Interannual large-scale variability in the Eastern Mediterranean Sea and interactions with the Aegean Sea

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Abstract

The Mediterranean Sea and its eastern sub-basin are marginal oceanic basins subjected to strong anthropogenic and natural pressures. During the last decades new findings have revised the way of assessing the circulation and physical functioning of the eastern Mediterranean Sea. Natural oscillations have been discovered while the impact of climate change has also been observed. Interannual variability has also been evident in the Aegean Sea, which is in close connection with the eastern Mediterranean. The continuous monitoring of the marine environment and the creation of long time series of marine observations is required in order to understand the functioning of the complex Mediterranean and Aegean ecosystems. The Hellenic Centre for Marine Research supports the creation of such time series by deploying multidisciplinary instrument moorings at specific key-points of the Aegean Sea, in an effort to provide scientific results essential for both sustainable development and mitigation of environmental pressures.

Keywords: Mediterranean Sea, Aegean Sea, Cretan Sea, Climate change

1. Introduction

In every enclosed sea basin surrounded by densely populated coastal areas with strong economic activity such as the Mediterranean Sea, knowledge about the functioning of the marine ecosystem and the climatic change effects is directly linked to both societal needs and the economy. Understanding and assessing climate change is not possible without the creation of long time series of observational data. This increasing demand for long-term oceanic observations has been widely acknowledged by the international community in both political, societal and scientific level.

The Mediterranean Sea is an enclosed, marginal marine basin connected to the world ocean by the rather narrow and shallow strait of Gibraltar. Albeit the relatively small size of the basin, the Mediterranean is considered as a "miniature ocean" ideal for climatic studies and scientific research, as almost all oceanographic processes can be observed and studied in the basin.

During the past decades, the Mediterranean waters have experienced strong and rapid increase in temperature and salinity (von Schuckmann et al., 2019), depicting clearly the tendency of the basin to respond to global warming and climate change much faster than most other oceanic areas. According to the same report, the Mediterranean Sea surface temperature has showed a positive trend of 0.04 ^{o}C/year between 1993 and 2017, while sea level during the same period has been rising by 2.4 mm/year. Climate change is one of the most important threats, especially for the coastal Mediterranean regions, where the impact of the anthropogenic pressures imposed on the marine ecosystem will certainly increase in the future. Mitigation policies should be applied in time, since it has been emphasized (Guiot and Cramer, 2016) that by the end of the current century, climate change will likely alter Mediterranean marine ecosystems "*in a way that is without precedent during the past 10 millennia*".

The Eastern Mediterranean (EMed) Sea is the marginal Mediterranean sub-basin that extends east of the Sicily strait, hence simulating a "small" Mediterranean inside the wider Mediterranean Sea with the strait of Sicily playing for the EMed the role Gibraltar strait plays for the whole basin. The oceanographic functioning of the EMed is of great importance since it encloses the main "engine" that drives the upper thermohaline circulation of the whole Mediterranean Sea, as will be discussed further on. Hence, the understanding of EMed oceanographic processes and its interannual variability is of fundamental importance for the assessment of the response of the whole Mediterranean Sea to climate change.

2. The EMed Sea interannual circulation variability

2.1. The Eastern Mediterranean oceanic functioning

The Mediterranean Sea is a marine basin where evaporation exceeds fresh water input by the atmosphere and rivers. As a result, the Mediterranean Sea imports low salinity surface waters of Atlantic origin through the strait of Gibraltar. This inflow of Atlantic Water (AW) travels towards the east and enters the EMed through the Sicily strait. Thereon, low salinity AW continues to travel eastwards at surface/subsurface depths, slowly increasing its salinity through interaction with the atmosphere and gradually being transformed into a more saline water mass. Strong winter heat losses mostly over the Levantine and Cretan Seas increase the density of this water mass that finally sinks at intermediate depths (see Robinson et al., 2001, amongst others). The formed intermediate water mass (named Levantine Intermediate Water – LIW) follows a westward path opposite to that of AW flow at intermediate depths, finally exiting the EMed through the Sicily strait. This dual-flow regime continues all the way to the Gibraltar strait running throughout the whole Mediterranean Sea, constituting what is called the upper "thermohaline conveyor belt". It can thus be argued that the EMed hosts the main thermohaline engine that drives the conveyor belt of the whole Mediterranean Sea. Finally, the Adriatic Sea is considered as the main source of very high density deep water masses in the EMed; however the Aegean Sea has been reported as a sporadic producer of deep waters (see Robinson et al., 2001, amongst others). During the period 1987 – 1995 a massive production of deep waters was recorded for the first time in history and observed in the Aegean Sea. The produced very dense waters plunged into the deep EMed basins and replaced the pre-existing deep waters of Adriatic origin (Roether et al., 1996). This event known as the Eastern Mediterranean transient (EMT) was triggered by a synergy of atmospheric and internal oceanic processes (Lascaratos et al., 1999).

2.2. Quasi-decadal circulation oscillations

One of the causes held responsible for the EMT event was an internal disruption of the upper thermohaline conveyor belt following which the Levantine and Aegean basins were deprived of low salinity AW between 1987 and 1997. For this reason, salinity in the Aegean Sea was increased thus making the deep water production in that area during the EMT much easier.

Later studies have revealed that the observed upper layer circulation changes that disrupt the EMed conveyor belt are recurrent phenomena on an almost quasi-decadal time scale, driven by internal dynamics (Gačić et al., 2011; Theocharis et al., 2014). These circulation oscillations are manifested by periodic reversals in the upper Ionian Sea circulation from cyclonic to anticyclonic and vice versa, with each mode favoring salinity preconditioning in the Adriatic or Aegean Seas respectively. In particular, the anti-cyclonic Ionian Sea upper circulation deflects low-salinity AW masses towards the Adriatic Sea. This in turn leads to increasing salinity in the Aegean Sea, favoring local deep water formation. During the opposite cyclonic phase, the AW masses are directed towards the Levantine and Aegean basins, thus leading to increased Adriatic Sea salinity and to possible dense water formation in that basin (Velaoras et al., 2014).

3. Variability in the south Aegean Sea during the last decades

Figure 1 shows the Hovmöller diagram of salinity evolution inside the Cretan (south Aegean) Sea between 1986 and 2020. The figure depicts in-situ measured salinity within a depth range of 100 to 2000 dbar. Data have been collected by repetitive oceanographic cruises in the area. The salinification of the whole water column can be seen in the early 1990s related to the EMT, followed by the intrusion of less saline waters of Mediterranean origin during the relaxation phase of event. After the early 2000s two distinct phases of salinification have been observed: a) between 2008 – 2011 and b) after 2017. These phases correlate with the respective periods of anticyclonic upper circulation in the Ionian Sea during which the eastern part of the EMed receives less amounts of AW resulting in the local salinity increase. Interestingly, during these two periods the salinity in the first hundreds of meters inside the Cretan Sea was much higher ($\Delta S>0.15$) than even during the peak-EMT phase. The reason why there was not a similar EMT event may lay in the fact that the atmospheric forcing was not strong enough during that period. However, it is known that the salinification of the 2008 – 2011 period led to the formation and export of intermediate water masses from the Aegean Sea (Velaoras et al., 2014). Future observations will reveal if the period which begun after 2017 will lead to the production of dense waters.

4. Conclusions, Current work & Future initiatives

The above findings clearly highlight the close interconnection between the EMed and the Aegean Sea. The hydrological properties of the Aegean basin seem to be directly linked to the EMed circulation oscillations. However, as seen in Fig.1, there is strong evidence of a positive salinity trend in the first hundreds of meters after the middle 2000's which should be further studied in order to trace possible links to climatic change.

The study of interannual variability in the Aegean Sea may be pursued by repetitive sampling, however the best way to study the response of the Aegean Sea to climate change and to detect any variability in hydrological properties and/or flows between the Aegean Sea and the EMed, is no other than the creation of long time series of data at specific "choke points". These are the straits connecting the Cretan Sea to the open EMed basin, since any water mass exchange between the two basins takes place through these straits. The Hellenic Centre for Marine Research (HCMR) has been supporting during the past years the deployment of instrument moorings at the Cretan Straits. Recently (February 2021), within the CLIMPACT network actions, HCMR has deployed two moorings with hydrological sensors, current meters and sediments traps in the west Cretan (Antikythira) strait and the Cretan Sea, aiming precisely at monitoring the interannual variability of the hydrological properties of the exchanged water masses along with the quantification of biochemical fluxes. The latter is pursued by the creation of time series of particulate matter flux that characterize the carbon cycle response which is found at the epicenter of the global biogeochemical cycles and climate change studies. The continuous monitoring of the marine environment will enable a better understanding of the functioning of this highly complex Mediterranean ecosystem, by providing scientific knowledge essential for both sustainable development and mitigation of environmental pressures.

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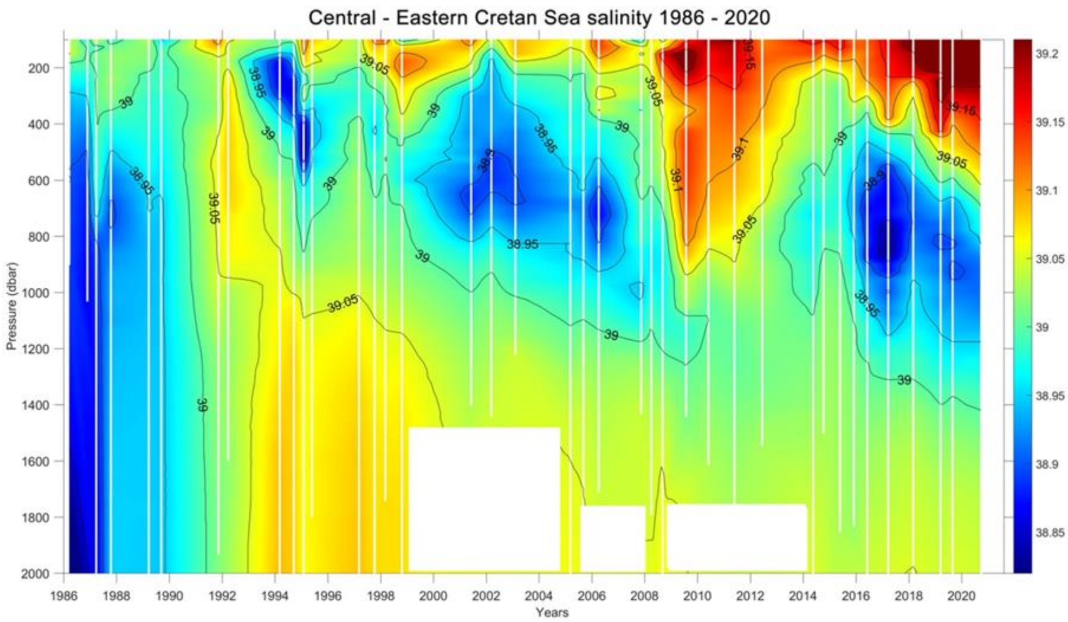

Figure 1. Hovmöller diagram of salinity evolution inside the Cretan (south Aegean) Sea between 1986 and 2020. It shows in-situ salinity values within a depth range of 100 to 2000 dbar. White lines denote sampling profiles.

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