deverli et al., 2006; 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~~biological processes have been focused on various spatial scales (large to meso-scale) ~~in numerous campaigns (POEM, PELAGOS,~~

~~MATER, INTERREG N.AEGEAN, METROMED, ANREC, KEYCOP, SESAME, BOOM etc); however these studies were at the best seasonal and only. Only two covered an studies on the annual cycle of biochemical parameters were performed [Cretan Sea (Tselepidis and Polychronaki, 2000) and Cilician Basin (Eker-Develi et al., 2006)], however with no data on micro and mesozooplankton. It is worth noticing that there are very few interannual scale studies of mesozooplankton in the open Mediterranean Sea (Siokou-Frangou et al., 2010).~~

The Cretan Sea biogeochemical – ecosystem observatory presented here, comes to fill the above gap. 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~~ ~~biochemistry~~ has been estimated that it represents an area in the Eastern Mediterranean ~~varying from~~ ~~of~~ 0.6 ~~to~~ -1.6×10^6 km² (Fig. 1) depending on the ~~biogeochemical variable (see variables in parameter (Fig. 1))~~ (Henson et al., 2016). Understanding Cretan's seas' features may be useful on larger oceanic 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~~ ~~biochemistry~~ with circulation patterns

The Cretan Sea plays an important role in the dynamics of the Eastern Mediterranean circulation and has been considered as heat, salt, and dissolved oxygen reservoir, since high temperature (>14 °C), salinity (>38.9) and dissolved oxygen concentrations (>4.3 mL/L) were detected in its intermediate and deep layers (e.g. Theoharis et al., 1993; 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 circulation patterns and intense mesoscale variability (e.g. Theoharis et al., 1999; Georgopoulos et al., 2000). Such areas of water formation are key locations for monitoring of the Mediterranean ~~biogeochemical~~ ~~biochemical~~ 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 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 (Theoharis et al., 2014). This transition known as the Eastern Mediterranean Transient (EMT) alternated dramatically the physical and ~~biogeochemical~~ ~~biochemical~~ properties at the intermediate and deep layers of the whole basin (Theoharis et al., 2009; Roether et al., 1996, 2007, among others). ~~Data~~ ~~The years following the EMT onset, the intermediate layer of the entire Cretan Sea was occupied by the 'nutrient rich, oxygen poor' Transition Mediterranean Water (TMW) that has intruded in the basin compensating the Cretan Deep Water (CDW) outflow (Souvermezoglou et al., 1999). The deep water outflow from the Aegean/Cretan is also a recurrent phenomenon that has been repeated in the past (i.e. 70's). The concentrations of nutrients within the TMW layer were often two times higher than those observed in the same area during previous studies undertaken before 1992 (Souvermezoglou et al., 1999). After 1995 the chemical characteristics of TMW were less~~

~~pronounced, a fact probably related to the decay of the transient behavior of the Eastern Mediterranean. Between 1999 and 2002 the Adriatic Sea has gradually started to regain its dense water formation role in the Eastern Mediterranean and, finally, the Adriatic Sea produced dense water in 2012. However, 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 During the last decade, dense water formation conditions have been identified showing that the basin is 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 decades (Sisma-Ventura et al., 2016). ~~A “winter time” (February 2006) snapshot of the distribution of the pCO₂ in the surface waters of the Aegean Sea revealed that the area is causing a net CO₂ uptake from the atmosphere (Krasakopoulou et al., 2009a). A “spring and late summer early autumn” snapshot (in 2008) showed that the Aegean acted as a sink for atmospheric CO₂ during spring, and as source of CO₂ during the warm period (Krasakopoulou et al., 2009b). Recently,~~ 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 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. Theocharis et al., 1999; Georgopoulos et al., 2000; Korres et al., 2014) and the strong coupling with the biogeochemical/biochemical 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.

2.2 Oligotrophy, ~~atmospheric deposition,~~ primary production, plankton stock and biodiversity hot spots

~~The Eastern Mediterranean is characterized by an anomalous nitrogen to phosphorus ratio ranging from 25 to 28, significantly higher than the normal oceanic Redfield ratio (16:1) (Kress and Herut, 2001; Kress et al., 2003). In this basin, riverine nutrient inputs are very low (Koçak et al., 2010), and 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 references therein). Interactions between atmospheric deposition of nutrients and ocean productivity can be critical for both CO₂ storage in the ocean and marine ecosystems life. Moreover, the Mediterranean atmosphere is a cross road for air masses of distinct origin, highly affected by both natural and anthropogenic emissions into the atmosphere that strongly interact chemically, due to the high photochemical activity in the area, leading to the formation of nutrients such as nitrogen compounds (Vrekoussis et al., 2006; Finlayson Pitts, 2009). Dust aerosols from the African continent are also affecting the area as carriers of nutrients, such as phosphorus and iron (Gallissai et al., 2014). Although the impact of this input upon primary productivity and key biochemical processes has been studied (Kouvarakis et al., 2001; Krom et al., 2004, 2010; Okin et al., 2011; Lazzari et al., 2011; Christodoulaki et al., 2013), the exact contribution to the balance of nutrients and the resulting impact of atmospheric deposition on the productivity of the oceans and climate remains uncertain and deserves further investigation (Duce et al., 2008).~~

The Eastern Mediterranean Basin is considered to be an ultra-oligotrophic system, in terms of both 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 Chl-a), the South-Central and Eastern Mediterranean (including the Cretan Sea) are clustered together within 60% of the total Mediterranean area ~~and are~~ ~~These areas are characterized by pronounced interannual variability, with~~ generally ~~characterized by~~ oligotrophic conditions ~~interrupted by pulses of biomass enhancement~~ (D'Ortenzio and Ribera d'Alcala, 2009). ~~The strong oligotrophy of the Cretan Sea has also been witnessed by primary production investigations (Ignatiades, 1998; Gotsis-Skretas et al., 1999; Psarra et al., 2000) giving an annual primary production of 24.8 gC m⁻² (Ignatiades et al., 2002). Oligotrophy in the Cretan~~
10 ~~Sea has been also suggested by the higher relative abundance of nanociliates (Pitta and Giannakourou, 2000), heterotrophic bacteria and nanoflagellates as well as by the level of bacterial production (Christaki et al., 1999; Van Wambeke et al., 2000). Mesozooplankton abundance in the Cretan Sea's epipelagic layer was found to be at the same level as in the open Ionian and Levantine and community composition have shown significant similarities with the above areas (Siokou-Frangou et al., 2010 and references therein).~~The dominance of the multivorous food
15 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 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); ~~Siokou et al., 2010~~). However, biodiversity studies are
20 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., ~~et al., 2010~~). ~~Marine diversity estimates are especially limited for deep seas and portions of the southern and eastern regions, with microbes' diversity being substantially underestimated (Danovaro et al., 2010).~~ In addition, the Eastern Mediterranean is more subject
25 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 biological carbon pump is the major oceanic process that photosynthetically converts the dissolved CO₂ in the surface layers of the ocean to particulate organic carbon, which is then consumed by pelagic biota, exported to depth by a combination of sinking particles, advection or vertical mixing of dissolved organic matter, and transport by animals, and/or sequestered in the deep sea. Buesseler and Boyd (2009) have noted that "the surface ocean" is "where the 'strength' of the biological pump is set" whereas "the subsurface ocean" is "where the 'efficiency' of the biological pump is determined."~~ The magnitude and efficiency of the biological carbon
30 ~~pump is controlled by physical and biogeochemical processes in surface, mesopelagic and bathypelagic layers, varying at daily, weekly, seasonal and inter-annual timescales. Several sediment trap experiments have been carried out over the past decades in the Mediterranean, both in continental shelf and open sea environments, studying mass fluxes, budgets of particulate organic carbon and other major and minor elements, and variability of particle fluxes and mechanisms controlling the transfer of particulate matter to the open sea (Stavrakakis et al., 2013 and references therein). Two of the most recent studies that have been conducted in the Eastern~~

~~Mediterranean, revealed that only a small portion of primary production (0.3–0.5%) reaches the bathypelagic zone (Gogou et al., 2014; Stavrakakis et al., 2013).~~

The inhabitants of the deep sea, play an important role in determining the depths to which carbon is 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 Mediterranean there have been several studies on deep living zooplankton, much less is known for the Eastern Mediterranean (review by Saiz et al., 2014), ~~although its stock and composition has been investigated (Siokou et al., 1997, 2013) and its importance in consuming sinking particles reported (Koppelman et al., 2004).~~

In the Cretan Sea, deep water mesozooplankton has occasionally been studied (Siokou et al., 2013) and 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 (Cardin et al., 2003; 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 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 terrestrial and aquatic ecosystems (Galloway et al., 2004, 2008), the understanding of the marine ecosystems' response to atmospheric and terrestrial input 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, oligotrophic areas, where 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 references therein), but the exact contribution to the balance of nutrients and the resulting impact on the dominant ocean productivity remains uncertain (Duce limiting factors (Powley et al., 2008).~~

~~2014; Van Cappellen~~ 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 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 limiting nutrients like P to support the phytoplankton growth in the N:P ratio in the ocean seems to have been driven by an increase in the atmospheric deposition of nitrogen due to human activities (Christodoulaki et al., 2016), although, potential changes in the atmospheric phosphorus deposition may also have contributed to this. Anthropogenic atmospheric inputs of phosphates to the ocean are 15% globally. In oligotrophic oceanic areas, such as Eastern Mediterranean Sea, where productivity may be limited by phosphorus, these inputs may contribute as much as 50% to the deposition (review by Mahowald et al., 2008).

Besides atmospheric deposition, a large part of the Mediterranean coasts host urban and/or industrial areas with coastal water contamination occurring by pollutants, especially in the vicinity of large cities, with

~~direct impact on marine ecosystems (EEA, 2006) and 2015). In addition,~~ changes on the quality and quantity of river inputs ~~have an impact on marine ecosystems, although this is evident only in the productive coastal areas~~ (Ludwig et al., 2009). ~~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 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 limiting nutrients like P to support the phytoplankton growth (Christodoulaki et al., 2016).~~

10 The Cretan Sea, based on a delineation of the Mediterranean basins according to the 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 anthropogenic impact. In fact, it has still to be verified against other poorly known ~~direct~~ open ocean anthropogenic activities in this area, such as fisheries (including deep ecosystems exploitation), maritime transport
15 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 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 ~~centres~~, forecasting system, and relevant human resources; POSEIDON-II (2005-2008) a system upgrade and expansion; and finally POSEIDON-III (2009-2011) a deep sea observing capacity expansion.
25 ~~During the period 2011 to Recently (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 due to~~ the implementation of an integrated marine monitoring program funded by the EEA Financial Mechanism 2009-2014. The POSEIDON's ~~biogeochemistry/biochemistry~~-ecosystem observational component aims, mainly achieved via its most oriented
30 biogeochemistry-ecosystem oriented subsystem of the Cretan Sea, are presented below.

~~A. The Management aims based on the experience acquired by POSEIDON team and international management recommendations (NRC, 2011; Karl, 2010; Ruhl et al., 2011) are:~~

~~a. Sustainability through prioritization and cost-effective management. This aim guides the expansion of the number and of the spatiotemporal coverage of the parameters studied (see Sect. 7)~~

35 ~~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 biochemical platforms (see Sect. 4), parameters and analysis methods (see Sect. 5)~~

~~a. Maintain a quality controlled biochemical ecosystem database, with reduced data delivery time and expanded accessibility (see Sect. 6)~~

~~a. Support ecosystem model validation for improved ecosystem forecasting and management~~

~~a. Provide a technology test bed for new biogeochemical sensors~~

5 ~~a. Maintain collaboration through strong networking with similar observatories for common strategy, complementary tasks, protocol standardisation, and transfer of knowledge (see Sect. 4)~~

H.A. A. The **scientific objectives** coming out from the international (Ruhl, ~~2011~~2004; 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), ~~food web structure (stock, functional groups, microbial loop, size spectra)~~ and ocean-atmosphere interactions (heat, dust, CO₂).

15 b. food web structure (stock, functional groups, microbial loop, size spectra) and biodiversity related variables~~unknowns~~ (number of species present and their temporal variability), in order to help understand species interaction with food web functioning and biogeochemical cycling.

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
20 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. B. The **Management aims** based on the experience acquired by POSEIDON team and international
25 management recommendations (NRC, 2011; Karl, 2010; Ruhl et al., 2011) are:

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 a. 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)

b. Maintain a quality controlled biogeochemical-ecosystem database, with reduced data delivery time and expanded accessibility (see Sect. 6)

c. Support ecosystem model validation for improved ecosystem forecasting and management

d. Provide a technology test bed for new biogeochemical sensors

35 e. 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
40 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 observatory aims to:

a-f. 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-g. Promote understanding of anthropogenic impact on the ocean systems, and at the same time the dependence on them.

e-h. Provide products to the end user through the POSEIDON operational [biogeochemistry](#)~~biochemistry~~ 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~~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

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~~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~~2006). ~~Biochemical~~ 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~~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~~parameter monitoring, the objective of the observatory has been ~~recently~~expanded to include regular monitoring of the epipelagic ecosystem and the associated ~~biogeochemistry~~biochemistry (see Sect. 4.2).

~~In Recently~~(2016), the Cretan Sea ~~Observatory~~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~~Outside the Cretan Sea, ~~also provide biogeochemical data (O₂, Chl-a). These two~~but within the POSEIDON network two, similar to E1-M3A, Oceanor Wavescan buoys ~~are~~were deployed in the N. Aegean and Ionian waters. ~~Both these buoys provide meteorological, physical, and since 2017, also biochemical (O₂, Chl-a) data.~~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~~R/V cruises). From occasional high spatial resolution snapshots to sustained temporal coverage

The ~~biogeochemistry~~biochemistry 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. 53) 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; Tselepidis 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. 53). Initially it included conductivity-temperature-depth (CTD) casts and seawater/plankton sampling providing multiple ~~variablesparameters~~ (e.g. T, S and Chl-a shown in Fig. 64). Latter on (2011) it was complemented with two sediment traps, and a year later (2012) with an acoustic Doppler current profiler (ADCP) (see Sect. 4.3). 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

10 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
15 seasonal scale) of large zooplankton from 400 m to the surface (Fig. 75; Potiris et al., this issue).

4.4 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, ~~(Nittis et al., 2006)~~. This fully automated, flow-through system included sensors for
20 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 and operates since then (with a gap from late 2014 to mid 2017), with an upgrade to provide also measurements of
~~the components, that now include~~ O₂, CO₂ and pH ~~sensors~~. 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
25 prognostic numerical circulation models to improve their accuracy (Korres et al., 2014). For surface Chl-a validation/calibration, a comparison of FB's fluorescence ~~(e.g. Fig. 6)~~ 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 higher values used by both platforms in the Saronikos Gulf (Fig. 8) and opens questions that need investigation. First, the comparison denotes differences
30 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). ~~observatory scientific team.~~

~~4.51.1 Personnel. From separate specialists to multitask collaborators~~

~~Specialized personnel is the major component for a smooth, 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 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.~~

4.74.5 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.

4.84.6 Gliders

Two SeaExplorer gliders were ~~added in recently (2017)~~ added 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.

4.94.7 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~~~~parameters~~ 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.; Christodoulaki et al., 2013; Kalaroni et al., 2016). 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. 4.9), 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 data in BGC models (Kalaroni et al., 2016).

4.8 Personnel. From separate specialists to multitask collaborators

Specialized personnel is the major component for a smooth, 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 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.

4.104.9 Land based support facilities

5 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
10 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 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
15 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
20 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
25 observations in the area (Kanakidou et al., 2011). The proximity of Finokalia monitoring station with the Cretan Sea ~~Observatory~~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).

4.114.10 Connection with European and international observatories

A regional observatory can reach a higher potential when it belongs to a wide network of observatories (Ruhl
30 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
35 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~~ ~~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~~ ~~biochemistry~~ (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~~ ~~parameters~~

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.goosoocean.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~~ ~~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~~ ~~observatory's~~ biogeochemical ~~variables~~ ~~parameters~~, associated platforms and their spatiotemporal coverage are summarized in [Fig. 107](#), and detailed in the Sect. 5.1 and 5.2.

5.1 ~~Biogeochemical~~ ~~Biochemical~~ Sensors

Table 1 presents the BGC and associated ~~variables~~ ~~parameters~~ 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. 4.9). 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~~ ~~Biochemical~~ sampling and analytical (lab) methodology

Seawater and plankton samples are taken regularly in the vicinity of the fixed ~~biogeochemical~~ ~~biochemical~~ platforms and on-board the FB. In addition, samples of sinking particulate matter are collected with sediment traps. The ~~variables studied~~ ~~parameters obtained~~ 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 (62m) or medium (23m) 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.

5 HCMR has therefore invested to grow up its capabilities (e.g. new winch allowing casts much deeper than 1000 m – Fig. 118).

During the R/V visits in the area of the fixed ~~biogeochemical~~ ~~biochemical~~ 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
10 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
15 200 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).

20 5.3 Derived ~~biogeochemical~~ ~~biochemical~~-ecosystem ~~variables~~ ~~parameters~~ and model state variables

Any necessary unit conversion of physical and chemical oceanographic data for model validation, is generally straightforward. However, many biological ~~variables~~ ~~parameters~~ 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).
25 In the case of the Cretan Sea ~~biogeochemical~~ ~~biochemical~~-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~~ ~~parameters~~ often have no direct correspondence with the state variables of the operational
30 biogeochemical model. ~~Fig.~~ ~~Figure 129~~ summarizes the correspondence between measured ~~variables~~ ~~parameters~~ 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), ~~grouped together~~, 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 data collected from the different platforms undergo Quality Control procedures according to EuroGOOS and OceanSITES working group standards and methodologies.~~ The POSEIDON database is set to include BGC and BGC-associated variablesparameters, 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 The-POSEIDON stations comply with the Copernicus Marine Environment Monitoring Service (CMEMS) Insitu Thematic Assembly Center (TAC) proceduresData Centre, 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 relevantecollection unit of the CMEMS, provides the compatibility of the recorded data with the existing large European data files. The data quality control process includes different routines for Near Real-Time (NRT) products infrastructures (EMODnet, CMEMS 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 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 INSTAC 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 ~~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 (MFSPP) 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~~ ~~recently~~ the observatory became part of the ~~Hellenic Integrated Marine and Inland Observing Forecasting and Offshore Technology Systems Observing and Forecasting System (HIMIOFOTS),~~ a research infrastructure ~~that has been accepted as~~ 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~~ ~~parameters~~ 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~~ ~~multi-parameter~~ ~~multiplatform~~ ~~observatory~~ approach ~~and the resulting scientific production (>80 peer reviewed publications, >170 conference presentations, 7 PhD thesis) allowed,~~ ~~allows~~ 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~~~~biochemical~~ 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~~~~European Marine Board~~ 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~~~~parameters~~ together with a further expansion of the recorded ~~variables~~~~parameters~~, with a greater focus in air-sea interaction. Based on the key ~~variables~~~~parameters~~ 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~~~~biochemical~~ 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~~~~biochemical~~-ecosystems ~~variables~~~~parameters~~ and spatiotemporal coverage of the observational system, including the capacity to perform deep ~~biogeochemical~~~~biochemical~~ 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/parameters (T, S) measured from sensors in the POSEIDON platforms

<u>Variable/Parameter</u>	<u>Platform</u>	<u>Sensor</u>	<u>Sensor accuracy/sensitivity</u>	<u>Frequency of measurements</u>
Temperature /Salinity	Buoys (E1-M3A, HCB, AB, PB)	SBE 16plus-IMP C-T-P SBE 37 IM C-T	± 0.005 °C / ± 0.0005 S/m	180 min
	Ferrybox	Thermo-Salinometer SBE 45	± 0.005 °C / ± 0.0005 S/m	1 min
	RV (CTD)	SBE 19+ OR SBE911	± 0.005 °C / ± 0.0005 S/m	1 sec
	<u>Glider</u>	<u>SBE GPCTD</u> <u>(Glider Payload CTD)</u>	± 0.002 °C / ± 0.0003 S/m	30 sec
Fluorescence (Chl-a)	Buoys (E1-M3A, AB, PB)	Wetlabs FLNTU	0.025 µg/L Chl	180 min
	Ferrybox	Scufa II Turner Design	0.02 µg/L Chl	1 min
	RV (CTD)	WET Labs ECO-AFL/FL 9 or Chelsea Aqua 3	0.025 µg/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 optode	$\pm 5\%$	1 min
	Bio-Argos	Aanderaa optode	$\pm 5\%$	1 min
	RV (CTD)	SBE 43	$\pm 2\%$	1 sec
	<u>Glider</u>	<u>SBE 43F</u>	$\pm 2\%$	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	± 0.005 pH units	180 min
	Ferrybox	Meinsberg probe	± 0.3 pH units	1 min
<u>pCO₂</u>	<u>Ferrybox</u>	<u>ControsCO2</u>	$\pm 0.5\%$	1 min
	<u>Buoy (E1-M3A)</u>	<u>Pro-Oceanus</u>	2 ppm	180 min
<u>ADCP (backscattering)</u>	<u>Buoy (E1-M3A)</u>	<u>Teledyne RDI 75kHz</u>	$\pm 1\%$	180 min

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

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

Table 3: VariablesParameters 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.

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

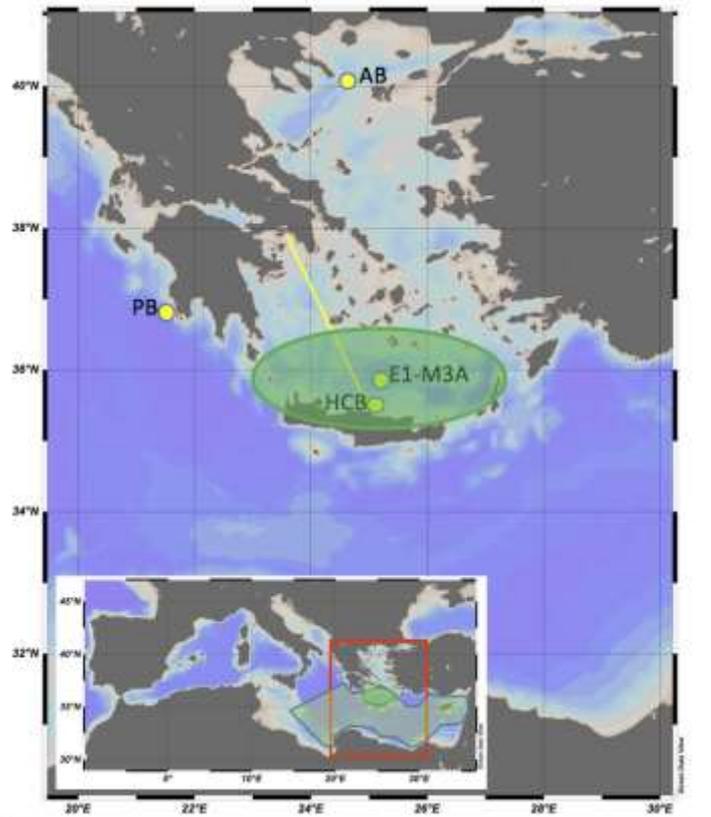
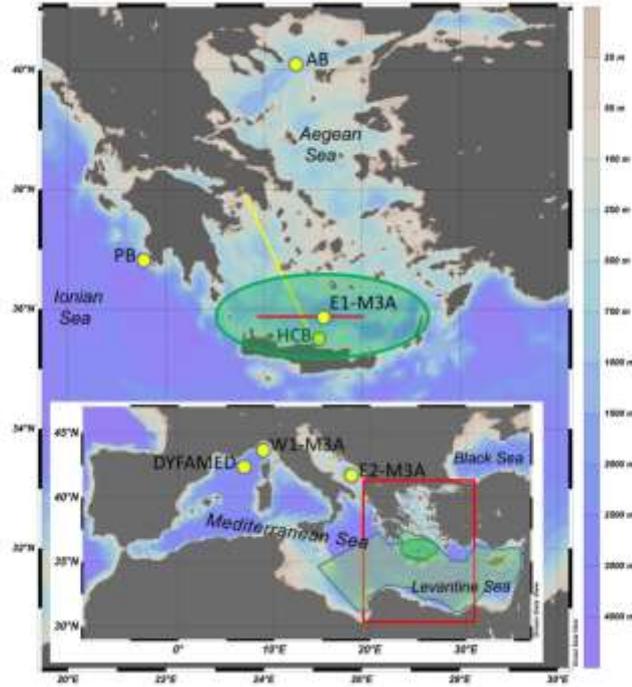


Figure 1: Map of showing the location of the Cretan Sea (green ellipse) and all POSEIDON system BGC fixed platforms (yellow dots, see Sect. 4.1), glider endurance line (red line, see Sect. 4.64.1) and Ferrybox (yellow line, see Sect. 4.4.4). Inset map shows location within the Mediterranean Sea (red 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.

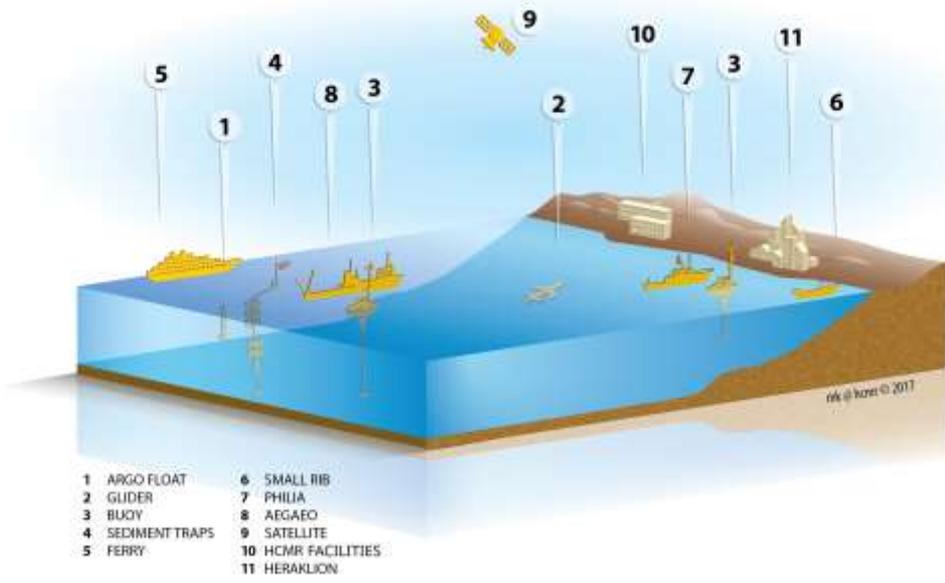


Figure 2: Platforms of the Cretan Sea biogeochemical-ecosystem observatory.

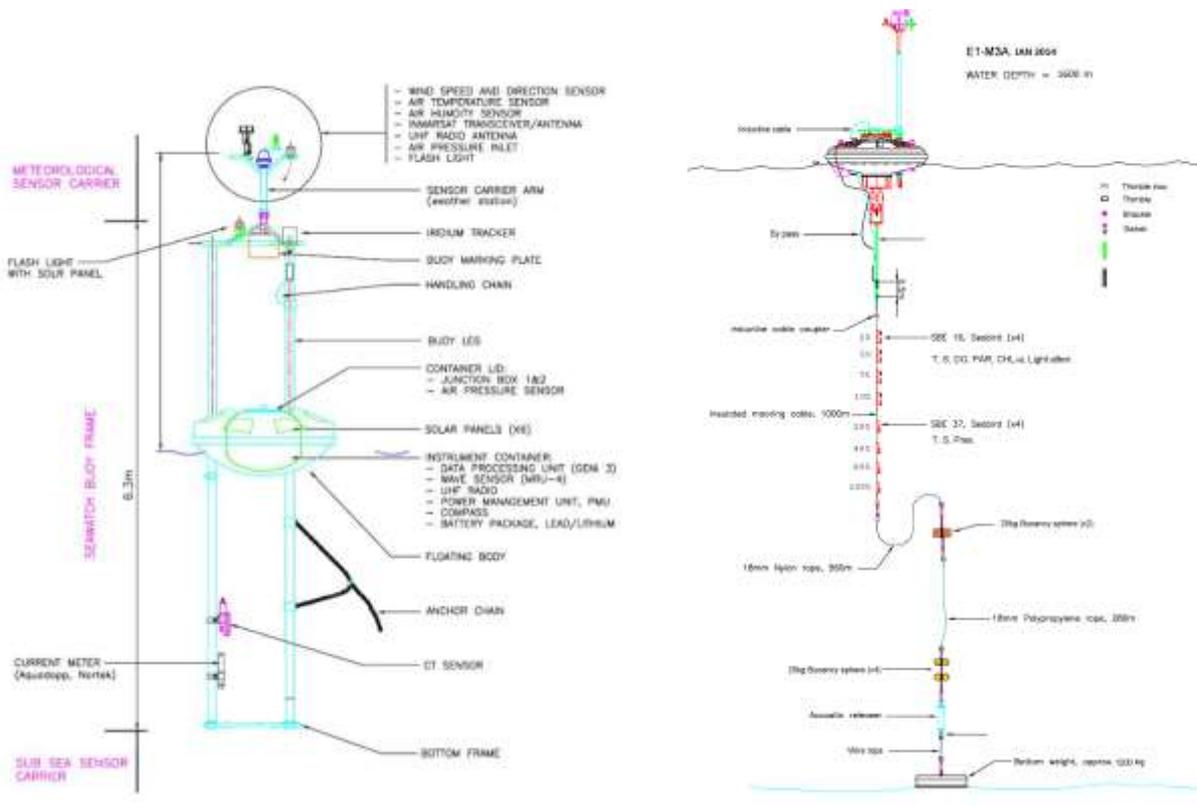


Figure 3: Coastal (left) and open sea (right) fixed platforms configuration with scheme of payload

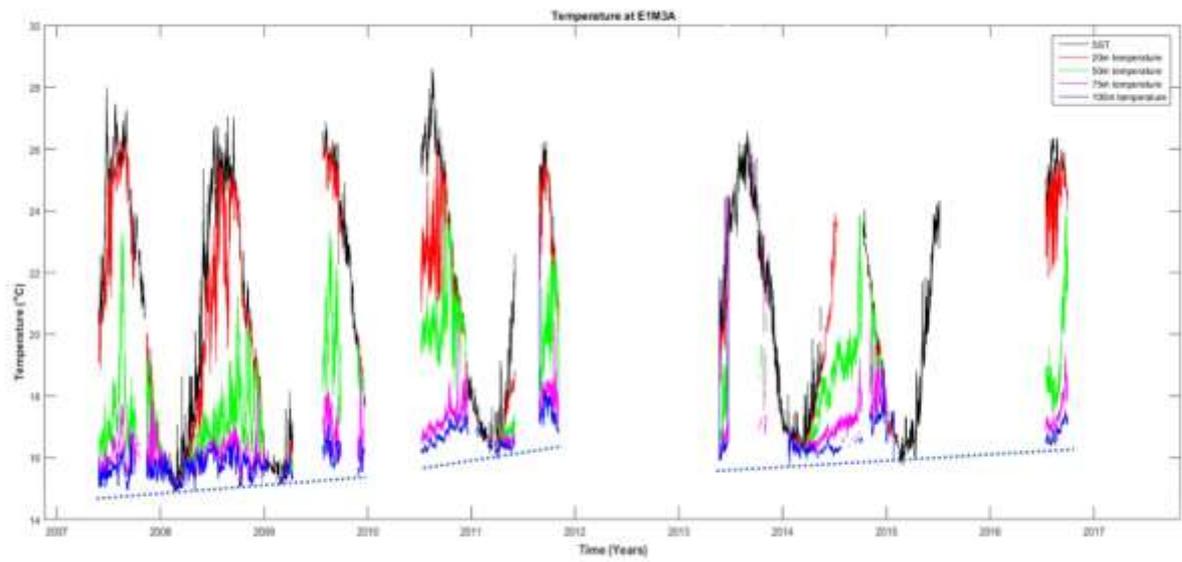
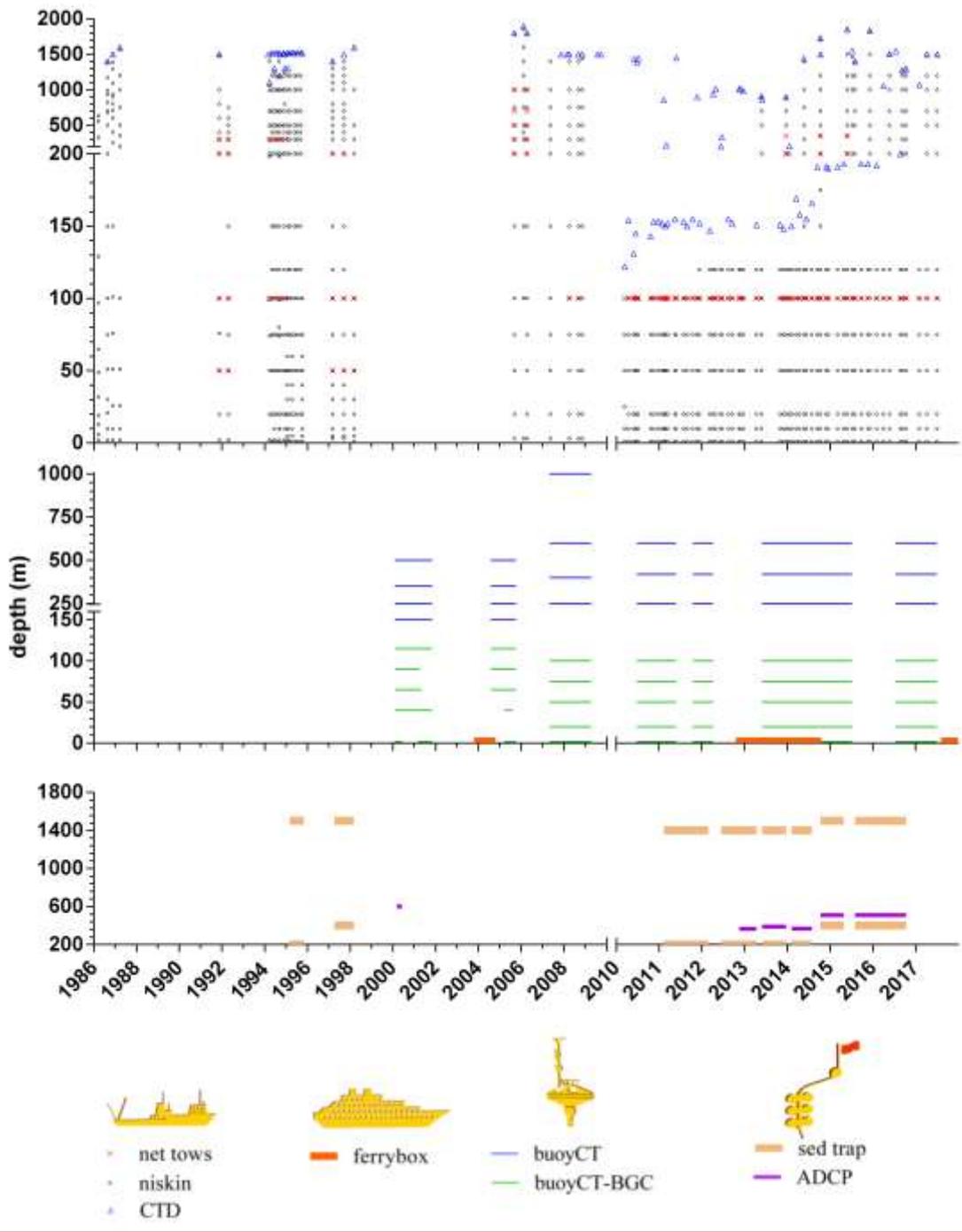


Figure 4: Temperature recordings at the E1-M3A buoy from 2007 to 2017.



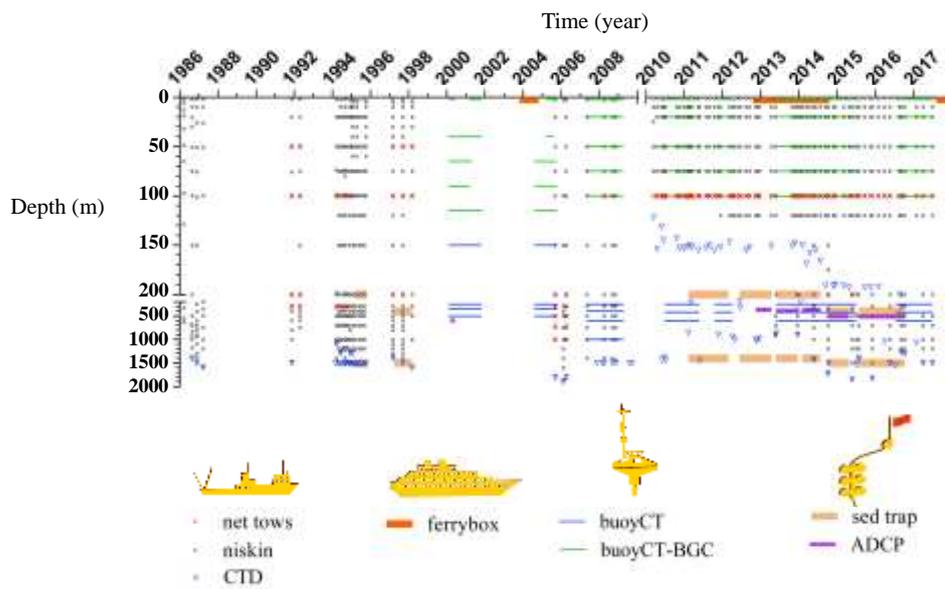
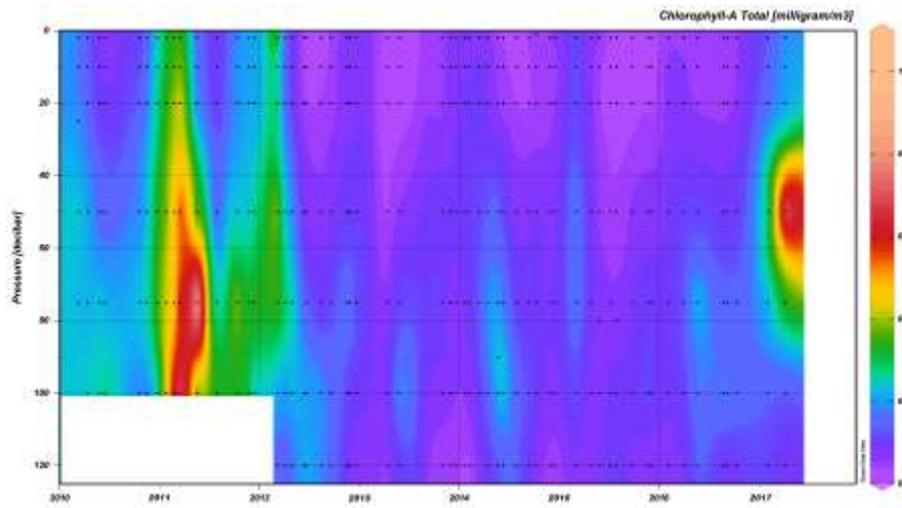
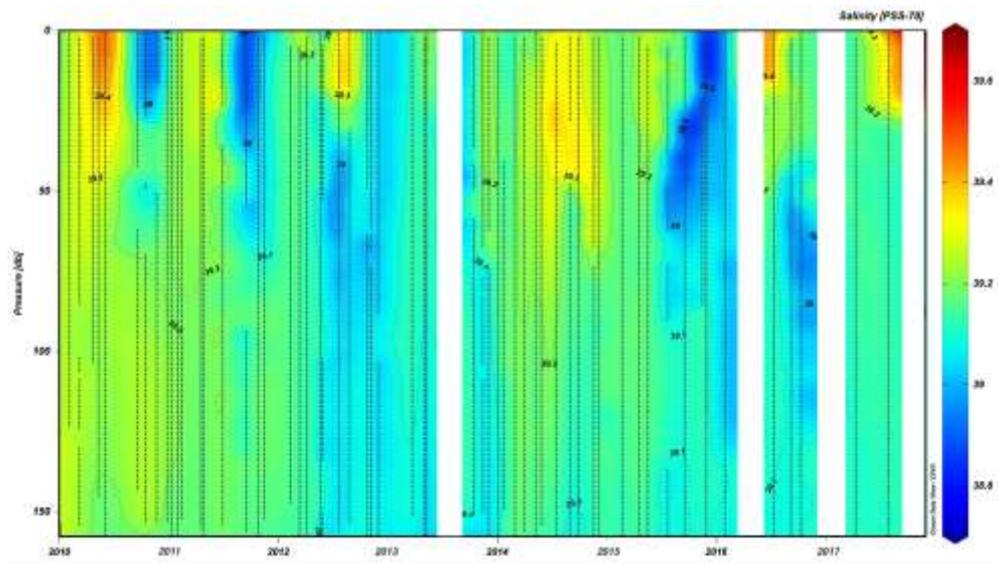
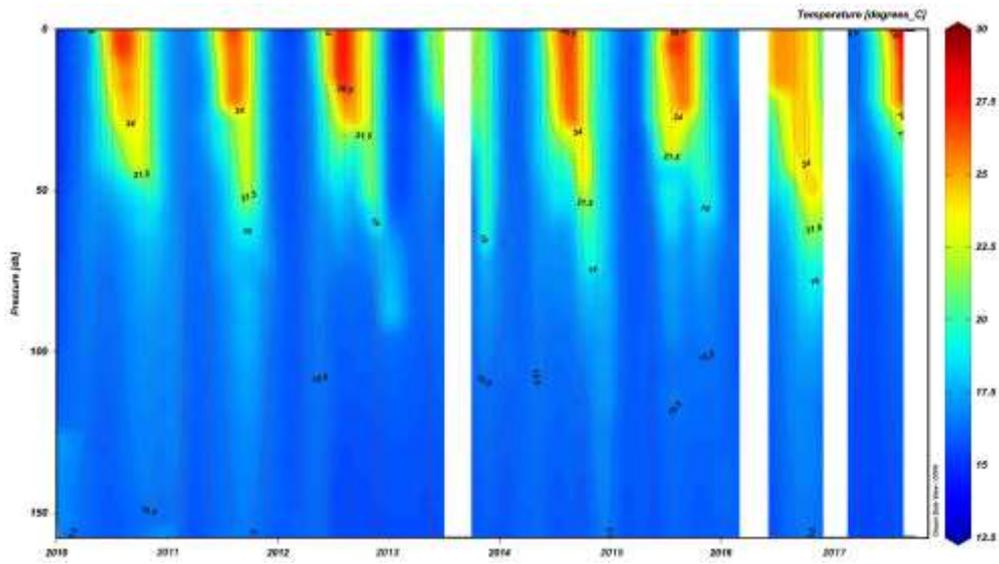


Figure S3: Periods of operation of the different platforms located in the open Cretan Sea (historical metadata within a circle of 20 nautical miles radius around the position of E1-M3A; exclusion of metadata made within 10 nautical miles from a coast). Before 2010 the metadata listed may not be exhaustive. 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.



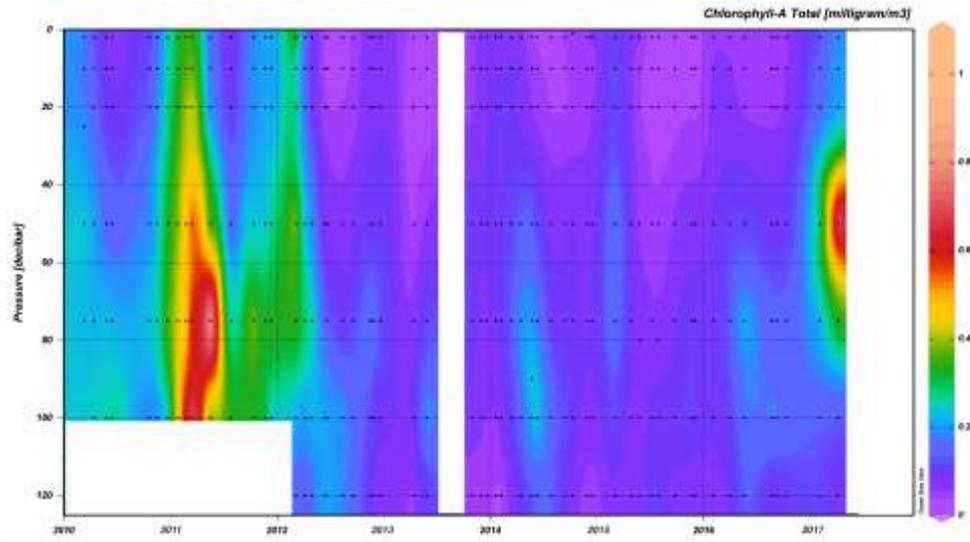


Figure 6: Vertical distribution of temperature, salinity (CTD casts) and total Chl-a at the POSEIDON E1-M3A location from 2010 to 2017 (fluorometric analysis of seawater from bottle sampling) from 2010 to 2017 at the POSEIDON E1-M3A location.->

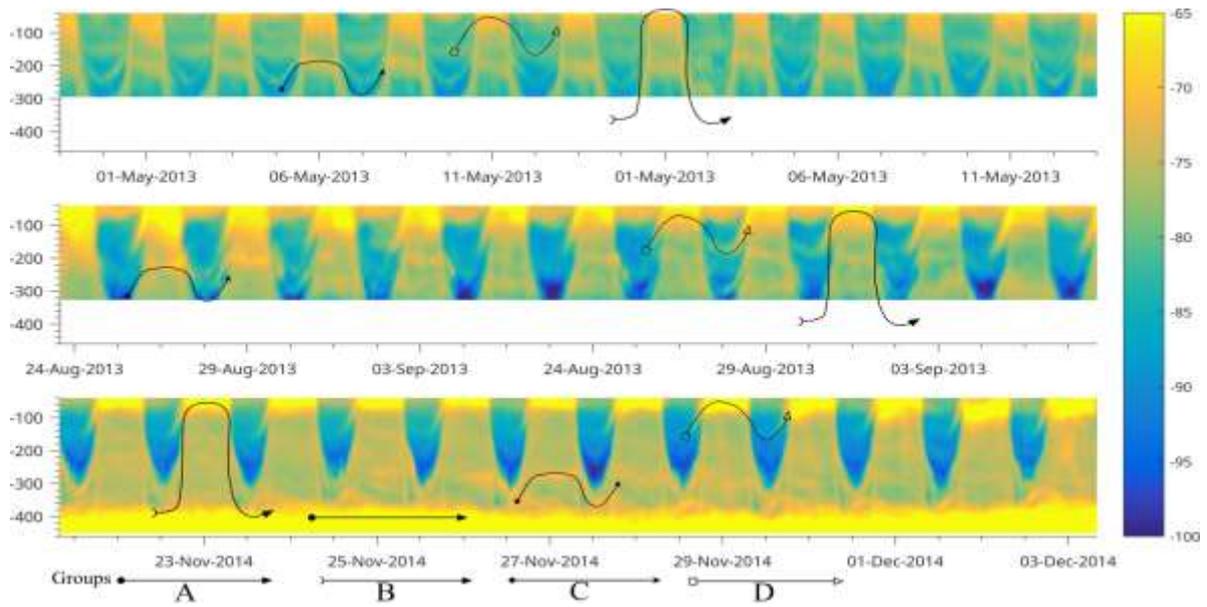


Figure 75: Backscatter coefficient Sv from the 75 kHz ADCP placed at the POSEIDON E1-M3A location. Hand-drawn trails are attributed to different groups of zooplanktonic and micro-nectonic organisms (from Potiris et al., this issue).

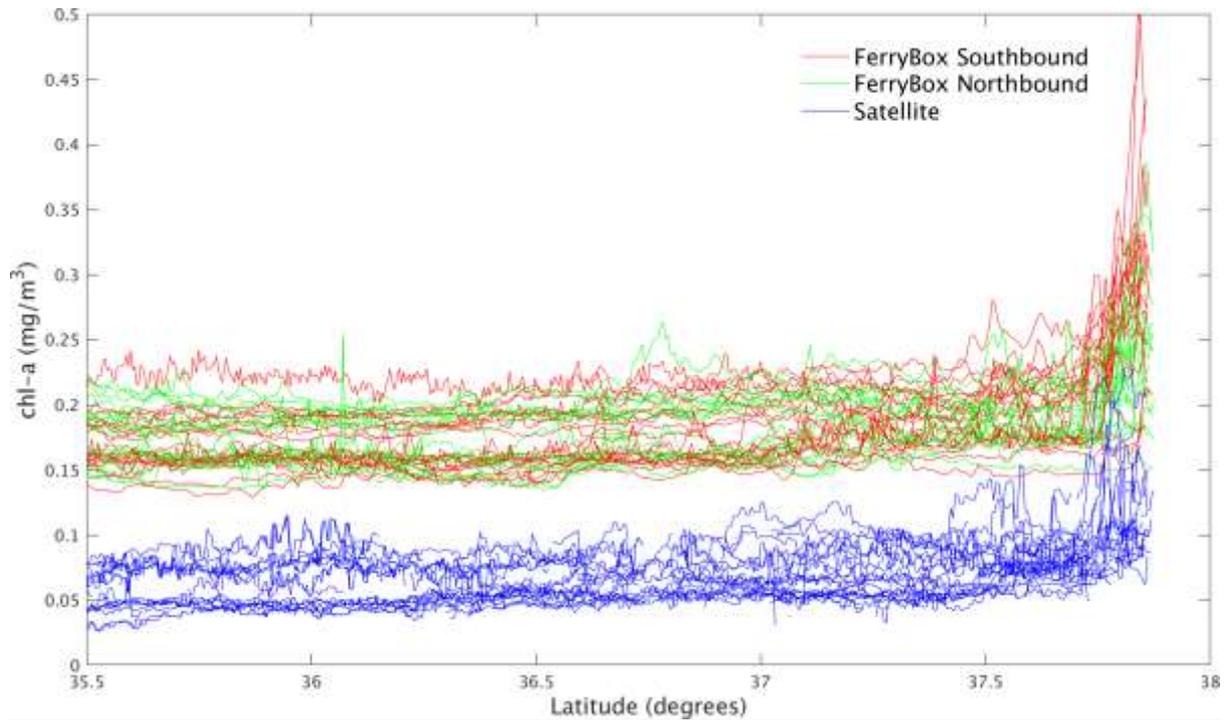
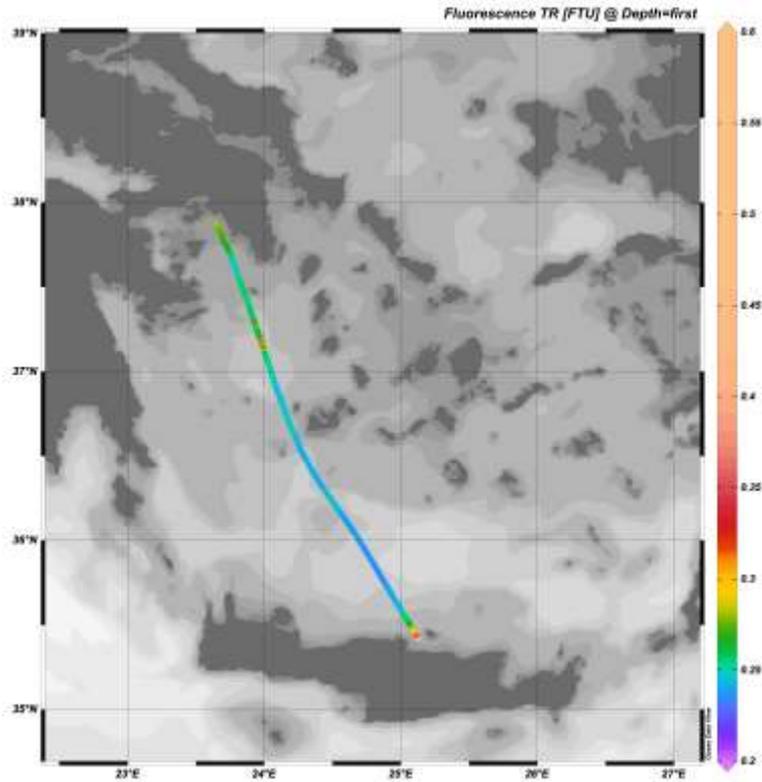


Figure 8: Comparison of POSEIDON Ferrybox’s fluorescence data with satellite ocean colour data over a selected period (October 2017 to January 2018). FB data are separated depending on the direction of the vessel (green lines: southward towards Heraklion, red lines: northward towards Piraeus). Satellite 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> ~~Figure 6: POSEIDON Ferrybox's fluorescence recordings on 01/07/2012.~~

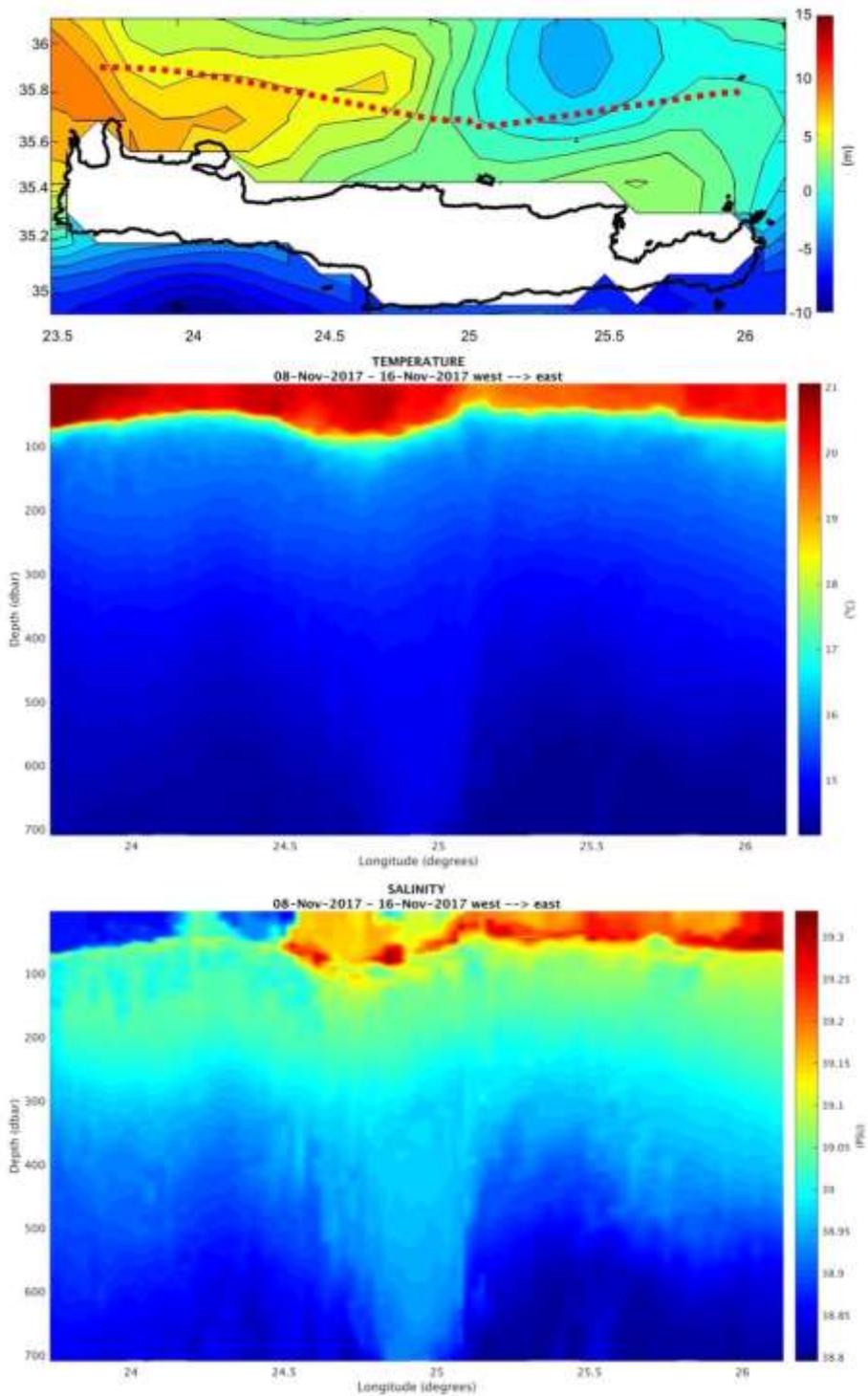


Figure 9: Sea-surface height (top panel) derived from satellite altimetry in the Cretan Sea in November 2017, in comparison to the vertical distribution of temperature (middle panel) and salinity (bottom panel) obtained by the glider along a west-east transect (red dotted line in top panel).

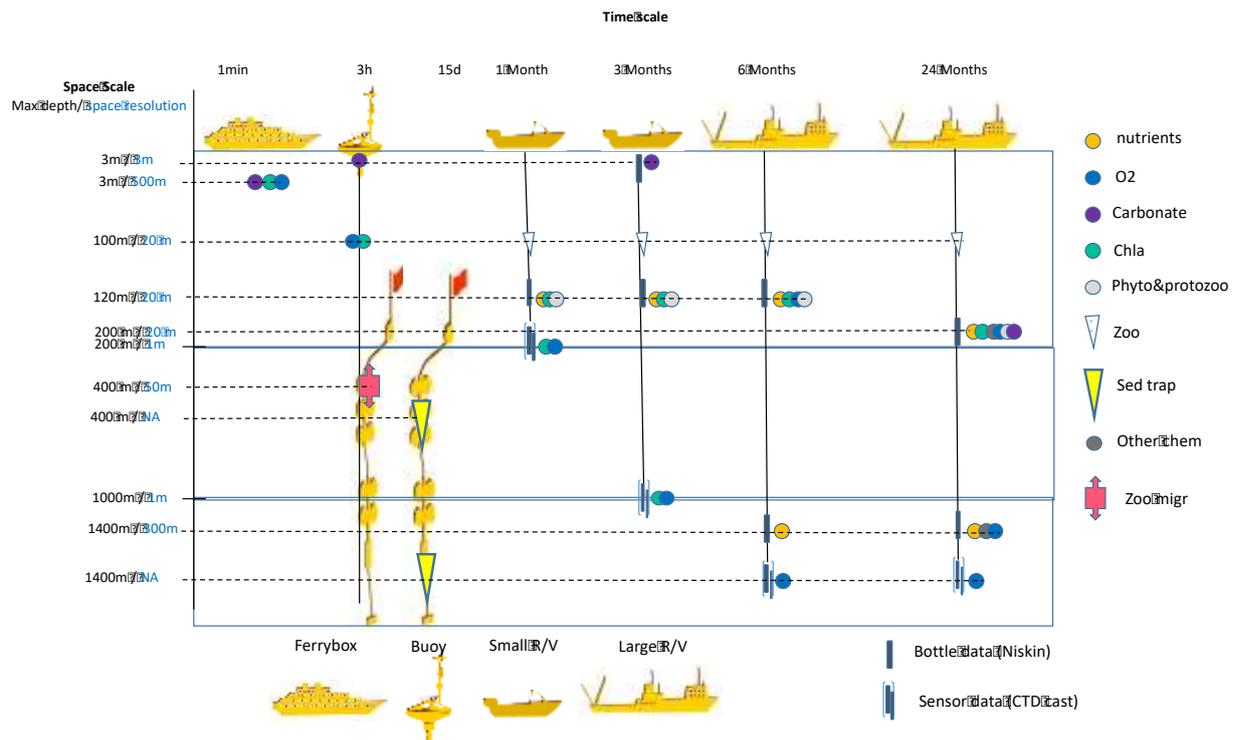


Figure 107: Time and space resolution of **biogeochemical/biochemical** data acquisition by the different platforms of the observatory. The list of **variables/parameters** can be found in tables 1 to 3. Space resolution is vertical except in the case of Ferrybox. Carbonate: pH , pCO_2 or C_T & A_T , Other chem: other chemical **variables/parameters**, Sed trap: sediment trap, Phyto & protozoo: phytoplankton and protozoans; zoo: metazoans (collected with nets), Zoo migr: ADCP backscatter data for zooplankton migration.

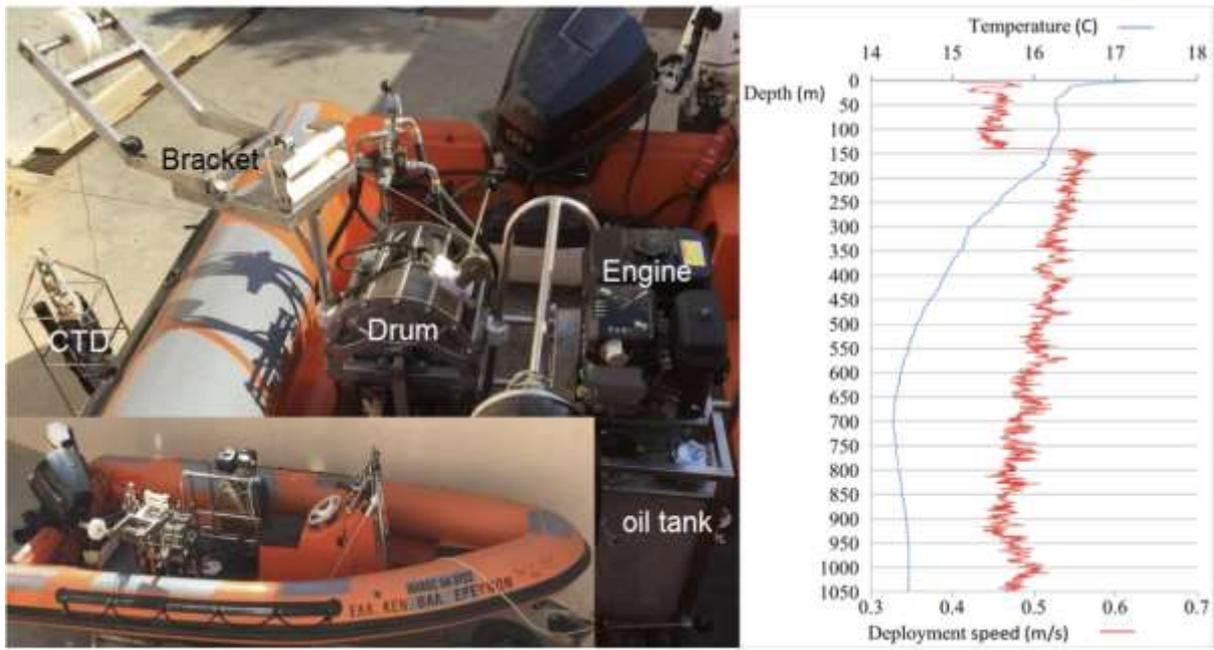


Figure 118: Left: Hydraulic winch positioned on a small RIB allowing casts >1000 m (Pettas et al., 2015); Right: Temperature and deployment speed against depth from a CTD cast made using the hydraulic winch. Deployment speed decrease above 150m was made in order for the CTD to respond better to rapid environment changes like thermocline.

