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Physical oceanographic features of the Cilician Basin and wastewater dumping at the coastal zone of Kyrenia

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ABSTRACT

To investigate the physical oceanographic features, their temporal and spatial variabilities, the interactions between coastal and open water masses, and the seawater quality, ocean sub-mesoscale study with a relatively high frequency conducted in the Cilician Basin and particularly in the neritic zone of the Kyrenia region. The study carried out between November 2015 and June 2018 on a five nautical mile zonal section offshore of Kyrenia. The results revealed that the general circulation of the Cilician Basin is a highly complex and dynamic system with meandering and reversing currents and reappearing cyclonic/anti-cyclonic energetic mesoscale eddies with temporal variabilities. The dominating driving mechanism of the general circulation appears to be the temporarily and spatially change between the currents (Cilician Current and Asia Minor Current) and the cyclonic and anti-cyclonic eddies with temporal variabilities observed offshore of Kyrenia. Throughout the study, the upper 25 m of the water column observed to be well mixed and uniform. However, the seasonal stratification, thermocline, and halocline formation ranged between 25 and 80 m in all seasons except winters where the water column observed to be well mixed and uniform from the sea surface to the depth of *circa* 200 m, especially between January and March. The physical features and physical oceanographic characteristics should be taken into consideration for the determination of their effects on the marine ecosystems, furthermore for the planning and implementation of wastewater treatment and coastal management.

Keywords: Kıbrıs time series; Physical oceanographic properties; Neritic systems; Wastewater dumping; Cilician Basin

1. Introduction

Marine strategy framework directive, 2008/56/EC of the European Union (EU) in 2008, constituted for effective protection of the marine environment of European waters. The main goal of this directive is to achieve good environmental status (GES) of EU marine waters by 2020 [1,2]. Furthermore, the Mediterranean Action Plan of the United Nations Environmental Programme (UNEP/MAP) was constituted in the Barcelona Convention, 1976. The convention was then expanded, amended and renamed as the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean, in 1995 [3]. In addition to the Barcelona Convention, The Integrated Monitoring and Assessment Programme (IMAP) was adopted by the EU and 21 Mediterranean Countries, including Cyprus [4]. The main goal of these conventions and programs is to achieve GES of the Mediterranean region and the EU marine waters. To achieve this goal, the physical oceanographic characteristics of the region shall be carefully evaluated and determined.

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The Cilician Basin is the north-eastern part of the Levantine Basin, located between the Antalya Basin on the west and Iskenderun Bay on the east. Comprehensive and systematic sub-basin and mesoscale studies of the Physical Oceanography of the Eastern Mediterranean Group (The POEM Group), which were conducted between 1985 and 1995 revealed that the general circulation of the Cilician Basin is a highly complex and dynamic system, which forms meandering and reversing currents, reappearing cyclonic/anti-cyclonic mesoscale eddies with temporal and spatial variabilities. The dominant driving mechanism of the general circulation temporarily and spatially changes between the current systems (i.e. Cilician Current and Asia Minor Current) and the eddies. Characteristic water masses of the Cilician Basin are; warm and saline Levantine surface water (LSW) within the mixed layer above seasonal stratification layer, relatively fresh modified Atlantic water (MAW) below seasonal stratification layer, deep salinity maximum Levantine intermediate water (LIW) at intermediate depths, and dense and cold East Mediterranean deep water (EMDW) at depths of 500 m and more [5–7].

The study of Pazi and Kucuksezgin [8], which was consist of three independent hydrographic cruises respectively in May 1997, July 1998 and October 2003 revealed similar results and was consistent with the POEM studies in the region [8].

Between June 2015 and May 2018, a multi-institutional and multidisciplinary oceanographic project, namely "Determination of influence of anthropogenic and natural processes on the Cilician Basin (between Turkish Republic of Northern Cyprus and Turkey) Marine Ecosystem", was conducted within the framework of the Scientific and Technological Research Council of Turkey (TUBITAK) through the 114Y139 coded project [2]. This project was the most systematic and comprehensive study conducted in the region since the POEM studies. The primary aim of this project was to investigate physical and biogeochemical properties, their temporal and spatial variabilities, interactions between coastal and open waters, and the seawater quality in the Cilician Basin, and particularly in the neritic zone of the Kyrenia region. The first regional oceanographic time-series studies, namely the "Kıbrıs time series" (KTS), which is the subject to this study, established within the framework of the project mentioned above. The physical oceanographic results of the project were consistent with the POEM studies and with the previous studies which were conducted in the region. The seawater quality in the region, and particularly in the Kyrenia region (KTS transect) investigated under the scope of the same project and concluded to be in good status according to IMAP standards [2].

Kyrenia is a coastal town located on the northern coast of Cyprus. According to the report of the Prime Ministry Office of the Turkish Republic of Northern Cyprus (T.R.N.C.) in 2015, over 60% of the touristic resorts of the T.R.N.C. are located in Kyrenia district [9]. Wastewater management and wastewater dumping protocols are defined and determined by the Environmental Act 18/2012, 30/2014 and Article 19 of 09/1990 of the T.R.N.C parliament. According to these regulations and codes in force, the wastewater shall be discharged at a depth of minimum 20 m if possible, or if it is not possible, the length of the wastewater discharge pipeline shall not be less than 1,300 m in areas with daily flow rate of 200–2,000 m^3, and shall not be less than 500 m in areas with daily flow rate of <200 m^3.

This study aims to investigate the physical oceanographic characteristics of the Kyrenia region by conducting a sub-mesoscale and relatively high-frequency study to determine physical oceanographic features and properties, their temporal and spatial variabilities and interactions between coastal and open waters. It is also aimed to suggest proper and effective applications regarding where to dump the wastewater effluents to keep GES of coastal zones of Kyrenia according to physical oceanographic characteristics.

2. Material and method

To investigate the physical and biogeochemical properties and features of the region, a total of 11 seasonal cruises were conducted at a total of 26 stations, denoted by "T" and "A" in Fig. 1, by the research vessels of the University of Kyrenia (UoK) and Middle East Technical University - Institute of Marine Sciences (METU - IMS), between June 2015 and May 2018. Besides, the first oceanographic time-series studies of the T.R.N.C., the "Kıbrıs time series" studies, had been established offshore of Kyrenia, in November 2015. High frequency and sub-mesoscale KTS studies were conducted to investigate physical properties and variabilities, and to investigate spatial and temporal interactions between coastal and open sea waters in the study area. In this scope, 27 monthly cruises were conducted during the study by R/V Teal Jr. of University of Kyrenia at 7 stations denoted by "K" at Fig. 1 and Table 1, on a 5 nautical mile (nm) zonal section, located 2.5 nautical miles west of Kyrenia Port, offshore of Yilan Adasi, Kyrenia (Fig. 1). This study is focused on the physical oceanographic properties and features of the KTS studies. Due to its purpose, along with the physical oceanographic data of the KTS stations ("K" stations), the physical oceanographic data of the seasonal stations of the project ("T" and "A" stations) adopted and presented in this study, whenever necessary.

Due to narrow and fast deepening continental shelf of the region, the coastal stations K01, K02, K03, and K04 distributed very close to each other, within a 0.5 NM from coastline to cover the shallow zone, while stations K05, K06, and K07 located at 1.5, 3.5, and 5 NM, respectively from the coastline. In every cruise and at every station of KTS studies, the conductivity, temperature, depth (CTD), Seabird 19plus V2 SeaCAT model profiler was used to measure and obtain the vertical profile of the water column from the sea surface to the sea bottom. The sampling speed of the CTD was four samples per second, and the downcast and upcast speed of the ship's winch system was between 0.6 and 1.0 m per second (m/s). Both downcast and upcast data were measured and stored into the CTD memory. At the end of each cruise, all downcast and upcast data stored in CTD memory had been uploaded to a computer with the aid of Seaterm V2 (Version 2.6.3.104) software and processed by the aid of SBE data processing software (Version 7.26.7). Seven different processing steps had been used to obtain the best average data from the raw data. Salinity and density values had been calculated from CTD measurements during data processing, by using the Practical Salinity Scale 1978 (PSS78) [10] and Equation of State 1980 (EOS-80) formula [11], respectively.

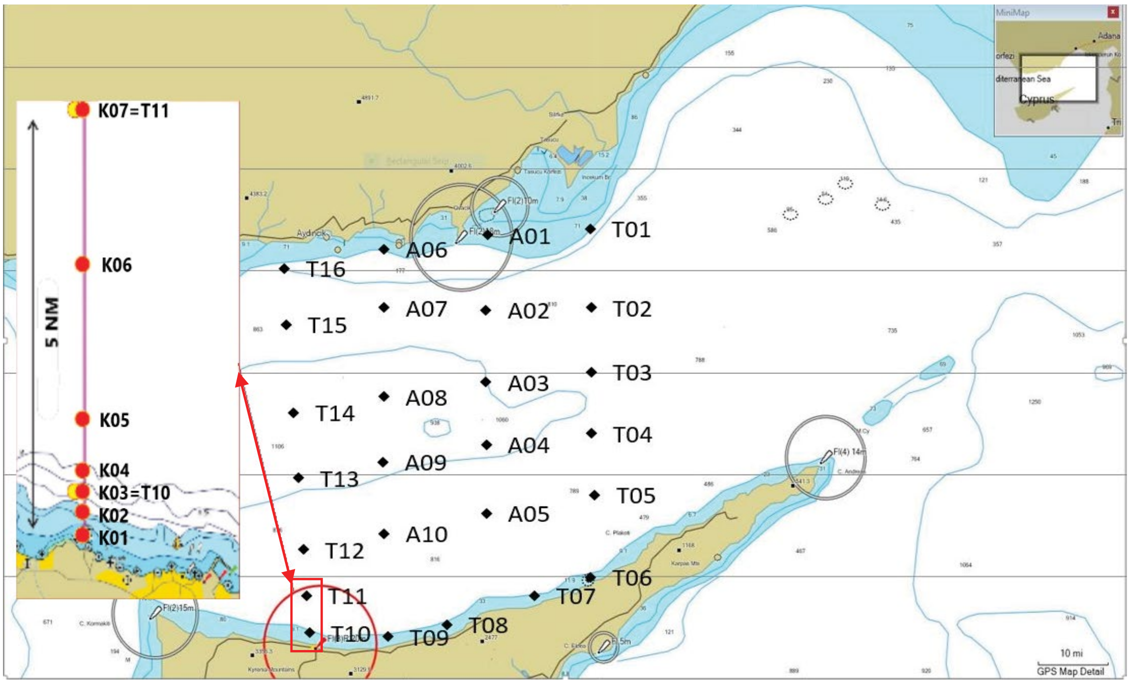

Fig. 1. Sampling station map of 114Y139 code numbered TUBITAK project and map of KTS zonal section.

Table 1
KTS station details

Station name	Total depth	Latitude/Longitude
K01	25 m	35 21.171 N/033 17.732 E
K02	50 m	35 21.339 N/033 17.710 E
K03	100 m	35 21.572 N/033 17.703 E
K04	150 m	35 21.679 N/033 17.726 E
K05	425 m	35 22.525 N/033 17.671 E
K06	610 m	35 24.491 N/033 17.439 E
K07	670 m	35 26.218 N/033 17.283 E

Ocean data viewer software (Version 5.1.0) used to create appropriate graphics and plots of each parameter.

3. Results and discussion

Time series plots of temperature (°C), salinity (per mille) and potential density anomaly (kg/m^3) of stations K01, K03, and K07 between November 2015 and June 2018 are presented in Figs. 2–4 to describe and discuss seasonal and annual mixing processes, seasonal and permanent stratification layers and presence of identical water masses of Cilician Basin (i.e. LSW, MAW, LIW, and EMDW) in the KTS study region. Results of stations K01 and K03 are presented to discuss the neritic zone of the study area, and station K07 is presented as it is expected to reveal all physical oceanographic characteristics of the Cilician Basin itself.

With bottom depths of about 25 m and distance of about 300 m from the coastline, station K01 is the shallowest and nearest KTS station to the coastline, and it is expected to be the most affected station from anthropogenic processes in the study area. Station K03 is one of four coastal stations distributed within 0.5 NM in KTS studies to cover the neritic zone. With bottom depths of about 100 m, it is expected to reveal surface and subsurface physical oceanographic characteristics of the Cilician Basin. Along with stations K01 and K02, station K03 considered being most affected by anthropogenic processes in the study area. With bottom depths of about 670 m and distance of 5 NM from the coastline, station K07 is the deepest and offshore station of the KTS studies, and it is considered being the least affected station by man impact, thus shall be considered as a reference.

As shown in Figs. 2–4, upper 25–30 m of the water column in the KTS transect was well mixed and uniformed almost all along with the study. During winter seasons, especially between January and March, upper 150–200 m of the water column in the KTS transect was relatively dense (28.65–28.85 kg/m^3), well mixed and uniform. With increasing temperatures over the course of spring and summer seasons, surface waters warmed up, salinities increased and especially between May and November, seasonal stratification of the water column observed at depths of between 25 and 80 m. With a temperature of >27.50°C and salinity of >39.60 per mille, strong seasonal stratification observed in summer seasons throughout the study. Warm (>23.00°C) and saline (>39.60 per mille) LSW located above halocline during stratified seasons, especially between May and November. Relatively fresh MAW (<39.10 per mille) located just below halocline and trapped by two saltier water masses from above and below during stratified seasons, especially between May and November. Deep salinity maximum LIW (39.10–39.40 per mille) located at intermediate depths, between MAW and depths of about 200 m during stratified seasons throughout the study. Permanent stratification layer located at depths of about 300–400 m throughout the

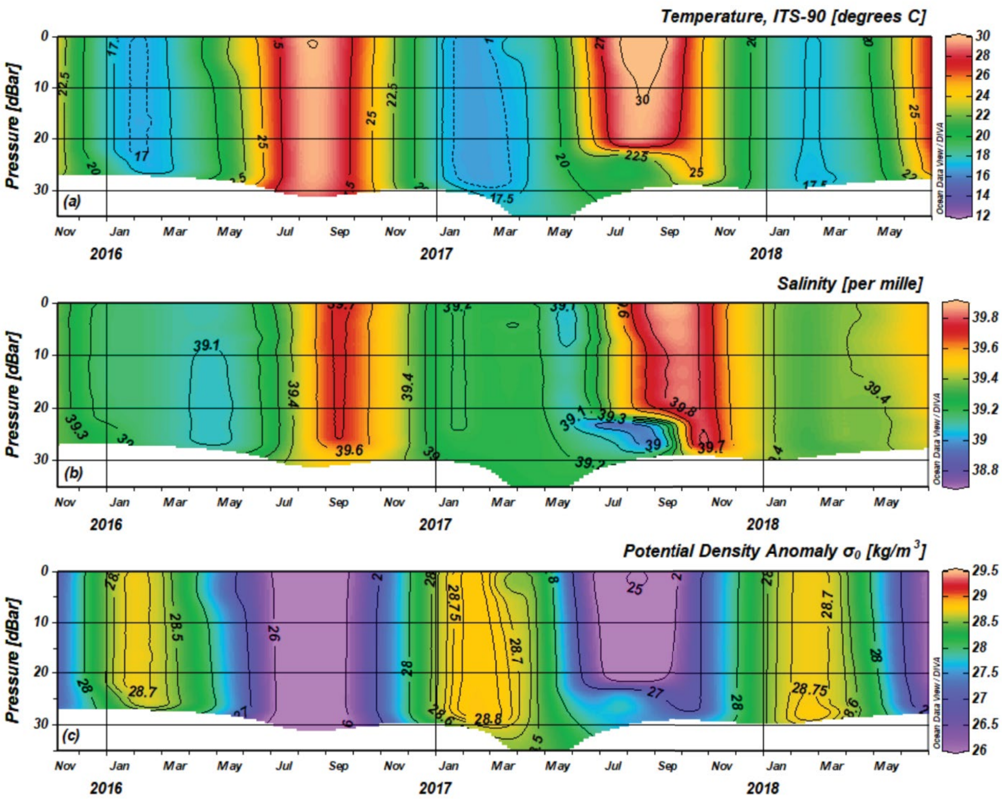

Fig. 2. Time series plots of station K01. (a) Temperature vs. depth, (b) salinity vs. depth, and (c) potential density vs. depth.

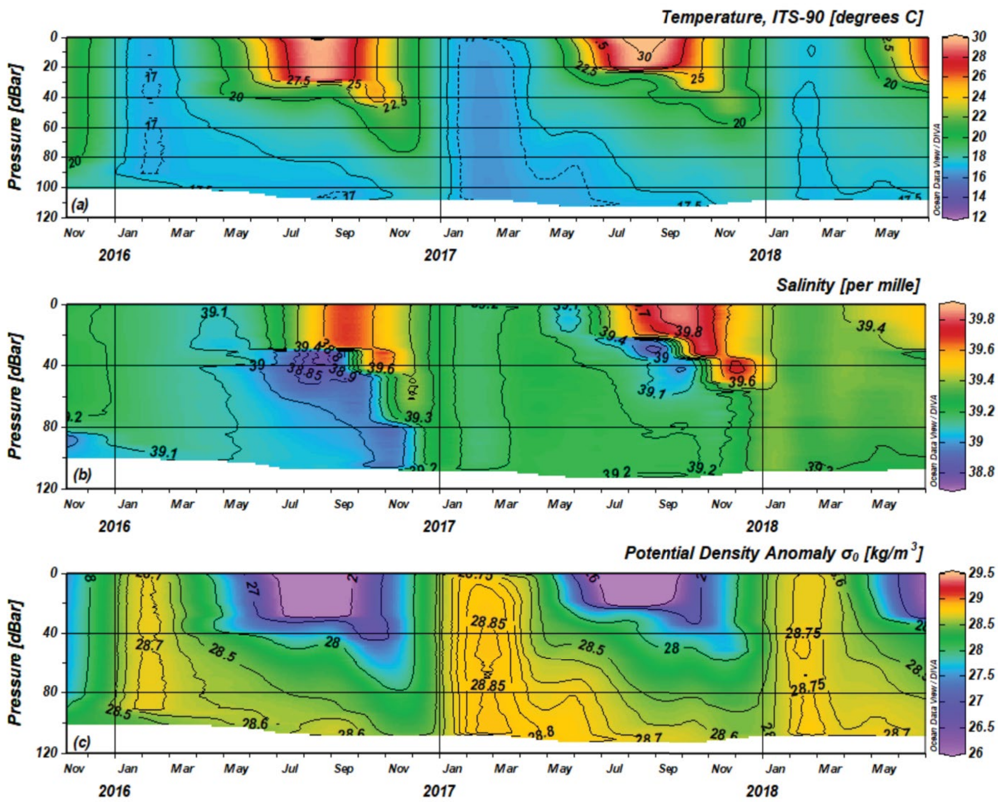

Fig. 3. Time series plots of station K03. (a) Temperature vs. depth, (b) salinity vs. depth, and (c) potential density vs. depth.

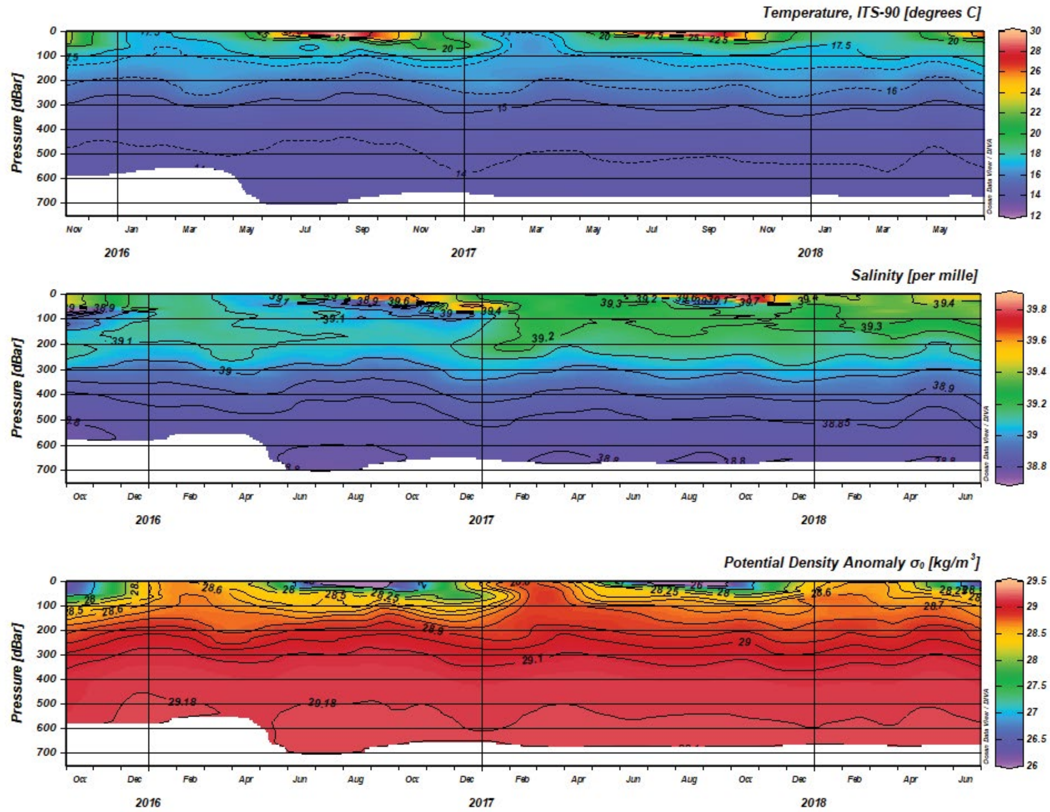

Fig. 4. Time series plots of station K07. (a) Temperature vs. depth, (b) salinity vs. depth, and (c) potential density vs. depth.

study. Below the permanent thermocline, uniform and relatively dense, cold and less saline EMDW with <14.00°C temperature, <38.85 per mille salinity and >29.18 kg/m^3 potential density anomaly located at depths of 500 m and more throughout the study.

The bottom depth of station K01 is shallower than the upper limit of the seasonal stratification layer. Therefore, the water column of the station K01 was well mixed and uniform from the sea surface to the bottom of the sea almost throughout the study, as shown in Fig. 2. Station K03 located at 0.5 nm from the nearest coastline in the neritic zone. Fig. 3 is representing station K03, and as it is shown in Fig. 3, the water column was well mixed and uniform from the sea surface to the bottom of the sea in winter seasons, especially between January and March. From spring on, surface waters warmed up, and seasonal stratification of the water column was formed every year in May and was present in the area until December, at depths of between 25 and 80 m. Every year between July and September, the water column of station K03 was dominated by strong summer stratification at depths of about 25–30 m.

Results of station K07 (Fig. 4) revealed that all the physical oceanographic characteristics identical to the Cilician Basin were present in the area throughout the study. Upper 150–200 m of the water column was well mixed and uniform in winter seasons, especially between January and March. From spring on, surface waters warmed up, and seasonal stratification of the water column was formed every year in May and was present in the area until December, at depths of between 25 and 80 m. Every year between July and September, the water column of station K03 was dominated by strong summer stratification at depths of about 25–30 m. Permanent stratification depth located at about 300–400 m throughout the year. As shown in Fig. 4b, multi-layered vertical structure of the water column (i.e. LSW, MAW, LIW, and EMDW) observed at station K07 throughout the study.

Seasonal and annual mixing processes, stratification processes and water masses identical to the Cilician Basin (i.e. LSW, MAW, LIW, and EMDW) observed in the KTS transect throughout the study and were consistent with previous studies conducted in the region [2,5–8].

Another critical physical oceanographic feature that affects the study area is general circulation. Seasonal dynamic height plots, which were calculated for 20 m with reference to 300 m are presented in Fig. 5 to describe and discuss the general circulation of the Cilician Basin. These data sets of the dynamic height plots presented in this study were collected under the framework of 114Y139 code numbered TUBITAK project ("T" and "A" stations) and includes data sets of the KTS studies ("K" stations).

In November 2015 (Fig. 5a), the study area dominated by a cyclonic eddy located at the central basin, which causes upwelling in the water column in the study area. In February 2016 (Fig. 5b), the study area was under the influence of westbound current systems. In April 2016 (Fig. 5c), the flow was affected by an anticyclonic eddy at the northern part and two cyclonic eddies at the central part of the basin. In October 2016 (Fig. 5d), the study area was

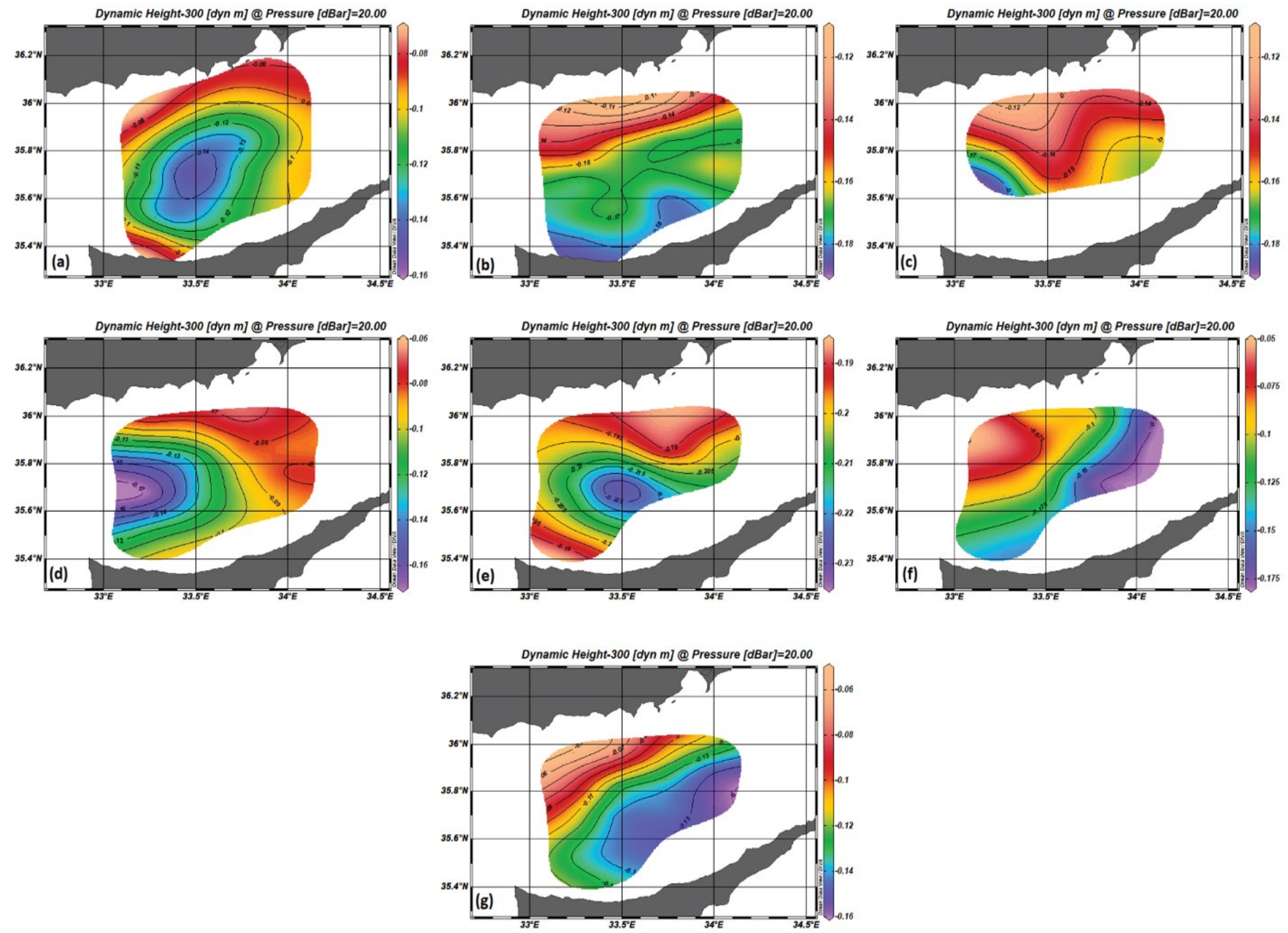

Fig. 5. Seasonal dynamic height plots of the Cilician Basin. (a) November 2015, (b) February 2016, (c) April 2016, (d) October 2016, (e) February 2017, (f) July 2017, and (g) November 2017.

under the influence of a sizeable anticyclonic circulation at the eastern part and a cyclonic eddy at the western part of the basin. In February 2017 (Fig. 5e), the northern part of the basin was dominated by westbound current systems and the central part of the basin was under the influence of a cyclonic eddy which causes upwelling in the water column. In July 2017 (Fig. 5f) and November 2017 (Fig. 5g), the study area was dominated by a sizeable anticyclonic eddy at the western part and a large cyclonic eddy at the eastern part of the basin which resulting southwestern flow in the basin. The cyclonic eddy creates upwelling in the eastern part of the study area.

As shown in Figs. 5a–g, the general circulation of the Cilician Basin is temporally and spatially change between the current systems and the eddies. General circulation is westward; however, eddies affect the general circulation of the Cilician Basin, reverse the direction of flow and trap the water masses in their cores as long as they are present in the area. These trapped water masses eventually wash up coastal zones of the region by disappearing of eddies. Cyclonic and anticyclonic eddies generate upwelling and downwelling respectively and cause vertical transport of the water masses in the study area.

4. Conclusion

A better understanding of the regional oceanographic characteristics of the northern coast of Cyprus is probably the most important outcome of this study. The general circulation of the Cilician Basin is a highly complex and dynamic system with meandering and reversing currents and reappearing cyclonic/anti-cyclonic energetic mesoscale eddies with temporal and spatial variabilities. The dominant driving mechanism of the general circulation temporarily and spatially changes between the current systems (i.e. Cilician Current and Asia Minor Current) and the eddies. In general, current systems in Cilician Basin flows westward; however, eddies affect the general circulation of the Cilician Basin, reverse the direction of circulation and trap the water masses in their cores as long as they are present in the area. These trapped water masses eventually wash up coastal zones of the region by disappearing of eddies.

Analyzed results of this study revealed that upper 25–30 m of the water column is well mixed and uniform throughout the year. Mix layer depth is about 150–200 m in winter seasons. Seasonal stratification dominates the area from spring to the beginning of winter seasons. Seasonal stratification depth, thus the mixed layer depth varies between 25 and 80 m during stratified seasons. The permanent stratification layer was located at depths of about 300–400 m throughout the year.

These results posses' important implications on wastewater management and coastal management plans. Discharging wastewater within the mixed layer causes dumped wastewater to be stuck at the surface layer, and eventually wash up the coastal zones, which threatens the environment and human health. Current rules and regulations regarding wastewater discharge in T.R.N.C. allow dumping wastewater to the depth of 20 m, which is within the mixed layer depth. The results of this study suggest that it is safer and proper to dump wastewater below the stratified surface layer. Therefore, current rules and regulations in force are not practical and proper applications for the region and shall be updated according to the physical oceanographic characteristics of the region.

Physical oceanographic features and properties are the driving mechanisms of chemical and biological processes, which are good indicators of the health of the oceans, determines the anthropogenic and natural effects on marine ecosystems and are important for coastal zone planning and management. Therefore, these processes and their interactions have to be well known.

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