3-DIMENSIONAL NUMERICAL CIRCULATION MODELING: A CASE STUDY ON THE COASTAL PROCESSES IN GOCEK AND FETHIYE BAYS, TURKEY

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ABSTRACT

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Göcek – Fethiye Bay is a unique marine area in Turkey; however, increasing human activities and related pollution affect decrease in the water quality. The water quality can be reserved if there is sufficient amount of water exchange between bays and the offshore region. The coastal morphology and wind driven currents and tidal motion are other important factors facilitate circulation and improve the quality marine environment. Therefore, all factors forcing water exchange should be investigated and the adverse effects (mainly from human activities) should be evaluated by proper methods. This study is specifically concerned with three - dimensional numerical circulation modeling of Göcek and Fethiye Bays. Bathymetric, oceanographic and meteorological site surveys are conducted before setting up the numerical model, MIKE 3 Flow Model Hydrodynamic Module. Monthly and seasonally met – ocean variations on the site was studied by using database available from Turkish State Meteorological Service. The circulation model within the boundaries was set up by applying at least two main directions of current and wind for twelve months with total twenty-four different scenarios. On the basis of the results of this study, the water exchange capacity of Göcek and Fethiye Bays, and investigations on improvements of water exchange and related environmental parameters are performed. Future recommendations for the management perspective on increasing the water quality will be developed.

Keywords: circulation, modeling, water exchange, Fethiye-Göcek, MIKE 3

ÖZ

3 BOYUTLU SAYISAL ÇEVRİM MODELLEMESİ; GÖCEK VE FETHİYE KÖRFEZLERİ KIYI SÜREÇLERİNE UYGULAMA

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Göcek ve Fethiye Körfezleri Türkiye'de bulunan eşsiz kıyı alanlarıdır, fakat artan yoğun kullanımın beraberinde getirdiği kirlilik nedeniyle su kalitesi günden güne azalmaktadır. Ancak açık deniz ve koylar arasında yeterli miktarda su alışverişi sağlanırsa, su kalitesi korunabilir. Kıyı morfolojisi, rüzgarla oluşan akıntı ve gelgit hareketi su çevrimini kolaylaştıran ve körfez-açık deniz su etkileşimine yardımcı olan faktörlerdendir. Bu çalışma kapsamında körfez ile açık deniz su alışverişini etkileyen faktörler gerekli veriler kullanılarak değerlendirilecek, olumsuz etmenler arasında yer alan insan kaynaklı kirliliğin zamansal değişimi kullanılacak ve modelleme yardımı ile araştırılarak çözüm seçenekleri oluşturulacaktır. Bu çalışmada geniş uygulama alanı olan MIKE 3 "Flow Model Hydrodynamic Module" kullanılarak, Göcek ve Fethiye körfezlerinin 3 boyutlu sayısal modellemesi yapılacaktır. Sayısal model kurulması sırasında yöre ile ilgili önceden yapılmış batimetrik, oşinografik ve meteorolojik saha ölçüm verileri analiz edilerek model girdileri hazırlanacaktır. Bölgedeki aylık - yıllık rüzgar, dalga ve iklim koşulları bilgisi Türkiye Meteoroloji Genel Müdürlüğünden alınmıştır. Model belirlenen sınırlar içerisinde, 12 ay süresince ve minimum 2 ana akıntı ve rüzgâr yönü, toplamda 24 senaryo olmak üzere kurulması planlanmaktadır. Bu çalışmanın sonucunda, Göcek ve Fethiye Körfezlerinin açık deniz ile su alışveriş kapasitesi belirlenecek, su kalitesinin ve ilgili çevresel parametrelerin sınırlar içinde kalması için gerek kullanım sınırlamaları gerekse yapısal öneriler oluşturulacaktır.

Anahtar Kelimeler: su çevrimi, modelleme, su değişimi, Fethiye-Göcek, MIKE 3

To my family and beloved friend, Mustafa Gürel…

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After graduating from Civil Engineering Bachelor's degree, without losing any time, I have applied for master's degree for Coastal and Ocean Engineering Division of Civil Engineering Department in Middle East Technical University. As soon as I have learnt the acceptance to the degree, my adventure has begun. Within this period, I have faced many challenges both in courses and in thesis work. However, I have overcome all these challenges with joy and support I have seen from my supervisor, family and friends.

I would like to express my most sincere gratitude to my dear supervisor Prof. Dr. Ahmet Cevdet Yalçıner. He is the most optimistic person I have ever met. Whatever the case is, he always cheered me just like a real relative and showed me the way so that I can achieve success. He always showed great hospitality to me and my friends. I have learnt many things from him not only about academic life but also about real life. I am glad to be his student.

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LIST OF ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
DHI	Danish Hydraulic Institute
DSI	General Directorate of State Hydraulic Works
E	East
FVCOM	Finite Volume Coastal Ocean Model
FVM	Finite Volume Method
GEBCO	General Bathymetric Chart of the Oceans
ICZM	Integrated Coastal Zone Management
N	North
PANORMUS	Parallel Numerical Open-source Model for Unsteady Flow Simulation
S	South
SEPA	Special Environmental Protection Areas
W	West

CHAPTER 1

INTRODUCTION

Coastal zone is the junction of land and water. In other words, it is a heavenly combination of land environment and marine environment, furthermore, humanity has an impact on both coast and sea. Due to accelerated increase of human population, rapid development of industry and tourism has been observed. This contributes to growth of economic activities in coasts and oceans, which leads to over-exploitation of natural and marine resources, thus increasing pollution. Due to these adverse effects, Integrated Coastal Zone Management is emerged in need of sustainable development in coastal zones.

The major emphasis of Integrated Coastal Zone Management (ICZM) is on finding a balance between the protection of natural resources and socio-economic development of the coastal zone (Prof. Dr. Ayşen Ergin, Marinas, Lecture Notes, February 2011, Middle East Technical University, Ankara). ICZM aims sustainable development in coastal areas and for sustainable development, three main components have to be in harmony. These can be listed as follows;

- Economy
- Society
- Environment

In terms of sustainability and ICZM, one can say that, resources should be used in such a way that not only the current generation but also the future generations will benefit from them. In other words, instead of short-term gains, long term advantages should be aimed.

In this study, the work area is selected as Fethiye and Göcek Bays. This area is one of the most popular and significant locations due to its natural beauty. Fethiye has been one of the most critical settlement in the area since from the ancient ages. The previous names of Fethiye are known as Telmessos, which was used by Lydians, and Meğri, which was used during Ottoman Period. In 1914 during World War I, Fethi Bey, who was a pilot and one of the first air force martyrs in Turkish History, was shot down and landed to Fethiye. In his honor, the name of the settlement is changed to Fethiye. (www.fetav.com).

In modern times, Fethiye has become a touristic paradise attracting many people all around the globe. Both due to intense touristic and industrial activities, the bays are becoming more polluted as time passes. This thesis work is done so that natural occurrence and behavior of the current in the bay can be observed so that mitigative and adaptive solutions to pollution and intense human activity can be found. In this thesis work, the circulation characteristics and water exchange capacity of Fethiye and Göcek Bays are analyzed under Coriolis, tidal and wind forces using MIKE 3.

This thesis has in total 7 chapters, including the introduction as the first chapter. Chapter 2 covers an in-depth research of the literature. In Chapter 3, the detailed description of the study area is given. Then, in Chapter 4, theoretical information about the hydrodynamic numerical modeling tool is mentioned. Later, the data processing for the application to Fethiye and Göcek Bays is performed in Chapter 5. In Chapter 6, the model of Göcek and Fethiye Bay is set up and the simulation results are also given briefly. Finally, Chapter 7 consists of a conclusion and a brief discussion of the results.

CHAPTER 2

LITERATURE REVIEW

To observe the changes in water level and velocity patterns in coastal lagoons under the influence of wind forcing, tidal forcing and density gradient, a three-dimensional baroclinic numerical model was developed by Balas (2002). The model is implemented for Ölüdeniz Lagoon located in the southern part of Fethiye, Mediterranean Sea. The solution method used in the model is a composite finite difference and finite element method. The hydrodynamic model is based on the solution of Navier-Stokes equations. Water temperature and salinity measurements were carried out so that the model could be set up. The dominant wind direction for the area is South and wind speed of 4 m/sec-10 m/sec was applied. A tidal force with an amplitude of 15 cm and a period of 12 hours was also applied to the model. Tidal and wind-driven currents in Ölüdeniz Lagoon and Belceğiz Bay was simulated and it was seen that these forces can generate significant currents. Ölüdeniz is a single-entry lagoon and the connection to the sea is narrow. Therefore, the current speeds caused by tidal forces are lowered at the connection channel. It was considered that, for the formation of water circulation in the entrance of lagoon, the tidal force plays a dominant role. However, for the inner part of the lagoon, the wind force has a direct effect on water circulation. Under wind forcing, the current directions obtained at the sea surface and sea bottom are in reverse directions. However, for tidal forcing the current directions in a water column are in the same direction. (Balas, 2002)

Sayın and Pazı (2002) determine the water circulation inside Fethiye Bay using a three-dimensional mathematical model called Killworth during the basin dredging of Fethiye Marina. Similar to Balas (2002), the model is based on the solution of Navier-Stokes equations. Main aim of the study is to observe the dispersion of dumped material obtained from the dredging that does not settle but suspends in the sea. Five different scenarios for Fethiye Bay are studied and for these scenarios, temperature and salinity, four main wind directions (North, East, South, West) and water level are selected as inputs. The boundaries at the Aegean Sea are defined with open boundary conditions. The material is dumped from a specified point and % 98 of the material deposits to the sea bottom. The dispersion of the remaining suspended material in the bay and the amount of water exchange between Fethiye Bay and the Aegean Sea are measured. As a result of this study, it is obtained that under the influence of four different wind directions, the distribution of dumped material in the bay, affects approximately an area of 25-60 km^2 although it varies according to the wind directions. Therefore, it can be concluded that the effect of marine pollution due to dispersion of the suspended material is bounded by time and domain. According to the model results, the marina port area, interior part of Fethiye Bay, is an unaffected location by the dumped material.

Koçyiğit and Koçyiğit (2004) worked on how physical factors affect circulation patterns due to wind forcing under different scenarios by developing a three-dimensional semi-implicit finite difference code. Various circulation scenarios such as; a rectangular basin in which the depth is constant with changing topography and a small lake; Esthwaite Water in Cumbria, UK which has a complex bathymetry are worked on. After the numerical model was run and it was observed that it gave reasonable results when compared with the analytical solutions and literature data. According to the simulation results, bathymetry has a significant effect on the nature of water circulation. It is observed that coefficient of eddy viscosity, wind speed and direction are the other variables that affect the circulation. (Koçyiğit and Koçyiğit, 2004)

Sankaranarayanan (2007) worked through boundary-fitted hydrodynamic model, again a three-dimensional model, (BFHDYRO) for Buzzards Bay, Massachusetts. The objective of the study was to set up a model simulating the wind and tide-induced circulation in Buzzards Bay. Mainly, wind force is applied on the water surface and the tidal force was applied at the open boundaries. According to the data from the literature and measurements, the model calibration was performed. The simulation findings show that the wind is the primary source for the formation of barotropic residual currents in Buzzards Bay. (Sankaranarayanan, 2007)

In 2007, Mestres et al. set up a three-dimensional hydrodynamic model using COHERENS code. The code can be applied for biological, resuspension and pollution processes as well as coastal and estuarine waters. The main objective of their study was to observe the winter circulation characteristics of Tarragona Harbour (northeastern Spain) and estimate the water quality. Normally, water dynamics in a port is influenced by tidal force, wind surface stress and baroclinic effects. Several simulations were done, and it is ensued that for small-time scales wind is an important triggering factor for water exchange between in and out of the harbor. However, when long-term results were investigated, it was observed that waterbody's baroclinic structure is the most important mechanism that triggers the water exchange. (Mestres et al., 2007)

Iglesias et al. (2008) worked through the circulation characteristics of Ría de Muros (an estuary) located in the Rías Baixas area (NW Spain). A three-dimensional numerical model was prepared by the use of DELFT3D-FLOW. Necessary data for setting up the model such as; current velocity and direction, temperature, salinity, river discharges and wind speed and direction were collected. Current parameters are compared with the Acoustic Doppler Current Profiler (ADCP) measurements. The whole estuary, as well as dry and flood areas, which change with seasons, of the inner estuary, was covered in the model. Model results indicate that tide, wind, and river inflows are the important factors, however, the tide is the leading force that affects ría circulation. Besides, wind force has a contribution to the middle and outer parts of ría. (Iglesias et al., 2008)

In semi-enclosed basins, wind-induced circulation and sediment transportation was studied by Akbaşoğlu (2011). A numerical model named as Finite Volume Coastal Ocean Model (FVCOM) was employed in order to examine and understand the water exchange, current patterns and sediment distributions in Fethiye Bay under different wind (direction, speed and duration), river discharge and tidal conditions. Additionally, the effect of Coriolis forcing on Fethiye Bay was investigated. (Akbaşoğlu, 2011)

Jiang and Fissel (2012) customize the three-dimensional model called COCIRM-SED in order to simulate ocean currents and water levels in southern Discovery Passage and Canoe Pass, BC, Canada. The coastal numerical model is based on Reynolds-averaged Navier-Stokes fluid dynamics equations, with finite difference volume elements. According to the results of the model, possible locations for underwater tidal current turbines can be determined and potential environmental impacts can be predicted. In modeling southern Discovery Passage, tidal force, Coriolis force and freshwater discharge from Campwell River are included. Several parameters such as; water elevation and current were calibrated using available data and observations so that the model has a high precision. In Canoe Pass, there exists a man-made rock dam between Quadra Island and Maude Island. It was designed to abolish the dam and, instead of it, underwater tidal current turbines were arranged to be implemented. In the second model, Coriolis force and tidal force is included, and it was also calibrated according to the measurements and observations. As a result, both models have high resolution in terms of circulation. The flow patterns were obtained, and these results can give an idea of possible locations for constructing the underwater tidal turbines. (Jiang and Fissel, 2012)

Lončar, Leder and Paladin (2012) set up a 3-dimensional model by using MIKE 3 in order to obtain water circulation numerically in Northern Adriatic. Tidal forces, river discharges, salinity, bottom freshwater springs, atmospheric forces and wind forces were included in the model. The calibrations were done by comparing CTD and ADCP measurements. As a result of the circulation model, the current characteristics in Northern Adriatic was obtained and it was used to set up the second model; Lagrangian model of discrete particles. The aim of the oil contaminant transport model was to examine the possible cases of oil spills and spreading of the oil due to a breakdown of a ship. Simulation results show how much Northern Adriatic coasts are affected due to an oil spill that takes place near Poreč and Rovinj (Croatia).

Dzabic (2012) studied Fethiye Bay in terms of sea water circulation and yacht carrying capacity. FVCOM (Finite Volume Coastal Ocean Model) was used as a modeling tool. Wind force and tidal force are the main inputs for the model. In this study, three different models are prepared. The first one simulates the present bathymetry of Fethiye Bay. Secondly, dredging works are implemented at the east and southeast parts of the bay. Thirdly, a waterway is added to Karagözler district which is located in the southeast of the bay. In consequence of the study, it was observed that dredging and adding channel have a weak contribution to water exchange. To obtain yacht carrying capacity in Fethiye Bay, physical yacht carrying capacity together with natural yacht carrying capacity, present berthing distribution and wastewater volume due to yacht usage were considered. (Dzabic, 2012)

Gunaratna and Gunaratna (2012) established a three-dimensional model using MIKE 3 HD FM for Dubai coastal area enclosing Dubai Creek. The developed model was based on the previous numerical model which was done by DHI in 2009. The goal of this study is to observe the water circulation and to set up a three-dimensional hydrodynamical model in Dubai coasts for the use of future planned projects, especially projects in Dubai Creek. Besides, the flushing capacity of Dubai Creek was observed by using MIKE 3 TR (Transport) Module. The model was calibrated with high precision by using the water level, current, water temperature and salinity data. There exist proposals of designing artificial canals which will connect with Dubai Creek to the inland waters. It is observed that these potential advances can have an influence on the tidal flow regime and water quality of the area. (Gunaratna and Gunaratna, 2012)

In 2014, it was the first time that Augusta Bay (Italy), located in the east part of Sicily, was investigated in terms of water exchange and hydrodynamic circulation by De Marchis et al. In Augusta Harbour, chemical and petrochemical industries have been operating since 1954. As a result, this location was stated as the most contaminated coastal area in Italy. To examine the hydrodynamic circulation in an enclosed basin, a three-dimensional numerical model; PANORMUS (Parallel Numerical Open-source Model for Unsteady Flow Simulation) was used. The model is based on the solution of Reynold's averaged continuity and momentum equations. To observe each force's individual effect on circulation, three different simulations were done. These are named as WT (Wind-Tide), WNT (Wind-No-Tide) and TNW (Tide-No-Wind). The calibrations were done by comparing the numerical results with measured data. According to the results, it was obtained that wind force has a significant effect on circulation inside the harbour. Besides, water exchange between the bay and open sea is primarily triggered by tide variation. This study paves the way for further studies which will be carried out about wind and tidal-driven circulations in enclosed areas. (De Marchis et al., 2014)

Uddin et al. (2014) set up a two-dimensional numerical model by use of MIKE 21 HD FM, in the northern part of Bay of Bengal. High river flow, sediment transport, strong tide, winds, waves and cyclonic storm surges are the principal factors that has an impact on the coastal morphology of Bangladesh. The main aim of the study is to comprehend the flow pattern of the Bay of Bengal under various forces. For the model setup bathymetry, water level and discharge data are used. There are two open boundaries in the model; Lower Meghna River at Chadpur (the northern boundary) and Bay of Bengal (the southern boundary). The simulations are performed for dry and monsoon seasons after the calibration of the model. Moreover, by using the Bay of Bengal model, the residual flow, current speeds in Meghna Estuary and tidal meeting points in channels of Meghna Estuary are also determined. As a result of this study, it is obtained that in dry season the water flow in the Meghna Estuary is dominated by the tidal action. In monsoon, the water level and water flow are dominated by river discharge, tide and wind.

Yılmaz et al. (2017) carried out a study whose aim is to determine the relationship between land use and water quality. The study includes the measurements of the physical and chemical parameters (temperature, density, salinity, pH, concentrations of dissolved oxygen, nitrite, nitrate and total dissolved solid) by monthly field and laboratory measurements during summer and autumn seasons at the inner bay of Fethiye. The modeling of sea water quality is performed by using an implicit baroclinic three-dimensional numerical model named as HIDROTAM-3D. At predefined six-gauge points, the model estimations are compared with the measured parameters which are nitrite, nitrate and dissolved oxygen concentrations. The initial parameters for the numerical model are obtained from the evaluation the measurements. According to the simulation results of the water quality model, at all the gauge points, pH, salinity and sea water temperature values are close to the typical Mediterranean values. The dissolved oxygen concentrations were also observed to be close to the mean values of Mediterranean. Also, the nitrite and nitrate concentrations were below the pollution limits. However, the impact due to human activities can be seen at the mouth of Murt Stream. This stream is polluted by the discharges coming from the wastewater treatment plant, agricultural wastes and low the current speeds. According to the comparison between measured and modeled values, the model results are close to the measured values for the nitrite, nitrate and dissolved oxygen concentrations. The inner bay of Fethiye is a sheltered area which means it is protected from the direct effect of winds and waves. Yet this brings a lower water circulation and it is highly exposed to contamination. During the observation period, it can be seen that the Murt stream and the canals are very important causes for pollution at the inner bay of Fethiye due to the transfer of land-based wastes with fresh water.

3D numerical flow model was set up for the purpose of obtaining the kinetic energy potential of the Bosphorus. Öztürk, Şahin and Yüksel (2017) stated that regions with strong ocean currents have a high potential of energy. 3D simulations with MIKE 3 Flow Model Flexible Mesh were done so that the flow characteristics and current power potential in the strait: Bosphorus can be obtained and analyzed. This strait connects Black Sea and Marmara Sea. Generally, there exists a two-layer exchange between two water bodies if density of these bodies is different and divided by small channel. Differences in water level, water density and atmospheric pressure, wind speed and wind direction are the main triggering forces used as inputs. The output of MIKE software; the mean current speed, can be correlated with the average kinetic power. The study demonstrated that the current power potential in Bosphorus is affected by river discharges, meteorological conditions, water level and density difference between Marmara and Black Sea, bathymetry and geometry of the strait.

CHAPTER 3

DESCRIPTION OF THE STUDY AREA

In Turkey, there are 16 Special Environmental Protection Areas (SEPA) and the subject of this study; Fethiye and Göcek region is one of them. Fethiye and Göcek SEPA has an area of 805.37 km^2 which constitutes % 0.103 of the total area of Turkey. Therefore, great importance must be given for the protection of these sites. In this chapter, information about the study area is given in detail.

Fethiye - Göcek is a district within the boundaries of the city of Muğla which is in the Mediterranean coast of Turkey and site location map is shown in Figure 3.1. The settlements are on the foothills of Mendos mountain which is a part of Toros Mountain Range. Fethiye - Göcek has a natural beauty with a unique coast, ecological wealth with several endemic plants, ancient and cultural heritage and a feature of a natural marina. These factors make Fethiye and Göcek a remarkable spot in Turkey.

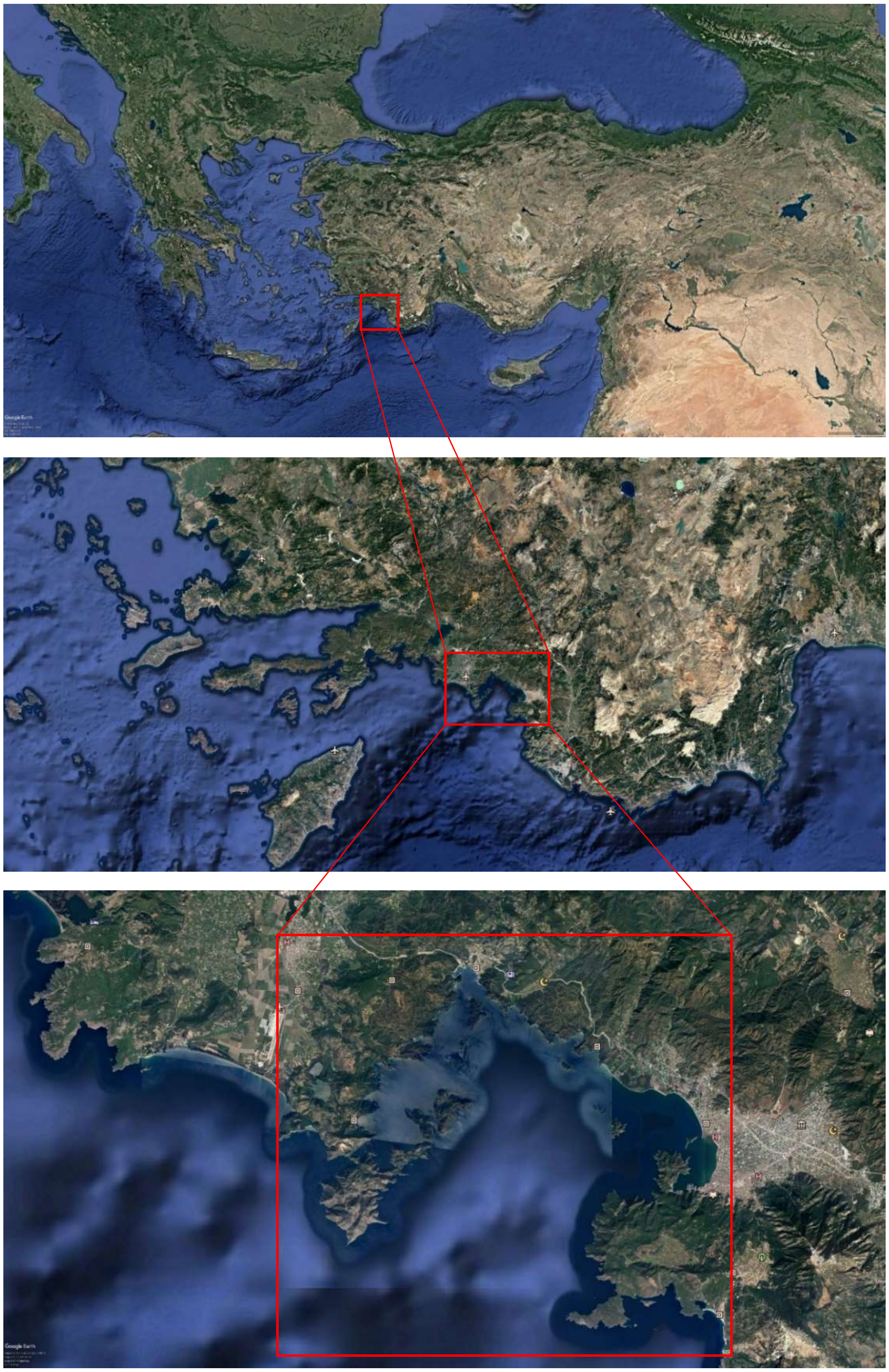


Figure 3.1. Site location map (Google Earth)

In ancient times, Fethiye is called as Telmessos. It is predicted that the ancient city dates back to 5th century BC. There are several historical remains in the area such as rock graves called Amintas and ancient city ruins. Ancient settlements found in the area are Ancient city of Tlos, Ancient city of Cadianda, Ancient city of Pinara, Ancient city of Xanthos, Ancient city of Letoon, Ancient city of Patara, Ancient city of Sidyma, Ancient city of Oenoanda, Ancient city of Araxa.

According to the population census results in 2016, Fethiye district has a total population of 151,474 people (http://www.fethiye.gov.tr/nufus-dagilimi). Agriculture in its fertile lands is the main source of income for Fethiye. Besides Fethiye is a top vacation spot during the summer. In summers, yachting and paragliding is the most demanding activity for both domestic and foreign tourists. Ölüdeniz is one of the best places to do paragliding activities due to its unique geographical characteristics.

In Fethiye and Göcek, the typical Mediterranean climate is dominant, which can be summarized as follows; in summer, weather is generally hot and dry and in winter season, it is warm and rainy. Table 3.1 shows the average maximum and minimum temperatures, precipitation and hours of sunshine for Muğla for every month. The table is taken from Turkish State Meteorological Service. The annual average temperature in Muğla is 15 °C. Minimum and maximum average temperatures are 9.6 °C and 21.2 °C, respectively. In average, rainy days is 95 days per year. The total amount of monthly average precipitation is 1194.6 mm per year.

Table 3.1. Meteorological Statistics for Muğla

MUĞLA (1926-2016)	1	2	3	4	5	6	7	8	9	10	11	12	Yearly
Average Temperature (°C)	5.5	6.1	8.4	13	18	23	26	26	22	16	10.7	7	15
Average Maximum Temperature (°C)	9.8	10.8	14.1	19	24	30	33	33	29	23	16.7	11.5	21.2
Average Minimum Temperature (°C)	1.6	1.9	3.5	7	11	16	20	20	15	10	5.9	3.2	9.6
Average Hours of Sunshine (hours)	3.4	4.4	6.6	7.3	8.5	11	11	11	9.4	7.1	5.6	3.3	88.5
Average Rainy Days (day)	15.2	12.7	10.7	8.9	7.5	3.4	1.6	1.3	2.6	6.4	9.8	14.9	95
Monthly Average Total Precipitation (mm)	241	180	125	65	50	21	8.5	8.2	19	73	138	267	1195

(https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=undefined&m=MUGLA)

Due to the geographical location of Fethiye and Göcek Bays, they are naturally protected by the direct effect of winds and waves. As it can be seen from Figure 3.2, in the entrance of Göcek Bay, Göcek Island prevents the waves to enter the bay directly, it serves as a natural barrier. The same condition is valid for Fethiye Bay, Şövalye Island is located in the entrance of Fethiye Bay (Figure 3.3). As a result, Fethiye becomes also a naturally protected calm place for yachts. However, the natural layout of these islands may have a negative effect on water exchange between bays and offshore.

Figure 3.2. Göcek Island (Google Earth)

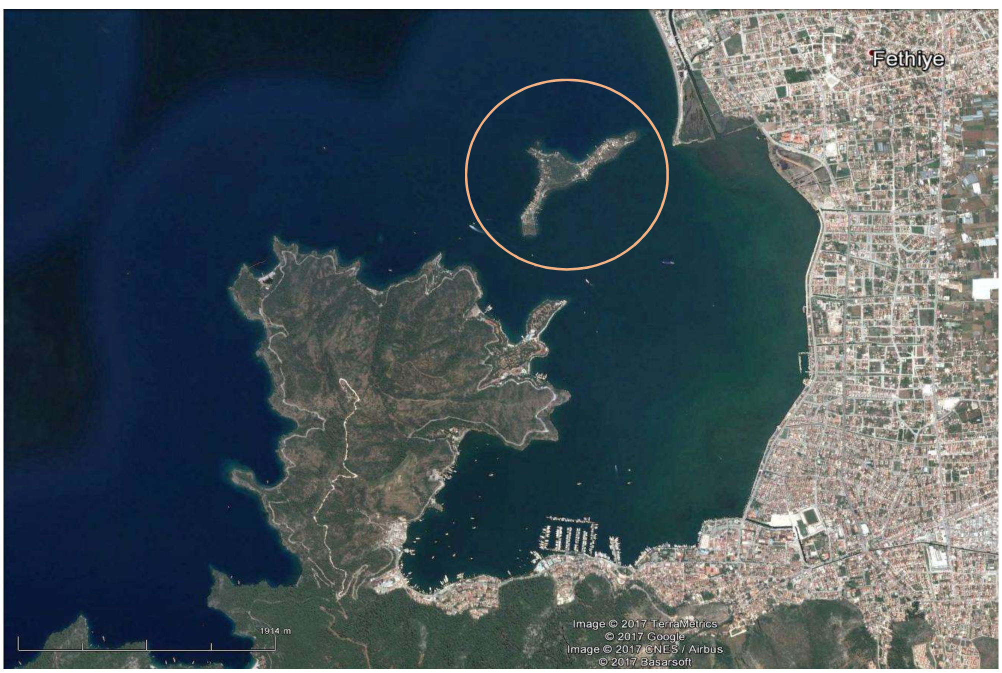


Figure 3.3. Şövalye Island (Google Earth)

Population growth and an increase in human settlement, excessive usage and exploitation of natural resources have negative effect on coastal areas and in the long-term, this leads to an increase in pollution. There are several pollutants that affect water quality in Fethiye and Göcek; solid wastes, wastes from vessels, domestic wastes, industrial wastes and agricultural wastes. Especially in the summer season, the population in Fethiye and Göcek nearly doubles and bays are exposed to heavy human actions. Due to these activities, unique and unspoiled places such as Ölüdeniz, Butterfly Valley, Kabak Valley and 12 islands vicinity, are in danger of being over polluted.

Many recreational boat tours are organized for visiting these places throughout the day. It can harm both the coastal ecosystem, habitat and biodiversity. According to a study performed in Göcek-Dalaman Bays (METU, 2007), the amount of wastewater discharged from the boats in Göcek and Dalaman Bays were approximately calculated as 360 m^3/day. In short term, it seems that these attractions have a contribution to the economy of the area, however, in the long run, it will increase the pollution and affect the sensitive marine species. The solid wastes discharged by the yachts is also an important cause for pollution. Also, there exists a boatyard in Karagözler. This place was built where there is scarcely any current motion and it adversely affects the coasts.

As a solution, environmental awareness should be raised so that excessive pollution can be avoided. Moreover, for boats coming from both territorial and international waters, Fethiye and Göcek ports shown in Figure 3.2 and Figure 3.3 become popular and preferable spots. Both ports can provide needs and resting places for sailors. The reason is that the ports in Fethiye and Göcek are well-equipped and located at the coinciding point of the Aegean and the Mediterranean Sea.

Circulation in the bays and water exchange between the bay and deep sea are important factors to be investigated to control water quality in the bays. This study is focused on these hydrodynamic characteristics in the region using mathematical modeling MIKE 3 HD FM which is described in the following sections.

CHAPTER 4

THEORETICAL FRAMEWORK

4.1 Coastal Circulation Models

The coastal circulation is a major controller of climate by collecting and transferring heat, carbon, nutrients and freshwater all around the world.

Below list shows the ocean circulation models used in the world.

- ADCIRC : Advanced Circulation Model for Oceanic, Coastal and Estuarine Waters
- BFHDYRO : Boundary Fitted Hydrodynamic Model
- CO-CIRMSED : Coastal Circulation Model
- COHERENS : Coupled Hydrodynamical Ecological model for Regional Shelf seas
- Delft3D-FLOW : Coastal Hydrodynamic Modeling
- FVCOM : Finite Volume Community Ocean Model
- FESOM : AWI Finite-Element / Volume Sea ice-Ocean Model
- HOPE : The Hamburg Ocean Primitive Equation General Circulation Model
- HYCOM : Hybrid Coordinate Ocean Model
- LSG : The Hamburg Large Scale Geostrophic Ocean General Circulation Model
- MICOM : Miami Isopycnic Coordinate Ocean Model

- MIKE 3 FM : Three-Dimensional Water Model
- MITgcm : M.I.T. General Circulation Model
- MOHID : Modelo Hidrodinâmico
- MOM GFDL : Modular Ocean Model
- NEMO : Nucleus for European Modelling of the Ocean
- OPYC : The Ocean Isopycnal General Circulation Model
- PANORMUS : Parallel Numerical Open-source Model for Unsteady Flow Simulation
- POM : Princeton Ocean Model
- POP : The Parallel Ocean Program
- ROMS : The Regional Ocean Modeling System
- SELFE : A Circulation Model for Oceans and Estuaries
- SLIM-Ocean Model : Second-generation Louvain-la-Neuve Ice-Ocean Model

4.2 MIKE 3 Flow Model Flexible Mesh – Hydrodynamic Module – Model Formulation

MIKE 3 Flow Model FM is a modeling tool developed by Danish Hydraulic Institute (DHI) to simulate oceanographic, estuarine and coastal areas. The model depends on the numerical solution of three-dimensional incompressible Reynolds averaged Navier-Stokes equations (RANS) depending on Boussinesq and of hydrostatic pressure assumptions (DHI, 2017).

MIKE 3 Flow Model FM is made up of set of equations as follows,

- Continuity Equation
- Momentum Equation
- Temperature Equation
- Salinity Equation
- Density Equation

The model calculates the flow according to turbulent closure scheme. The basic equations for MIKE 3 Flow Model FM are written below (DHI, 2016);

The Local Continuity Equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=S \qquad (4.1)$$

Horizontal Momentum Equations (x- and y-component)

$$\frac{\partial u}{\partial t}+\frac{\partial u^2}{\partial x}+\frac{\partial vu}{\partial y}+\frac{\partial wu}{\partial z}=fv-g\frac{\partial \eta}{\partial x}-\frac{1}{\rho_0}\frac{\partial p_a}{\partial x}-\frac{g}{\rho_0}\int_z^{\eta}\frac{\partial \rho}{\partial x}dz-\frac{1}{\rho_0 h}\left(\frac{\partial s_{xx}}{\partial x}+\frac{\partial s_{xy}}{\partial y}\right)+F_u+\frac{\partial}{\partial z}\left(v_t\frac{\partial u}{\partial z}\right)+u_sS \qquad (4.2)$$

$$\frac{\partial u}{\partial t}+\frac{\partial v^2}{\partial y}+\frac{\partial uv}{\partial x}+\frac{\partial wv}{\partial z}=-fu-g\frac{\partial \eta}{\partial y}-\frac{1}{\rho_0}\frac{\partial p_a}{\partial y}-\frac{g}{\rho_0}\int_z^{\eta}\frac{\partial \rho}{\partial y}dz-\frac{1}{\rho_0 h}\left(\frac{\partial s_{yx}}{\partial x}+\frac{\partial s_{yy}}{\partial y}\right)+F_v+\frac{\partial}{\partial z}\left(v_t\frac{\partial v}{\partial z}\right)+v_sS \qquad (4.3)$$

Where,

t	: time
x, y, z	: Cartesian coordinates
η	: surface elevation
d	: still water depth
$h=\eta+d$	: total water depth
u, v, w	: velocity components in x, y, z direction
$f=2\Omega sin\phi$	: Coriolis parameter
Ω	: angular rate of evolution
ϕ	: geographic latitude
g	: gravitational acceleration
ρ	: density of water
$s_{xx}, s_{xy}, s_{yx}, s_{yy}$	: components of the radiation stress tensor

v_t : vertical turbulent (eddy) viscosity

p_a : atmospheric pressure

ρ_0 : reference density of water

S : magnitude of the discharge due to point sources

(u_s, v_s) : velocity by which the water is discharged into ambient water

Horizontal stress terms (expressed by using gradient-stress relation)

$$F_u = \frac{\partial}{\partial x}\left(2A\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(A\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right) \tag{4. 4}$$

$$F_v = \frac{\partial}{\partial x}\left(A\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right) + \frac{\partial}{\partial y}\left(2A\frac{\partial v}{\partial y}\right) \tag{4. 5}$$

A : horizontal eddy viscosity

Surface and bottom boundary conditions

At z=η,

$$\frac{\partial \eta}{\partial t} + u\frac{\partial \eta}{\partial x} + v\frac{\partial \eta}{\partial y} - w = 0 \tag{4. 6}$$

$$\left(\frac{\partial u}{\partial z}, \frac{\partial v}{\partial z}\right) = \frac{1}{\rho_0 v_t}\left(\tau_{sx}, \tau_{sy}\right) \tag{4. 7}$$

At $z=-d$,

$$u\frac{\partial d}{\partial x} + v\frac{\partial d}{\partial y} + w = 0 \tag{4. 8}$$

$$\left(\frac{\partial u}{\partial z}, \frac{\partial v}{\partial z}\right) = \frac{1}{\rho_0 v_t}\left(\tau_{bx}, \tau_{by}\right) \tag{4. 9}$$

(τ_{sx}, τ_{sy}) : x and y components of surface wind stress

(τ_{bx}, τ_{by}) : x and y components of bottom wind stress

Total water depth value “h” can easily be calculated from kinematic boundary condition at the surface, if velocity field is determined from momentum and continuity equations. After the local continuity equation is integrated vertically, below equation is obtained.

$$\frac{\partial h}{\partial t} + \frac{\partial h\bar{u}}{\partial x} + \frac{\partial h\bar{v}}{\partial y} = hS + \hat{P} - \hat{E} \quad (4.\ 10)$$

$$h\bar{u} = \int_{-d}^{\eta} u dz \quad (4.\ 11)$$

$$h\bar{v} = \int_{-d}^{\eta} v dz \quad (4.\ 12)$$

(Assumption: the fluid is incompressible, therefore, the density (ρ), depends on the temperature (T) and salinity (s))

$$\rho = \rho(T, s) \quad (4.\ 13)$$

P : precipitation rates

E : evaporation rates

$\bar{u}, \bar{v}$: depth averaged velocities

Sea Water Density according to UNESCO Formula (UNESCO,1981)

$$\rho = \frac{\rho(S,T,0)}{1 - \frac{p}{K(S,T,p)}} \quad (4.\ 14)$$

$K(T, S, p)$: sea water compressibility

T : temperature (0 < T < 40°C)

S : salinity (0 < S < 42 PSU)

p : pressure

Wind Stress

$$\bar{\tau_s} = \rho_a c_d |u_w| \bar{u}_w \quad (4.\ 15)$$

$$\bar{\tau_s} = (\tau_{sx}, \tau_{sy}) \quad (4.\ 16)$$

$$\bar{u}_w = (u_w, v_w) \quad (4.\ 17)$$

$\bar{\tau_s}$: surface stress

ρ_a : density of air

c_d : empirical drag coefficient of air

$\bar{u}_w$: wind speed 10 m above sea surface

<u>CFL number (Courant-Friedrich-Léwy)</u>

CFL condition is essential for the convergence of shallow water equations. It is particularly affected by water depth. Stability is identified by means of Courant-Friedrich-Léwy number.

$$CFL_{HD} = \left(\sqrt{(g * h)} + |u|\right) * \frac{\Delta t}{\Delta x} + \left(\sqrt{(g * h)} + |v|\right) * \frac{\Delta t}{\Delta y} \quad (4.18)$$

h : total water depth

u,v : velocity components in the x- and y- direction, respectively

g : gravitational acceleration

$\Delta x, \Delta y$: characteristic length scale in the x- and y- direction, respectively for an element

Δt : time step interval

4.3 MIKE 3 Flow Model Flexible Mesh – Spatial Discretization

In MIKE 3 Flow Model FM, the spatial discretization of the domain is carried out by using a cell-centered method called Finite Volume Method (FVM). In a mesh system, finite volume means each node is enclosed by a small volume.

For MIKE 3 Flow Model FM, the three-dimensional hydrodynamic model, the domain is divided into non-overlapping cells or elements (triangular or quadrilateral). A layered mesh is used in the three-dimensional model and as shown in Figure 4.1, the model is based on flexible mesh approach which means in which an unstructured mesh is implemented in horizontal domain whereas a structured mesh is applied in the vertical domain. (DHI, 2017) To represent the existing environment real-like, spatially variable grid resolution is implemented to the model. By using unstructured mesh in horizontal domain, complex geometric shapes can be easily presented, and the boundaries can be smoothly presented. Also, refining the mesh resolution in specific areas can be possible.

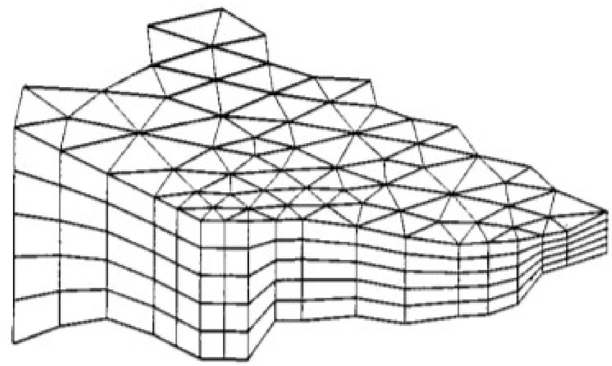


Figure 4.1. 3D Mesh (DHI, 2017)

4.4 MIKE 3 Flow Model FM – Boundary Conditions

For MIKE 3 Flow Model FM, there are two different specifications for the model boundaries; closed boundaries and open boundaries. A closed boundary, which is also termed as a land boundary, is a type of boundary that normal fluxes between land and sea are specified as zero. As a result, considering the momentum equations, the full-slip condition is valid on land boundaries. In the case of shallow water equations, if both normal and tangential velocity components are equal to zero, no-slip condition can also be used. On the other hand, for the open boundaries, there are many different boundary conditions can be specified such as flux, velocity, Flather, discharge and level boundaries. (DHI, 2017)

CHAPTER 5

DATA PROCESSING FOR THE APPLICATION TO FETHIYE AND GOCEK BAYS

In this chapter, the model inputs; bathymetry, river discharge, rainfall, wind, wave and current data of Fethiye and Göcek Bay are given, and the model applications are described together with the presentation of results and comparisons and discussions. The Coriolis, tidal wave and wind forcing are investigated by numerical modeling.

5.1 Bathymetry Data and Processing

In Göcek and Fethiye Bay, three different bathymetric data are available; Göcek Bay, Fethiye Bay and offshore. For Göcek and Fethiye Bays, bathymetric measurements carried out in May 2007 by Derinsu Underwater Engineering (METU, 2008) (TRANSFER, 2009). Göcek Bay measurements have grid size 50 m * 50 m. Fethiye Bay measurements have 100 m * 100 m grid size. Offshore bathymetry has a resolution of 900 m * 900 m and it is obtained from GEBCO (General Bathymetric Charts of the Oceans). Bathymetric data and measurements are gathered, and the overall bathymetry map shown in Figure 5.1 is obtained for the Fethiye and Göcek Bay.

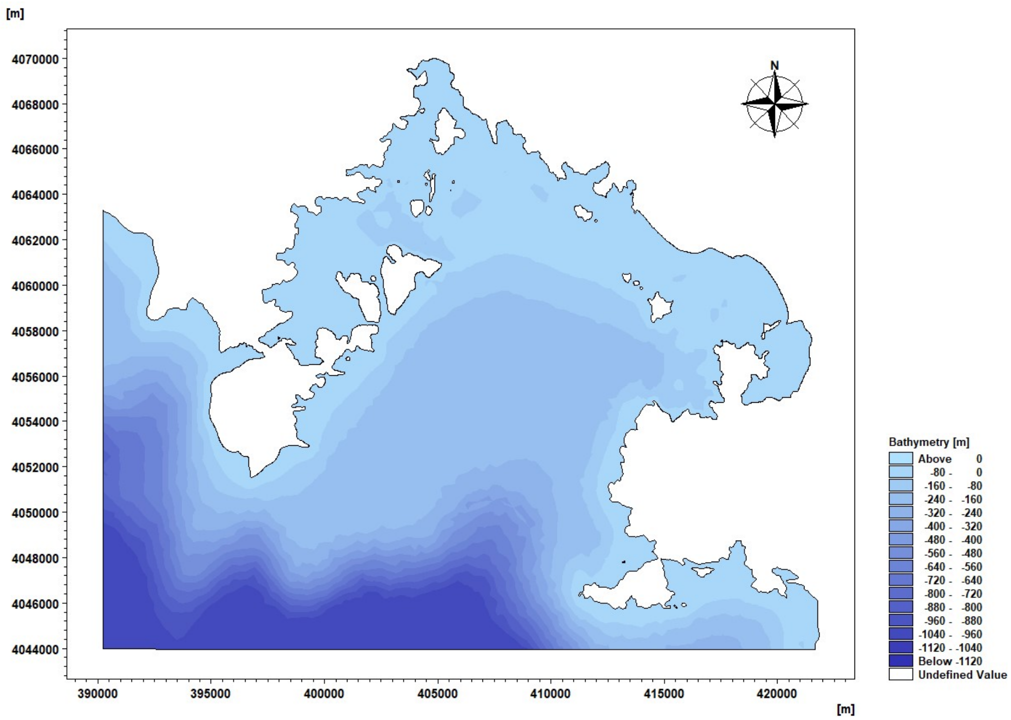


Figure 5.1. Bathymetry of Fethiye and Göcek Bays

5.2 River Discharge Data and Analysis

River discharge is vital for current behavior since the driving force in stream mouths is the discharge coming out of the river. If the particles near the stream mouths are laying off, it can be said that there exists a favorable circulation of water in that area. There are 3 main rivers discharging into the Göcek and Fethiye Bays. The rivers are named as Murt River, Kargı River and T2 DSI River. In Turkey, DSI (General Directorate of State Hydraulic Works) is recording the daily and monthly discharge measurements of these rivers. The locations are shown in Figure 5.2 and monthly average discharges are given in Table 5.1.

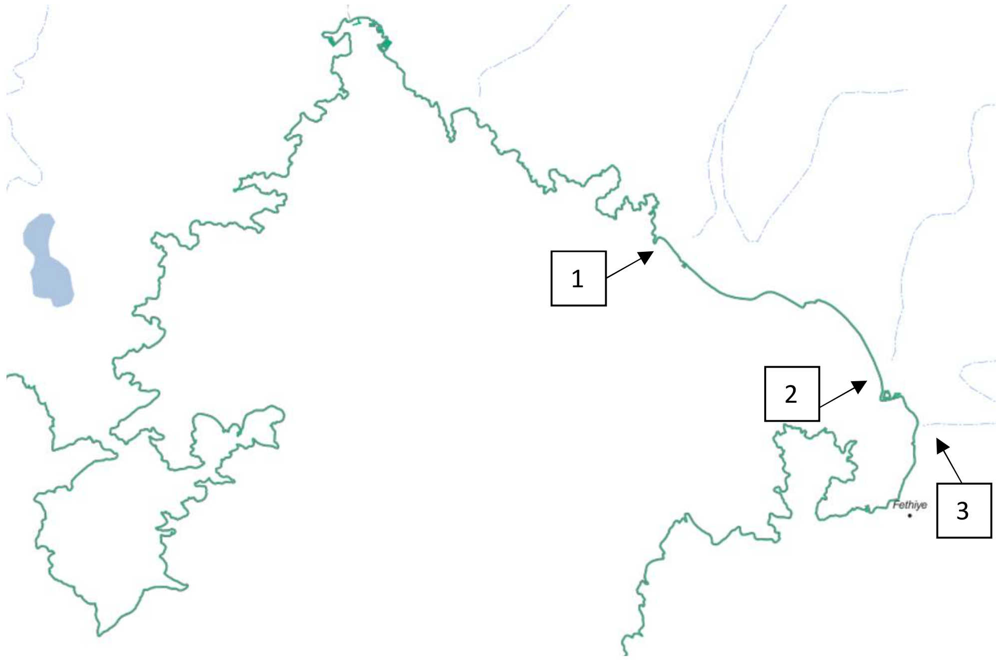


Figure 5.2. Locations of the River Discharges (DSI)

Table 5.1. Monthly Average Discharges (DSI)

Name	Discharge (m^3/hour)
Kargı River	3.89
Murt River	3.70
T2 DSI River	2.15

5.3 Rainfall Data and Analysis

In Fethiye and Göcek Bays, "Mediterranean Climate" is dominating. The summer seasons are dry, the winter seasons are mild and rainy. Yearly precipitation data is obtained by Akbaşoğlu in 2011 from DSI shown in Figure *5.3* and the data is tabulated in Table 5.2.

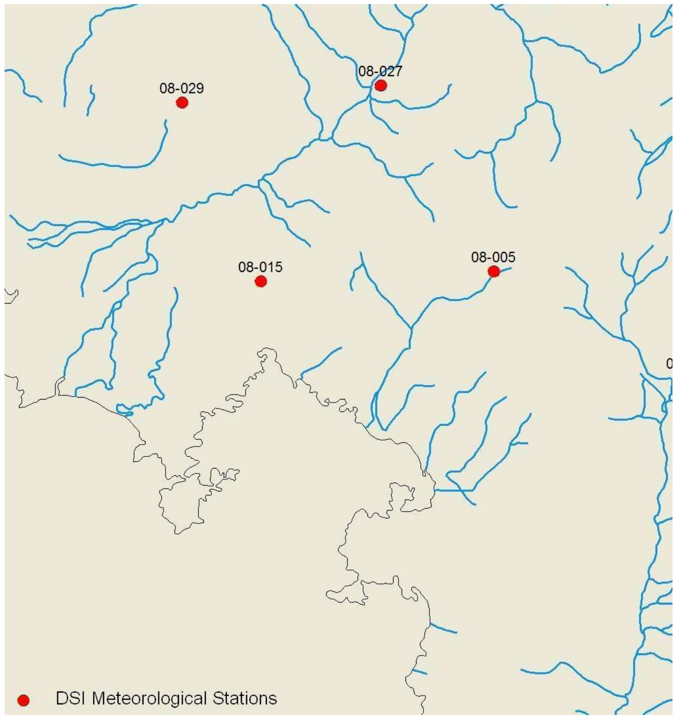


Figure 5.3. DSI Meteorological Stations (DSI)

Table 5.2. Yearly Precipitation (Akbaşoglu, 2011)

Name of the station	Observation Period (years)	Elevation from sea level (m)	Annual Average Precipitation(mm)
Fethiye (Nifköy) (DSI-08-005)	1962-2005	960	1521.6
Fethiye (Kızılkaya) (DSI-08-015)	1971-2005	280	1062.1
Köyceğiz (Narlı) (DSI-08-027)	1978-2005	430	996.9
Köyceğiz (Kavacık) (DSI-08-029)	1982-2002	700	1215.8

5.4 Wind Data and Analysis

Two meteorological stations named as Fethiye Meteorological Station (Station No:17296) and Dalaman Meteorological Station (Station No:17294) are taken into consideration during the characterization of the wind in the model area. These stations are different in several aspects; Fethiye Meteorological Station is located on the east of the Fethiye Bay and surrounded by hills and buildings. However, Dalaman Meteorological Station is located on the west and relatively lowland area. Both stations have long-term wind measurements and the wind data is analyzed to obtain the wind characteristics of Fethiye and Göcek Bay. The stations' locations are shown in Figure 5.4.

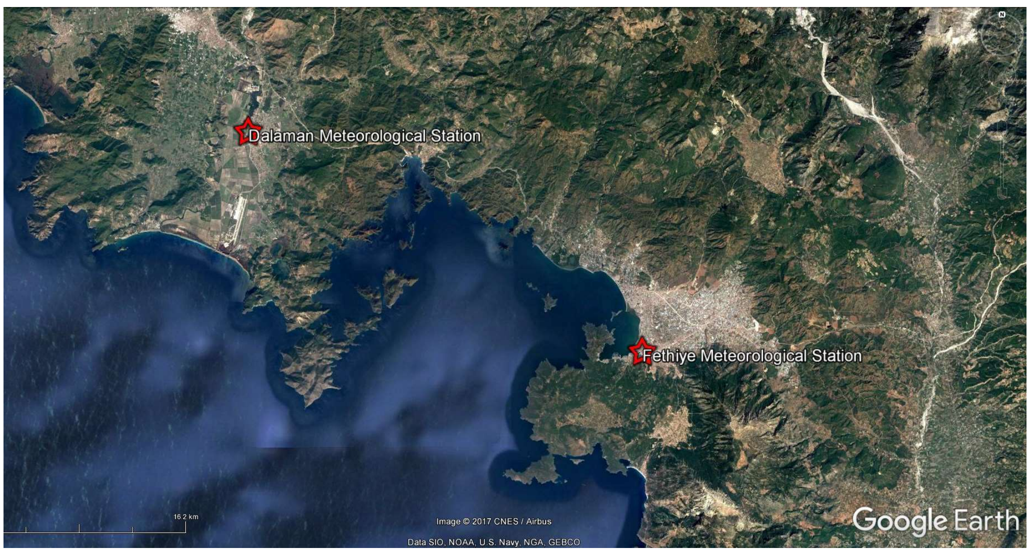


Figure 5.4. Location of Fethiye and Dalaman Meteorological Stations (Google Earth)

5.4.1 Fethiye Meteorological Station

For Fethiye Bay, yearly and seasonal wind roses are taken from the previous study of Akbaşoğlu (2011) based on wind measurements by Fethiye Meteorological Station between 1966-2007. On a yearly basis, it is stated that Fethiye is exposed to ENE, E, ESE, WSW, SSW, WNW oriented winds.

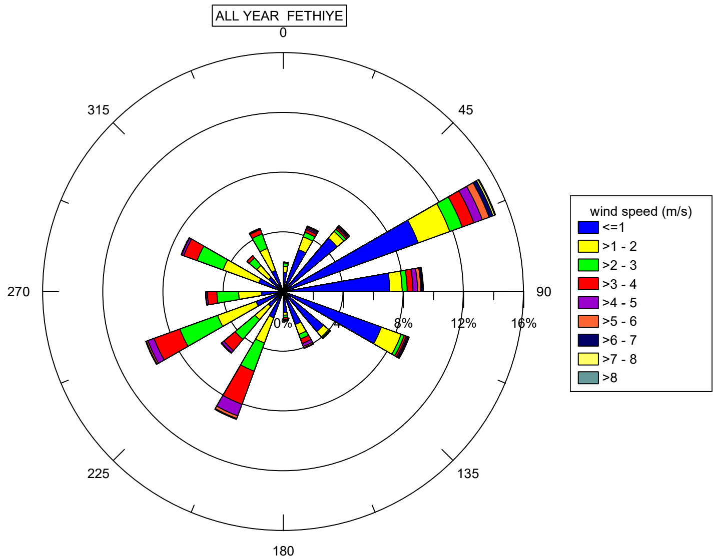


Figure 5.5. Fethiye Wind Rose - All year (Akbaşoğlu, 2011)

As it can be observed from Figure 5.5, annual dominant wave direction is ENE with more than 14 % of all year wind distribution. Other dominant wave directions are WSW, SSW and E with nearly 10 % for each direction.

The wind distribution for the autumn resembles the all year distribution. Likewise, governing wind direction is ENE. Also, E, ESE, WSW and SSW wind directions can be seen very often.

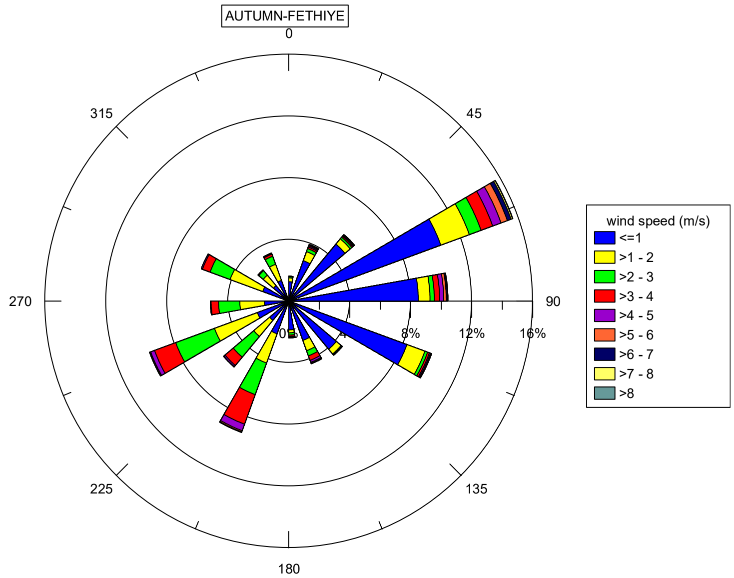


Figure 5.6. Fethiye Wind Rose - Autumn (Akbaşoğlu, 2011)

For the winter wind rose, one can observe that it is similar to the distribution of the whole year. ENE is the dominant wind blowing direction among the other directions with nearly 18 %. 12 % of winds are blowing from ESE and E direction.

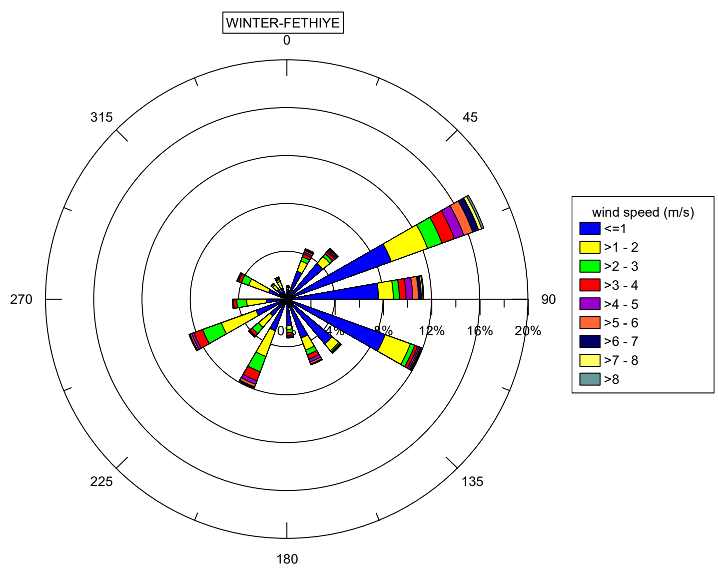


Figure 5.7. Fethiye Wind Rose - Winter (Akbaşoğlu, 2011)

In the spring, ENE is the dominant wave direction, but WSW and SSW oriented winds have also high percentage of blowing.

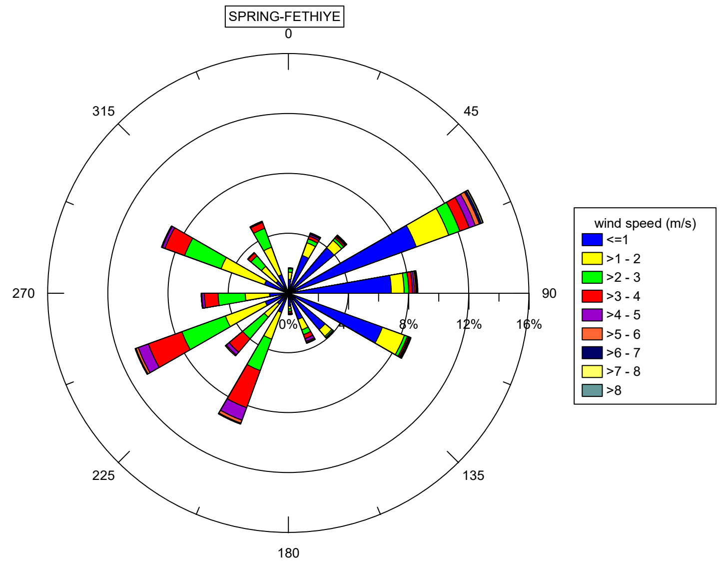


Figure 5.8. Fethiye Wind Rose - Spring (Akbaşoğlu, 2011)

Finally, for the summer wind rose, ENE wind is the main direction, and SSW, WSW and WNW are the secondary directions.

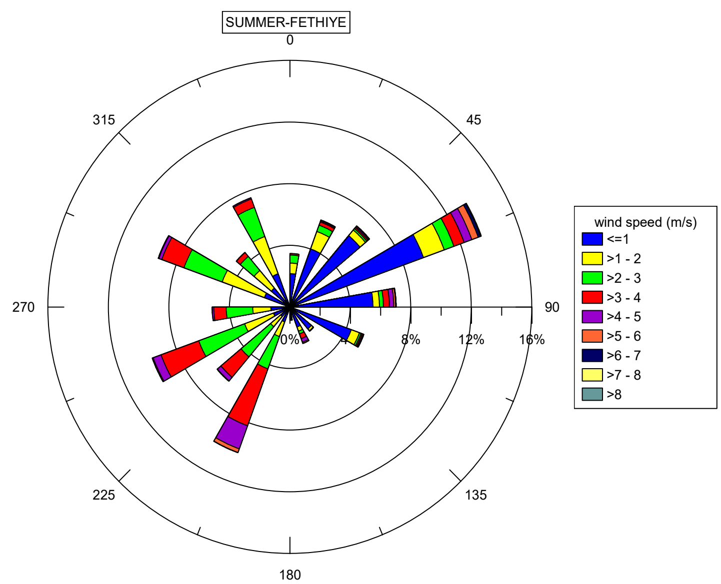


Figure 5.9. Fethiye Wind Rose - Summer (Akbaşoğlu, 2011)

All in all, the dominant directions are ENE and WSW for Fethiye Meteorological Station. For 16 directions, long-term wind analysis was performed by Akbaşoğlu, 2011. 41 years' data for Fethiye Meteorological Station was collected and with a wind speed interval of 0.5 m/s, wind blowing hours are tabularized as follows. Then, by using the wind blowing hours, long-term distribution graphs; long-term exceedance probability of wind speeds for all directions are drawn and shown in Figure 5.10, Figure 5.11, Figure 5.12 and Figure 5.13.

Wind speed (m/s)	N (hours)	NNE (hours)	NE (hours)	ENE (hours)	E (hours)	ESE (hours)	SE (hours)	SSE (hours)	S (hours)	SSW (hours)	SW (hours)	WSW (hours)	W (hours)	WNW (hours)	NW (hours)	NNW (hours)
0.0 - 0.5	2543	4247	8157	13112	13465	9767	5701	2801	2435	2172	1957	1861	1917	1726	1896	2062
0.5 - 1.0	2063	6460	8574	21074	11897	15079	6752	5555	2539	4443	2647	4982	3259	4437	2589	3316
1.0 - 1.5	855	2301	1524	5712	2228	4065	1342	1780	414	3564	1984	5372	2750	5177	2079	3182
1.5 - 2.0	588	954	563	2266	700	947	326	742	248	2880	2155	4379	2664	3880	1632	2437
2.0 - 2.5	480	675	372	1612	576	470	173	607	284	3307	3049	4788	2848	3519	1426	2096
2.5 - 3.0	318	473	284	1551	620	317	103	551	279	3862	3107	4762	2332	3061	924	1596
3.0 - 3.5	127	341	236	1401	607	259	54	572	231	4108	2205	3767	1498	2146	443	772
3.5 - 4.0	46	357	200	1532	765	222	51	590	236	4346	1300	2778	756	1227	167	351
4.0 - 4.5	15	190	158	1077	566	171	24	422	136	1981	468	1043	252	344	40	125
4.5 - 5.0	10	181	151	1052	536	139	24	330	86	962	186	531	101	156	15	59
5.0 - 5.5	3	132	130	876	402	118	22	191	54	435	88	223	31	64	11	44
5.5 - 6.0	5	141	95	873	368	102	8	137	39	244	37	136	20	33	2	26
6.0 - 6.5	2	91	77	572	195	67	13	73	22	92	12	66	7	20	3	22
6.5 - 7.0	1	48	46	391	150	52	17	45	19	53	8	45	3	7	2	11
7.0 - 7.5	3	52	28	263	97	28	6	28	9	35	4	28	3	6	0	9
7.5 - 8.0	4	26	27	187	80	24	6	10	2	15	7	10	0	4	0	4
8.0 - 8.5	4	23	16	112	47	16	5	9	1	16	1	12	1	2	1	5
8.5 -	1	19	11	114	57	36	10	10	2	10	4	7	1	2	0	3

Table 5.3. Fethiye Meteorological Station Wind Blowing Hours (Akbaşoğlu, 2011)

After tabularizing the Fethiye Meteorological Station wind blowing hours, long-term exceedance probabilities of wind speed for all directions are plotted in Akbaşoğlu, 2011 and listed in the figures below.

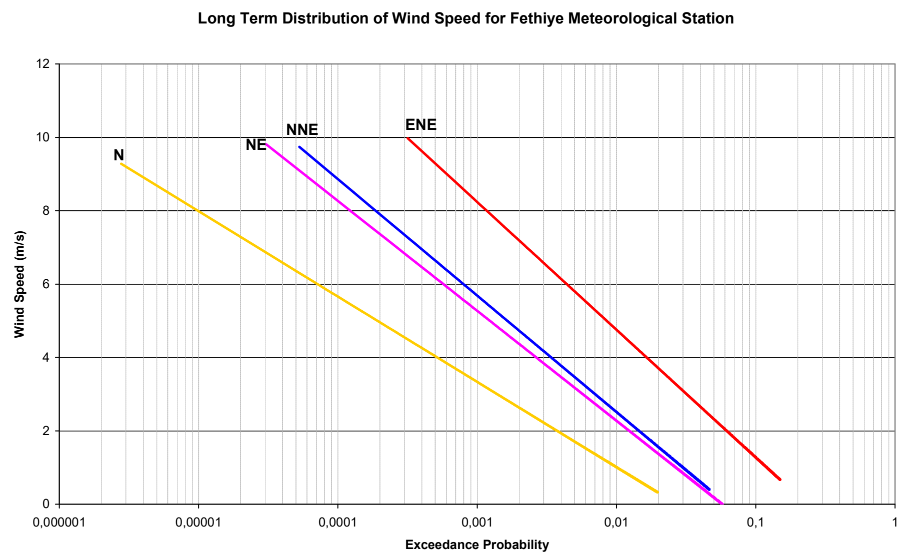


Figure 5.10. Long-term exceedance probability of wind speeds for N, NE, NNE, ENE directions for Fethiye Meteorological Station (Akbaşoğlu, 2011)

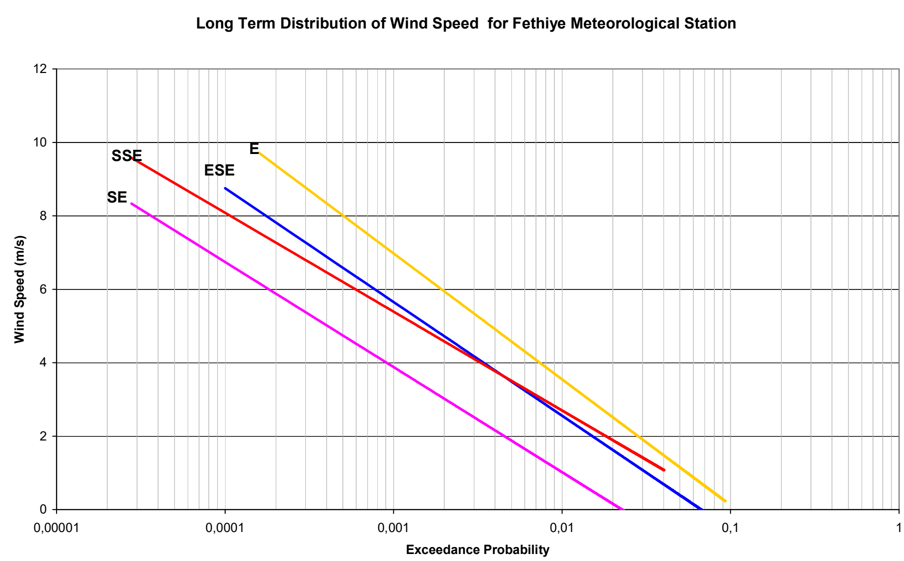


Figure 5.11. Long-term exceedance probability of wind speeds for SE, SSE, ESE, E directions for Fethiye Meteorological Station (Akbaşoğlu, 2011)

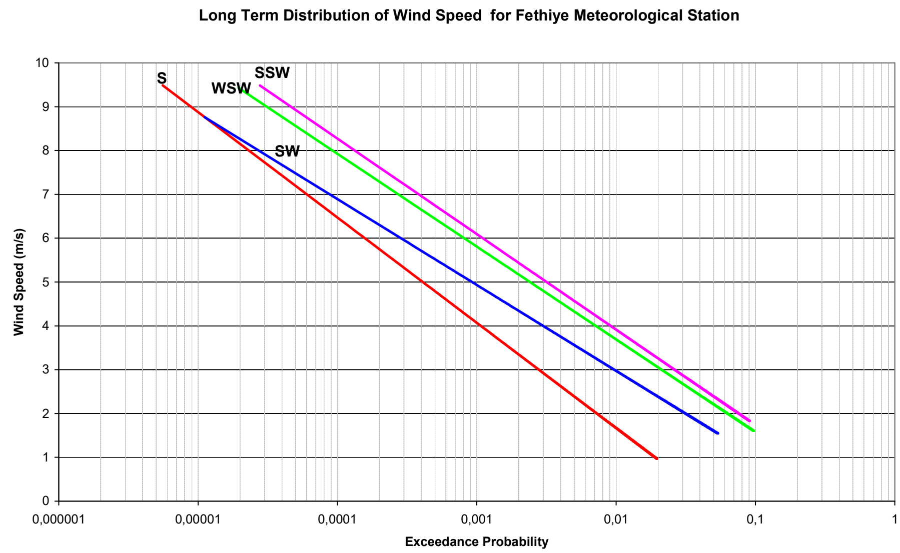


Figure 5.12. Long-term exceedance probability of wind speeds for S, SW, WSW, SSW directions for Fethiye Meteorological Station (Akbaşoğlu, 2011)

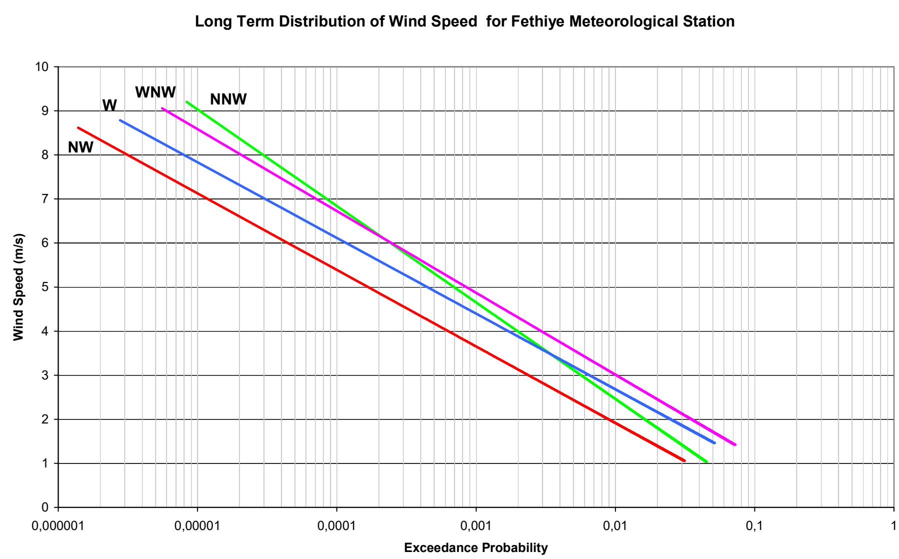


Figure 5.13. Long-term exceedance probability of wind speeds for NW, W, WNW, NNW directions for Fethiye Meteorological Station (Akbaşoğlu, 2011)

Using the long-term exceedance probability graphs, long-term probability equations are derived by Akbaşoğlu, 2011 and given in Table 5.4. Besides, the data from annual wind blowing durations of 10 hours and 100 hours are placed into the equations which calculate long term probability and for all directions varying wind speed values are obtained.

Table 5.4. Long-Term Probability Equations of 16 Wind Directions for Fethiye Meteorological Station (Akbaşoğlu, 2011)

Direction	Long-Term Probability Equation
N	S= -1.0101 ln(Q>S) – 3.6437
NNE	S= -1.3782 ln(Q>S) – 3.7178
NE	S= -1.5127 ln(Q>S) – 2.2104
ENE	S= -1.5127 ln(Q>S) – 2.2104
E	S= -1.4895 ln(Q>S) – 3.3129
ESE	S= -1.3453 ln(Q>S) – 3.6392
SE	S= -1.2430 ln(Q>S) – 4.7060
SSE	S= -1.1690 ln(Q>S) – 2.6848
S	S= -1.0432 ln(Q>S) – 3.1366
SSW	S= -0.9163 ln(Q>S) – 0.4439
SW	S= -0.8509 ln(Q>S) – 0.9454
WSW	S= -0.9196 ln(Q>S) – 0.5442
W	S= -0.7460 ln(Q>S) – 0.7555
WNW	S= -0.8066 ln(Q>S) – 0.7022
NW	S= -0.7547 ln(Q>S) – 1.5605
NNW	S= -0.9512 ln(Q>S) – 1.9187

Table 5.5. Wind Speeds for wind blowing durations of 10 hours and 100 hours per year for corresponding directions, Fethiye Meteorological Station (Akbaşoğlu, 2011)

Direction	Wind speed (m/s) for t=10 hours/year	Wind speed (m/s) for t=100 hours/year
N	3.2	0.9
NNE	5.5	2.3
NE	5.1	2.1
ENE	8	4.6
E	6.8	3.4

Direction	Wind speed (m/s) for t=10 hours/year	Wind speed (m/s) for t=100 hours/year
ESE	5.5	2.4
SE	3.7	0.9
SSE	5.2	2.5
S	3.9	1.5
SSW	6	3.8
SW	4.8	2.9
WSW	5.7	3.6
W	4.3	2.6
WNW	4.8	2.9
NW	3.6	1.8
NNW	4.5	2.3

The study of Akbaşoğlu which was carried out in 2011 indicates that the representative wind speed is 5 m/sec for 10 hours wind blowing duration in a year for Fethiye Bay.

5.4.2 Dalaman Meteorological Station

The model area covers the Dalaman Meteorological Station as well as Fethiye Meteorological Station. For the west side of the study area, the wind data of Dalaman Meteorological Station between 1987 and 2009 was used. The wind analysis is taken from the study of Akbaşoğlu, 2011. The meteorological station in Dalaman represents the wind characteristics of outer part of the Fethiye Bay. Yearly and monthly wind roses are shown in below figures. Figure 5.14 indicates that the principal wind directions for all year are S and NNW.

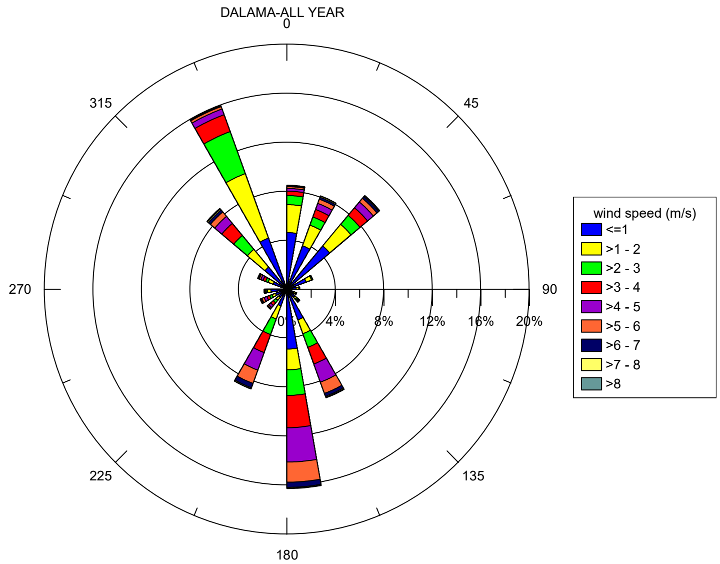


Figure 5.14. Dalaman Wind Rose - All year (Akbaşoğlu, 2011)

The wind speed and direction distribution of autumn is resembling the all year distribution. Namely, S and NNE are the dominant wind directions with nearly 16%.

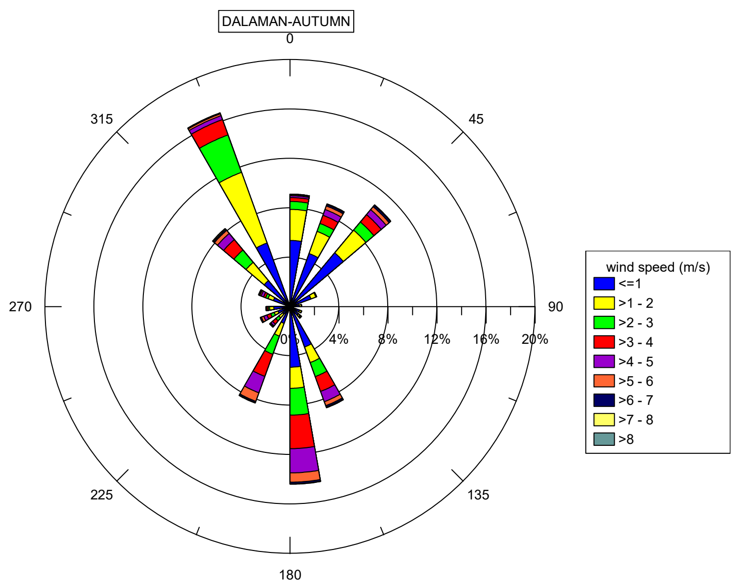


Figure 5.15. Dalaman Wind Rose - Autumn (Akbaşoğlu, 2011)

Remarkably, in the winter, more than 20% of the winds are blowing from NNE direction.

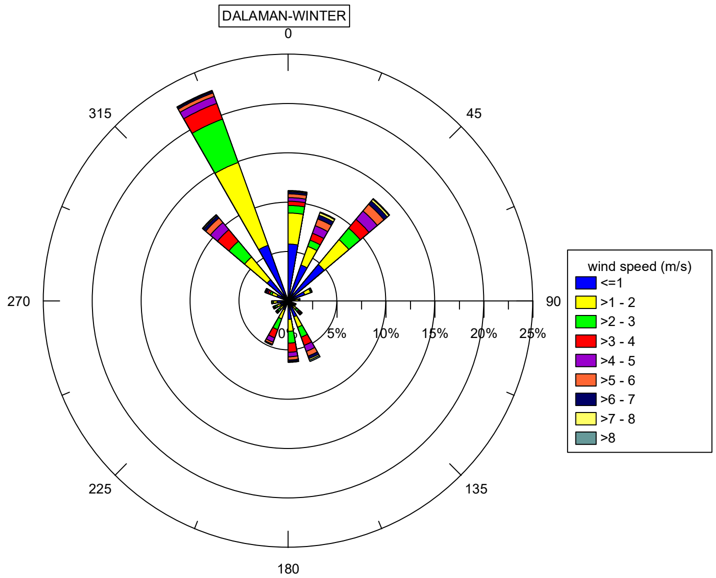


Figure 5.16. Dalaman Wind Rose - Winter (Akbaşoğlu, 2011)

Besides that, in the spring the dominant wind direction is S and NNE is the second dominant wind direction.

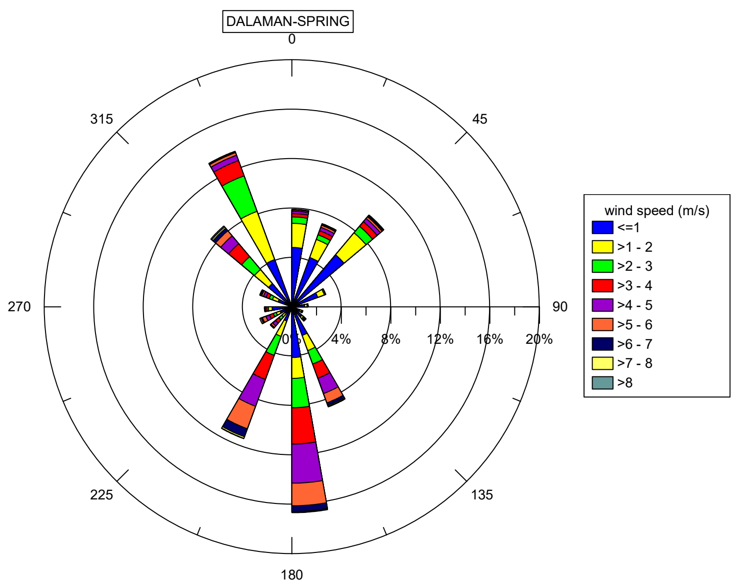


Figure 5.17. Dalaman Wind Rose - Spring (Akbaşoğlu, 2011)

From the analysis of summer wind distribution, S is dominant wind direction which means that nearly 30% of winds are blowing from this direction.

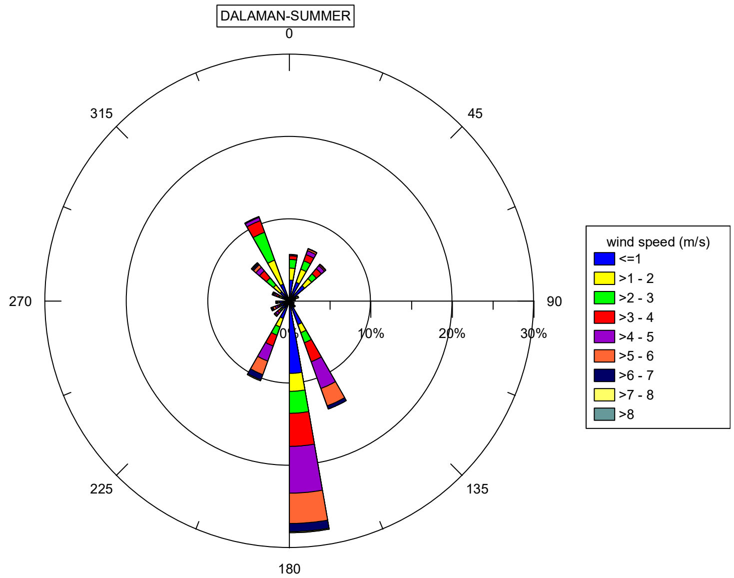


Figure 5.18. Dalaman Wind Rose - Summer (Akbaşoğlu, 2011)

The dominant wind direction for Fethiye and Dalaman Meteorological Station vary because of the topographical difference of their locations. Fethiye Meteorological Station is in the eastern part of the bay and confined with high hills and buildings. The seaward part is the only clearance that winds can blow from. On the other hand, Dalaman Meteorological Station is located near Dalaman Airport which is relatively plain compared to Fethiye Meteorological Station and the southern part is directly open to the Mediterranean Sea. In other words, topography dominates the wind directions. According to Dalaman Meteorological Station data, uttermost wind blowing directions are S and NNW.

For Dalaman Meteorological Station, wind blowing hours for 16 directions, 0.5 m/sec wind speed intervals and the 22-year period is collected and shown in Table 5.6 (Akbaşoğlu, 2011).

Long-term exceedance probability distributions of wind speeds are drawn and shown in Figure 5.19, Figure 5.20, Figure 5.21 and Figure 5.22. Long-term probability equations for each direction are derived by Akbaşoğlu, 2011 and given in Table 5.7.

To understand the wind climate for Dalaman, 10 hours and 100 hours wind blowing durations per year are placed into the long-term probability equations and wind speeds are obtained for all directions. As a result, the study of Akbaşoğlu (2011) points out that the representative wind speed is 5 m/sec for 10 hours wind blowing duration in a year for Dalaman.

Wind speed (m/s)	N (hours)	NNE (hours)	NE (hours)	ENE (hours)	E (hours)	ESE (hours)	SE (hours)	SSE (hours)	S (hours)	SSW (hours)	SW (hours)	WSW (hours)	W (hours)	WNW (hours)	NW (hours)	NNW (hours)
0.0 - 0.5	2453	1700	1860	890	483	422	668	2288	5165	1337	713	786	1018	786	1286	2157
0.5 - 1.0	5959	5164	6520	2176	898	664	876	2550	3730	1306	809	1028	1384	1401	3007	5922
1.0 - 1.5	2768	2236	2922	673	267	236	237	1178	1549	983	380	346	381	546	1899	5376
1.5 - 2.0	1378	1028	1249	191	139	105	155	1016	1533	1080	260	207	155	269	1538	4813
2.0 - 2.5	860	688	977	80	73	58	117	1069	1939	1269	240	187	106	214	1447	4054
2.5 - 3.0	495	604	781	45	22	33	96	1085	1872	1199	243	196	75	173	1239	2594
3.0 - 3.5	322	534	669	28	12	13	62	1086	1961	1205	197	187	65	170	1112	1516
3.5 - 4.0	336	650	812	11	9	19	68	1546	2830	1633	319	256	80	248	1223	1150
4.0 - 4.5	206	536	602	11	4	3	58	1486	2624	1448	207	224	35	193	798	567
4.5 - 5.0	191	423	525	4	1	5	52	1393	2473	1330	182	210	37	167	574	341
5.0 - 5.5	153	380	445	3	0	4	39	1089	1873	1271	134	215	33	143	519	240
5.5 - 6.0	115	289	265	0	1	1	32	689	1119	839	64	147	27	102	335	139
6.0 - 6.5	78	188	198	3	0	0	24	338	555	494	51	99	12	93	232	90
6.5 - 7.0	43	120	137	2	1	0	14	128	220	185	25	59	5	44	155	44
7.0 - 7.5	28	102	71	3	2	0	8	85	91	99	16	67	9	42	124	38
7.5 - 8.0	25	63	63	0	0	0	7	48	26	43	10	19	1	31	66	20
8.0 - 8.5	19	24	34	0	0	0	5	39	21	18	5	13	2	26	42	14
8.5 -	20	29	50	0	0	0	6	64	33	29	14	16	4	35	74	16

Table 5.6. Dalaman Meteorological Station Wind Blowing Hours (Akbaşoğlu, 2011)

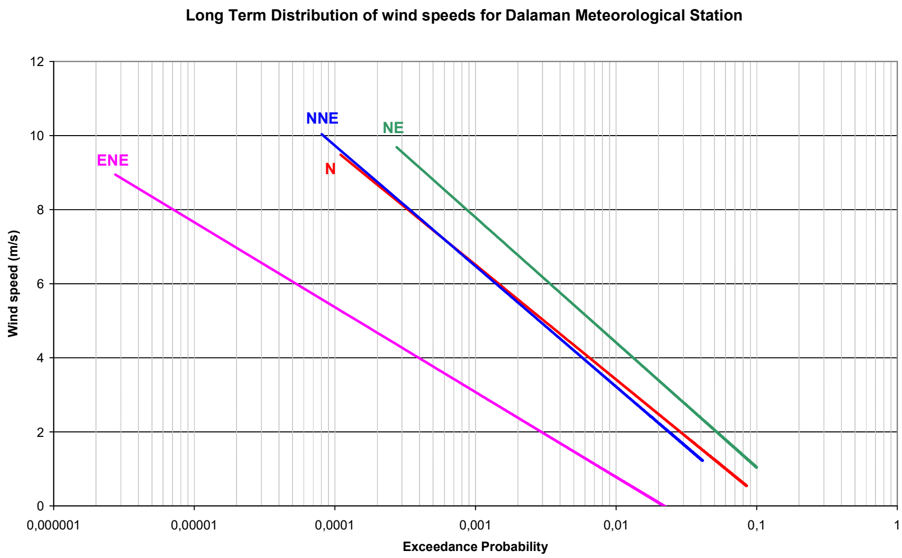


Figure 5.19. Long-term exceedance probability of wind speeds for ENE, N, NNE, NE directions for Dalaman Meteorological Station (Akbaşoğlu, 2011)

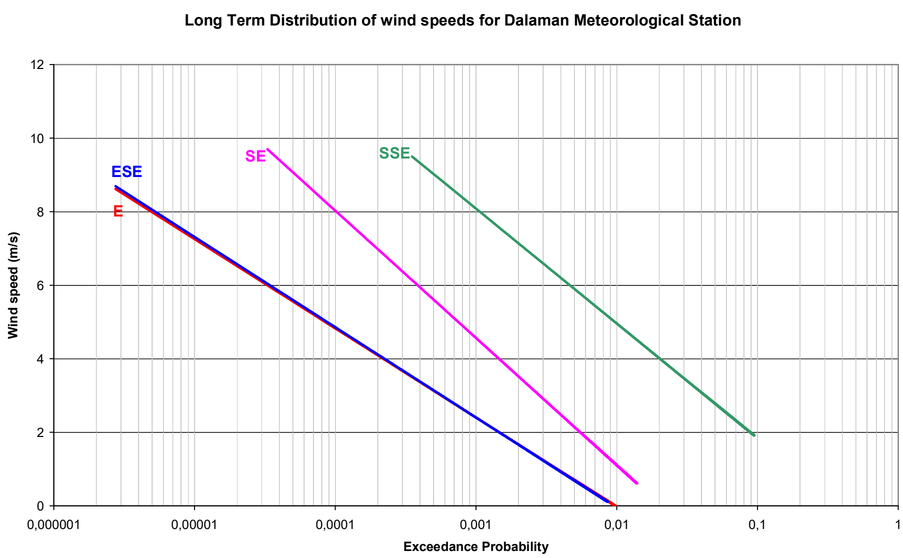


Figure 5.20. Long-term exceedance probability of wind speeds for E, ESE, SE, SSE directions for Dalaman Meteorological Station (Akbaşoğlu, 2011)

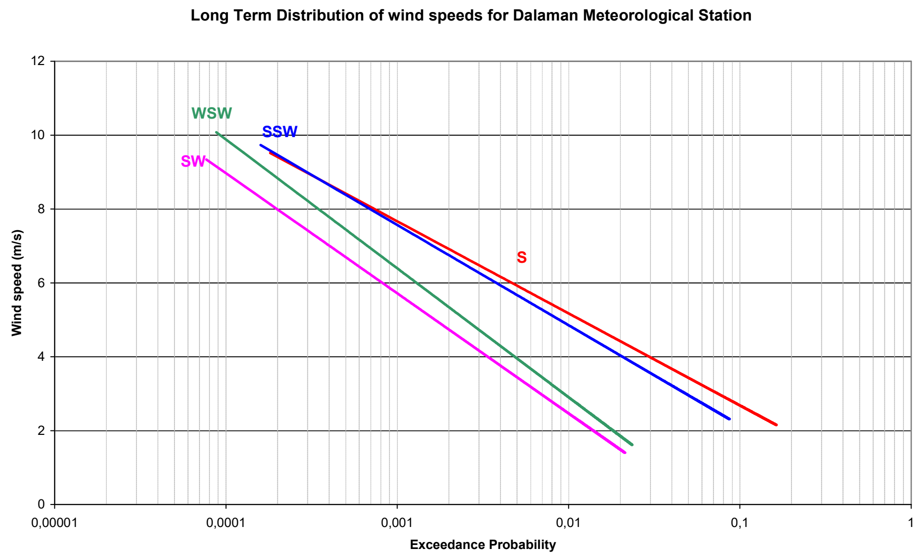


Figure 5.21. Long-term exceedance probability of wind speeds for SW, WSW, SSW, S directions for Dalaman Meteorological Station (Akbaşoğlu, 2011)

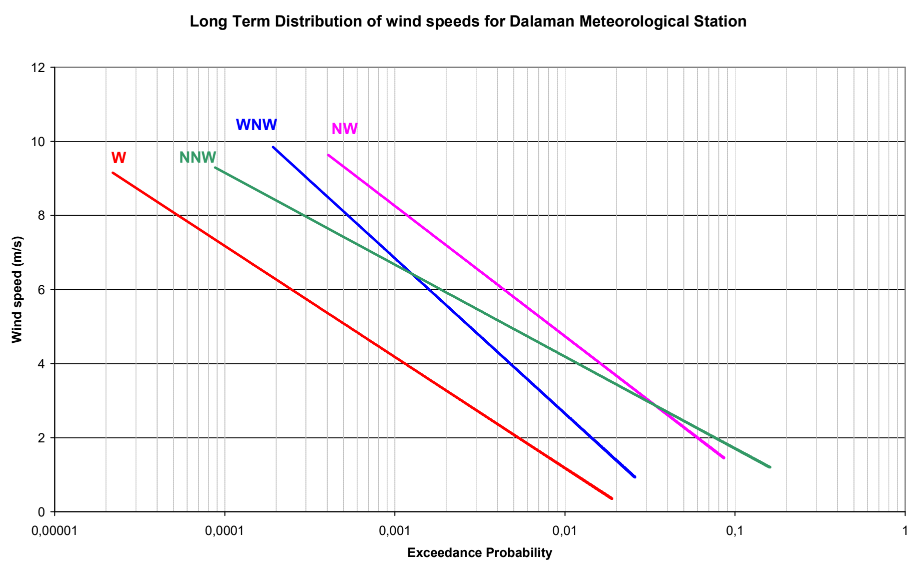


Figure 5.22. Long-term exceedance probability of wind speeds for W, NNW, WNW, NW directions for Dalaman Meteorological Station (Akbaşoğlu, 2011)

Table 5.7. Long-Term Probability Equations of 16 Wind Directions for Dalaman Meteorological Station (Akbaşoğlu, 2011)

Direction	Long-Term Probability Equation
N	S= -1.3453 ln(Q>S) – 2.7834
NNE	S= -1.4140 ln(Q>S) – 3.2929
NE	S= -1.4671 ln(Q>S) – 2.3448
ENE	S= -0.9963 ln(Q>S) – 3.8103
E	S= -1.0538 ln(Q>S) – 4.8800
ESE	S= -1.0662 ln(Q>S) – 4.9621
SE	S= -1.5038 ln(Q>S) – 5.8240
SSE	S= -1.3562 ln(Q>S) – 1.2872
S	S= -1.0828 ln(Q>S) + 0.1871
SSW	S= -1.1784 ln(Q>S) – 0.5729
SW	S= -1.4121 ln(Q>S) – 4.0371
WSW	S= -1.5158 ln(Q>S) – 4.0769
W	S= -1.3028 ln(Q>S) – 4.8228
WNW	S= -1.8206 ln(Q>S) – 5.7339
NW	S= -1.5284 ln(Q>S) – 2.3025
NNW	S= -1.0783 ln(Q>S) – 0.7788

Table 5.8. Wind Speeds for wind blowing durations of 10 hours and 100 hours for corresponding directions, Dalaman Meteorological Station (Akbaşoğlu, 2011)

Direction	Wind speed (m/s) for t=10 hours/year	Wind speed (m/s) for t=100 hours/year
N	6.3	3.2
NNE	6.3	3
NE	7.6	4.2
ENE	2.9	0.6
E	2.3	0
ESE	2.3	0
SE	4.4	0.9
SSE	7.9	4.8
S	7.5	5
SSW	7.4	4.7
SW	5.5	2.3
WSW	6.2	2.7

Direction	Wind speed (m/s) for t=10 hours/year	Wind speed (m/s) for t=100 hours/year
W	4	1
WNW	6.6	2.4
NW	8	4.5
NNW	6.5	4

By using the long-term exceedance probability distributions of 16 wind directions, yearly wind blowing hours for average wind speeds of 5 m/sec and 10 m/sec at both Fethiye and Dalaman Meteorological Stations are calculated and shown in Table 5.9.

According to the comparison of the wind blowing durations given in Table 5.9, four perpendicular directions; ENE, SSE, WSW and NNW are selected for the simulations. The wind speed is selected as 5 m/sec and 10 m/sec for a wind duration of 12 hours including 2 hours of ramping of the wind. Since the occurrence duration of the wind speed 10 m/sec is quite low, the results of these simulations are used for comparisons.

Table 5.9. Yearly wind blowing hours according to Fethiye and Dalaman Meteorological Stations for each direction

	Fethiye Meteorological Station (hour/year)		Dalaman Meteorological Station (hour/year)	
Direction	Wind Speed = 5 m/sec	Wind Speed = 10 m/sec	Wind Speed = 5 m/sec	Wind Speed = 10 m/sec
N	1.8	0.0	26.28	0.7
NNE	14.9	0.4	26.28	0.7
NE	11.4	0.2	61.32	2.0
ENE	74.5	2.7	1.31	0.0
E	33.3	1.3	0.79	0.0
ESE	14.0	0.4	0.79	0.0
SE	3.5	0.0	7.01	0.2
SSE	13.1	0.2	87.60	2.2
S	3.5	0.0	105.12	1.1
SSW	27.2	0.1	78.84	1.2
SW	7.9	0.0	14.02	0.4
WSW	21.9	0.1	21.90	0.8
W	3.9	0.0	4.64	0.1
WNW	7.5	0.0	23.65	1.6
NW	1.5	0.0	74.46	0.0
NNW	6.1	0.0	41.17	0.4

CHAPTER 6

CIRCULATION MODELING OF FETHIYE AND GOCEK BAYS

The Mediterranean Sea has always been a significant sea in terms of history and geography. It is a semi-enclosed sea, in other words, the oceanic system is nearly isolated. The reason behind this phenomenon is that temperature, salinity and other properties related to the quality of water are exchanged only via the Gibraltar Strait with the Atlantic Ocean. Robinson et al. (2001) explained the Mediterranean water circulation with various factors such as; wind force, exchange of water through straits, buoyancy flux caused by freshwater and heat flux at the sea surface.

The water circulation in Fethiye and Göcek Bay is an important issue that needs a special attention. As expected, water quality inside the bay is highly affected by this phenomenon. For this purpose, in the context of this thesis, a three-dimensional numerical model, MIKE 3 Flow Model Flexible Mesh – Hydrodynamic Module is set up so as to investigate and enhance the water exchange between bays and offshore.

Setting up a reliable model requires a well-formed mesh. As a first step, a model area is determined. Then, the next three main steps of modeling which are determining the adequate resolution of bathymetry and computational grid size and defining the land/open boundaries are performed (Figure 6.1). The final step is to divide the area into smaller elements. Smaller elements enable results with high accuracy. However, there is a limitation about the resolution of mesh; if mesh resolution of the model is increased, the computational time is also increased. At this point, optimization between the element size and computational time must be performed.

In this study, Göcek and Fethiye Bay is selected for the model area and for the model domain the most suitable mesh size by considering large in deep water and small in shallow area is applied.

MIKE 3 Flow Model FM is based on flexible mesh approach (DHI, 2017). This means, in horizontal domain, an unstructured mesh is used, however, in vertical domain, a structured mesh is used. In the present study, the horizontal mesh is adjusted by selecting an optimum mesh size for the domain. For the deep-water mesh resolution is low, however, in shallow water high resolution is aimed.

In the horizontal domain, the bathymetry has 30139 nodes and 52138 elements. On the other hand, the vertical domain is divided into 5 equidistant sigma layers which are minimum sufficient layers to understand the vertical distribution of the velocities at the channels. In Figure 6.2, a water column with a depth of 50 meters is divided into 5 equidistant layers is shown as an example and if equidistant sigma layer is applied, each layer will have a thickness of 10 meters.

In terms of the boundary definitions; the study domain includes one land boundary and two open boundaries: South and West. The horizontal mesh generated for the study domain is shown in Figure 6.3.

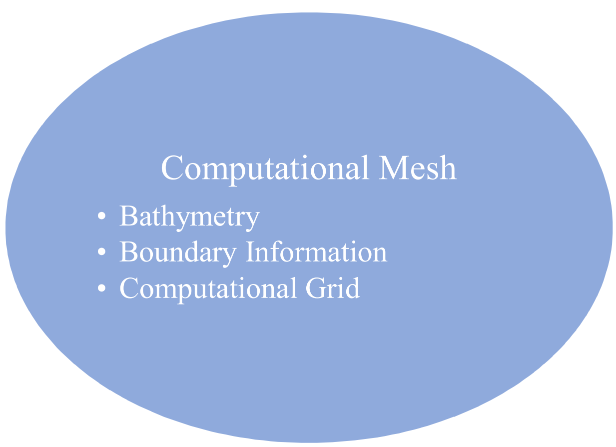


Figure 6.1. Computational mesh

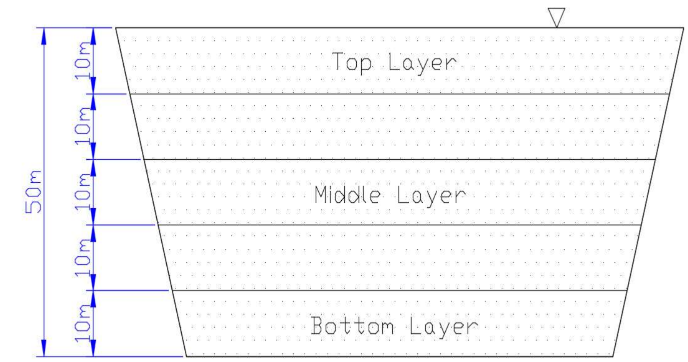


Figure 6.2. Vertical domain

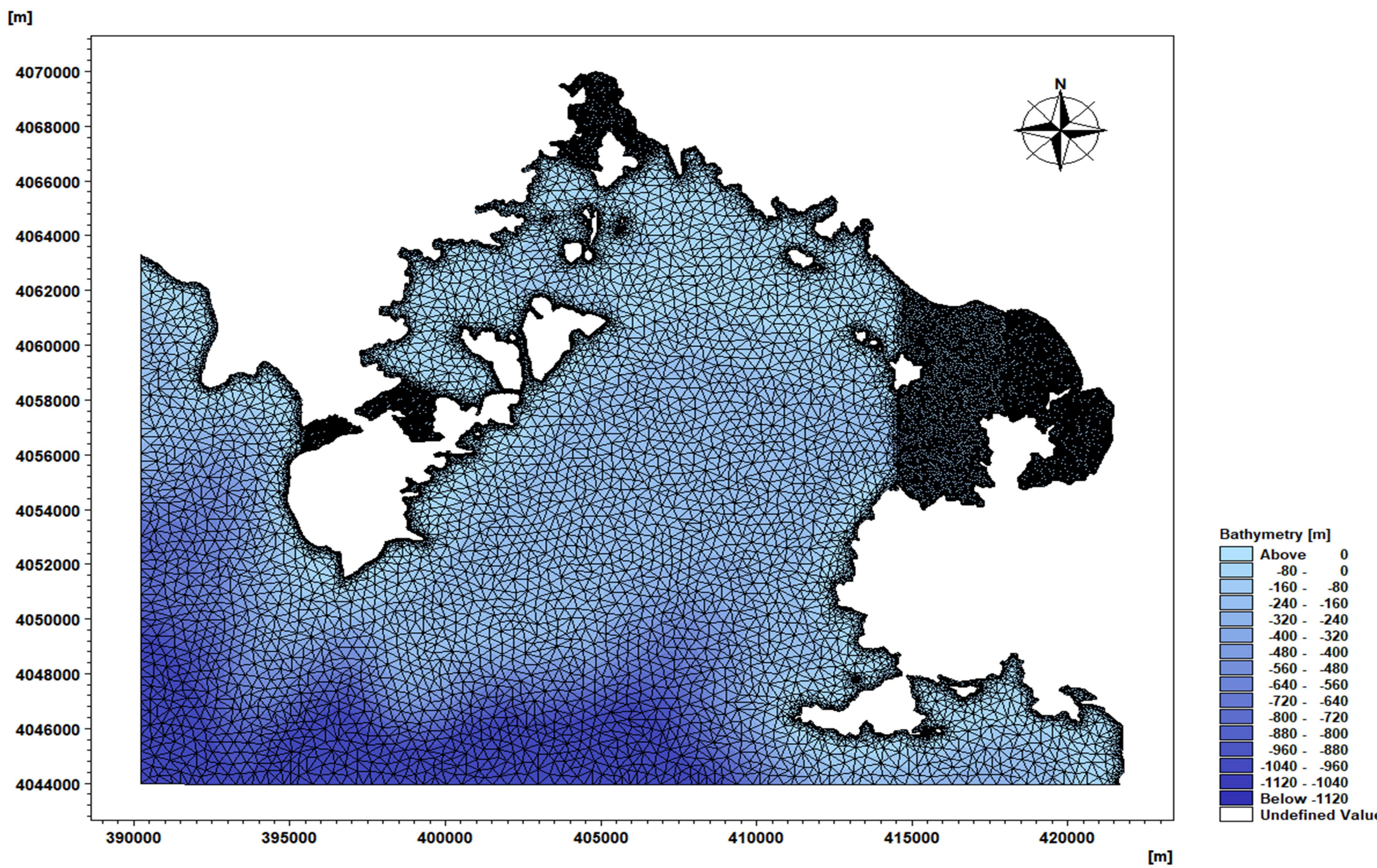


Figure 6.3. Mesh for Fethiye and Göcek Bay

In Göcek and Fethiye Bay, there are 3 main external forcing governing the circulation in the region. Those can be listed as;

- Coriolis Forcing
- Tidal Forcing
- Wind Forcing

These factors are applied one by one to the model to see their individual effect on water exchange in Göcek and Fethiye Bays.

In order to have a better understanding and interpret the computational results, the area of the study is detached and studied as four different sub areas. The first region, Fethiye Bay, the eastern part of the study area protected by the Şövalye Island is one of the most developed coastal areas in Turkey and it is highly demanded being located on the Mediterranean Sea. Secondly, Göcek Bay, which is located in the northern part of the study area, is partly protected by Göcek Island. Thirdly, the Dalaman-Göcek Bays should be investigated because there are many large and small islands around the bay which may affect the circulation and water exchange. Lastly, Hamam Bay is a sheltered spot near the Kapıdağ Peninsula is and this bay should also be examined in detail.

By using ArcGIS, surface area and volumetric calculations of Fethiye, Göcek and Dalaman Bays are done. According to the calculations, the total water volume in Fethiye Bay and Göcek Bay are obtained as 68 million m^3 and 133 million m^3, respectively. Dalaman-Göcek Bays have a total water volume of 1.150 billion m^3. In Figure 6.4, Figure 6.5 and Figure 6.6, the section that is used for total water area and volume calculation using ArcGIS are shown for Fethiye, Göcek and Dalaman bays, respectively.

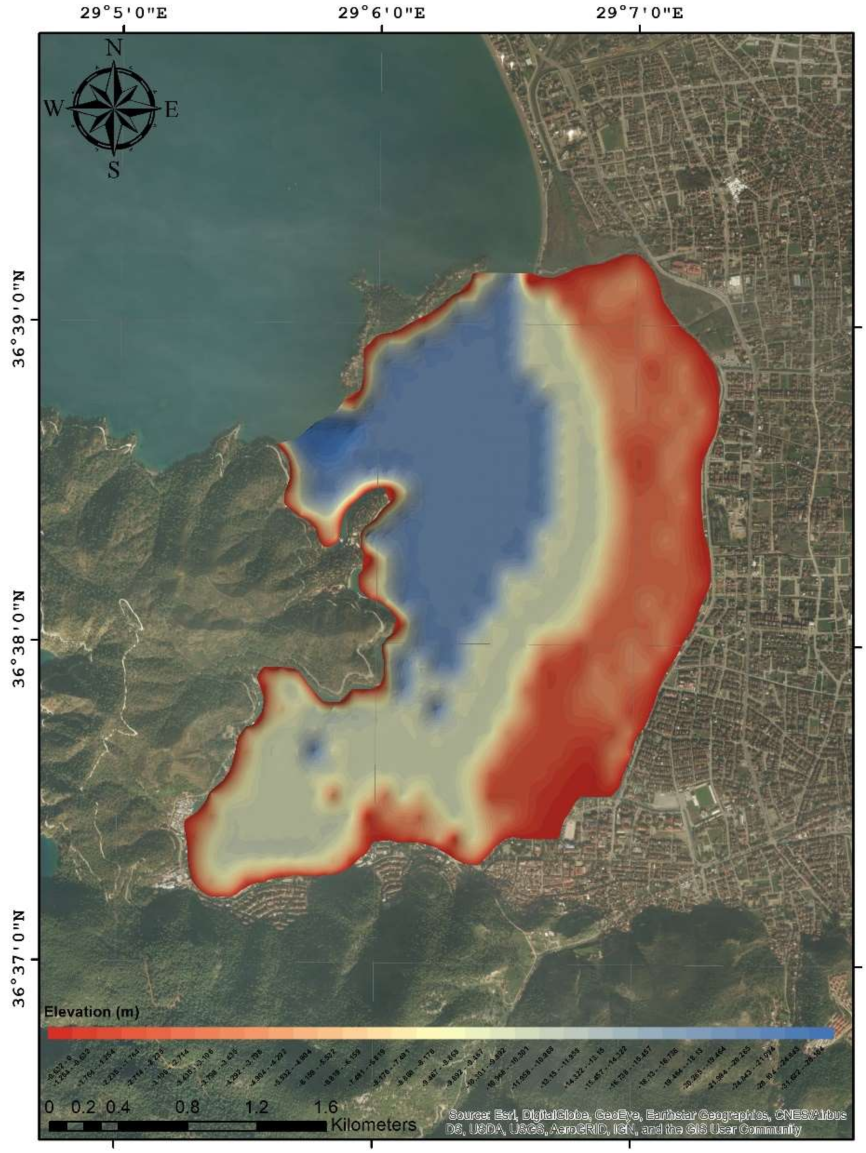


Figure 6.4. Computation Area and Depth Distribution in Fethiye Bay used for Calculation of Water Volume by ArcGIS

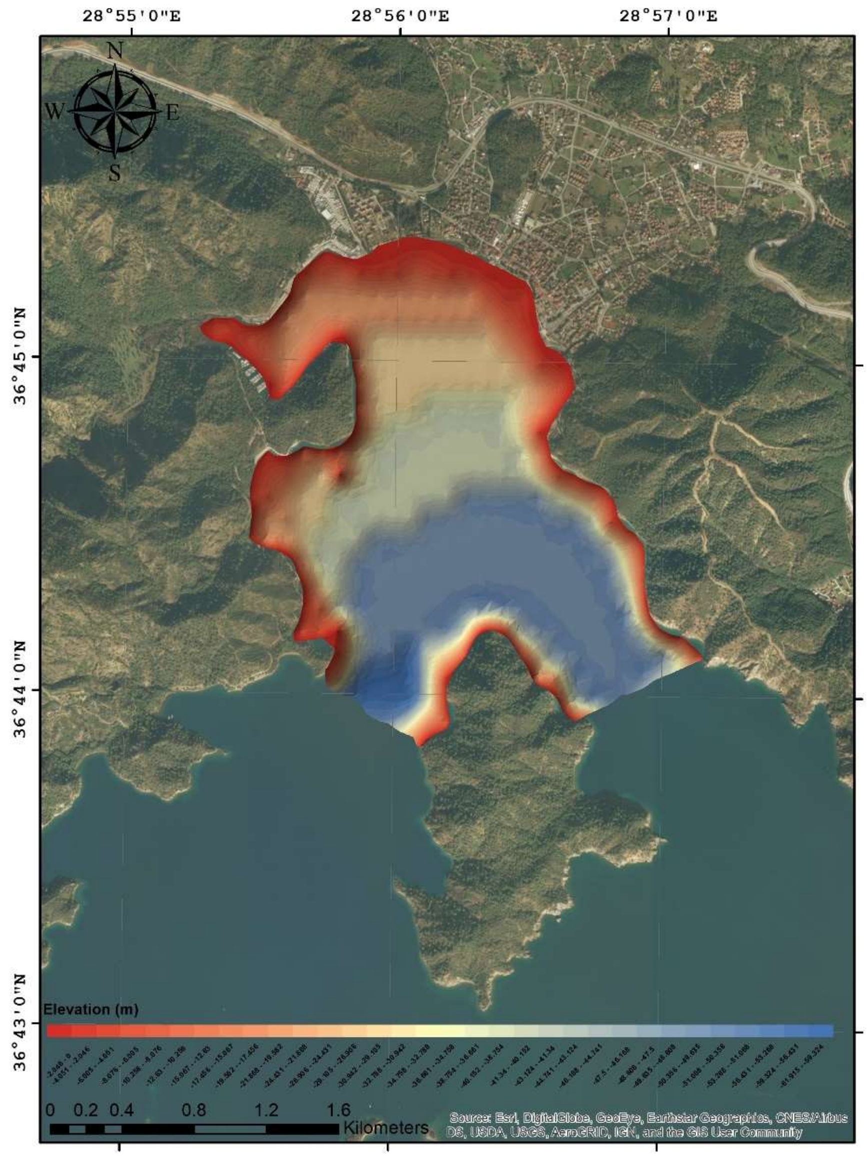


Figure 6.5. Computation Area and Depth Distribution in Göcek Bay used for Calculation of Water Volume by ArcGIS

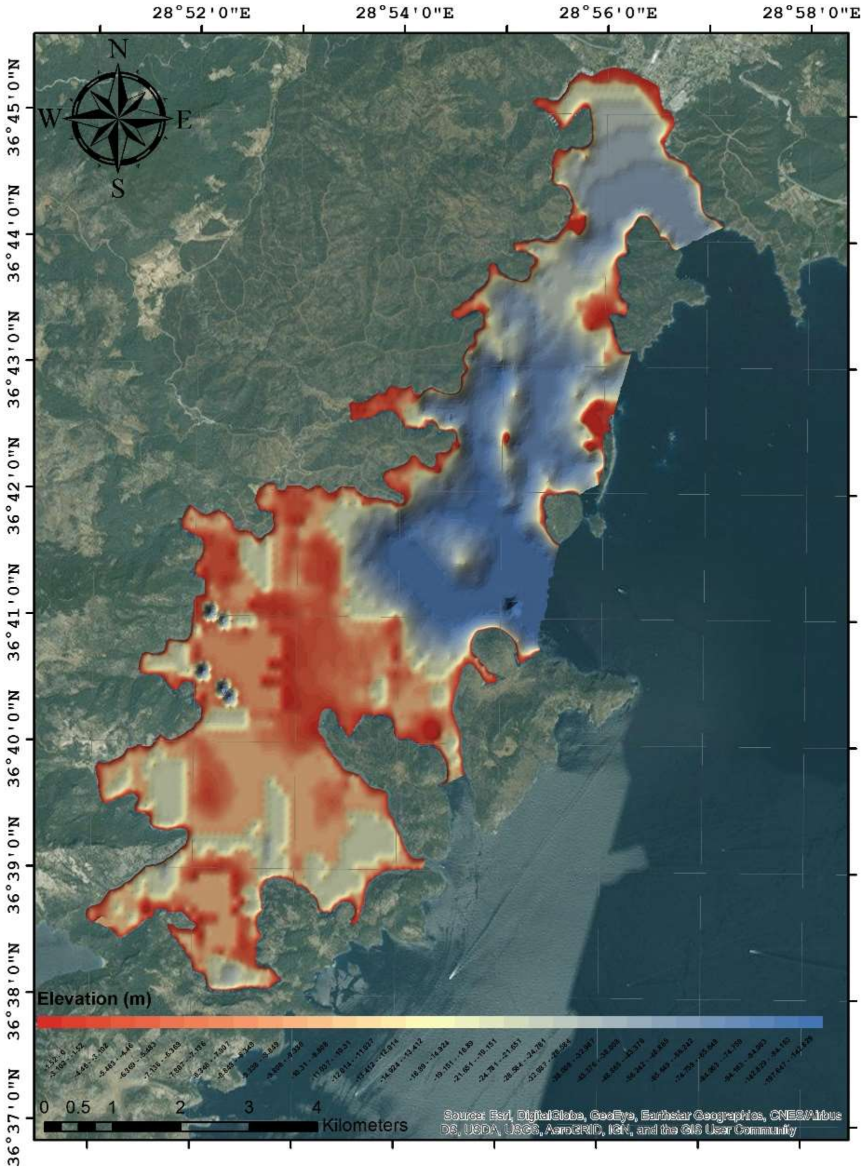


Figure 6.6. Computation Area and Depth Distribution in Dalaman-Göcek Bays used for Calculation of Water Volume by ArcGIS

There are 9 straits (channels) connecting Fethiye, Göcek and Dalaman-Göcek Bays to the offshore region. At the center of each strait, a numerical gauge point is placed. The straits and numerical gauge points are shown in Figure 6.7 and the coordinates of the numerical gauge points are given in Table 6.1. The number of numerical gauge point also represents the strait of the respective gauge point.

The numerical Gauge Point 1 and 2 have importance because they are located in the entrance channels of the Fethiye Bay and controls the water exchange of Fethiye Bay with the offshore region. Similarly, the numerical Gauge Point 3 and 4 are placed in the straits of Göcek Bay controls the water exchange of Göcek Bay with the offshore area. Therefore, computed volumetric discharge (m^3) going in and going out of the bays can also be calculated by using the average current speed and cross-sectional area of the channel.

The other numerical gauge points (5, 6, 7, 8, 9) are located in the straits between the islands surrounding Dalaman-Göcek Bays and connecting the bays with the offshore region. The flow pattern along these channels controls the water exchange of Dalaman-Göcek Bays with offshore. Additional numerical gauge points (10 and 11) are located to monitor the current circulation near the narrowest part of Kapıdağ Peninsula.

The net (accumulated) discharge (m^3) (positive/negative) at each channel (at each numerical gauge point) throughout the simulation are computed by MIKE 3 HD FM. There is a discharge output already included in the model which calculates the discharges that pass through a specified cross-section by using the entire water depth of the cross-section.

In this study, several simulations were performed to understand circulation and water exchange in the study domain by applying different forcing mechanisms (Coriolis, tidal wave and wind forces) separately. After each simulation is completed, the polar scatter plots of current speed and direction at each channel are plotted and presented in the following with discussions.

The circulation in Fethiye and Dalaman-Göcek Bays are simulated by MIKE 3 using different inputs as forcing (Coriolis, tide, and wind) effects and the results are given in the following sections.

At the end of each simulation, a summary table showing the computed volumetric discharge (m^3), flow direction, net volumetric discharge (m^3) at the gauge points 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11 between the channels and total volumes and percentages of water exchange in Fethiye, Göcek and Dalaman-Göcek Bays under each forcing mechanism are presented with comparisons and discussions.

For Gauge Point 1 and 2, positive (+) discharge means a water input occur into the Fethiye Bay. Similarly, for Gauge Point 3 and 4, positive (+) discharge represents water input to Göcek Bay. For Gauge Points 5, 6, 7, 8 and 9, positive (+) discharge means there is a water input to Dalaman-Göcek Bays. The simulations are performed using the present straits.

In order to observe the movement of water at specified time intervals, the circulation and current patterns at the top layer (5th layer) for both Fethiye Bay and Göcek Bay are drawn on a vector map and presented at the Appendix A to Appendix J. For Coriolis and tidal forcing, the circulation patterns at 8th, 16th and 24th hours are shown. However, for the wind forcing, the circulation patterns at 4th, 8th and 12th hours are shown.

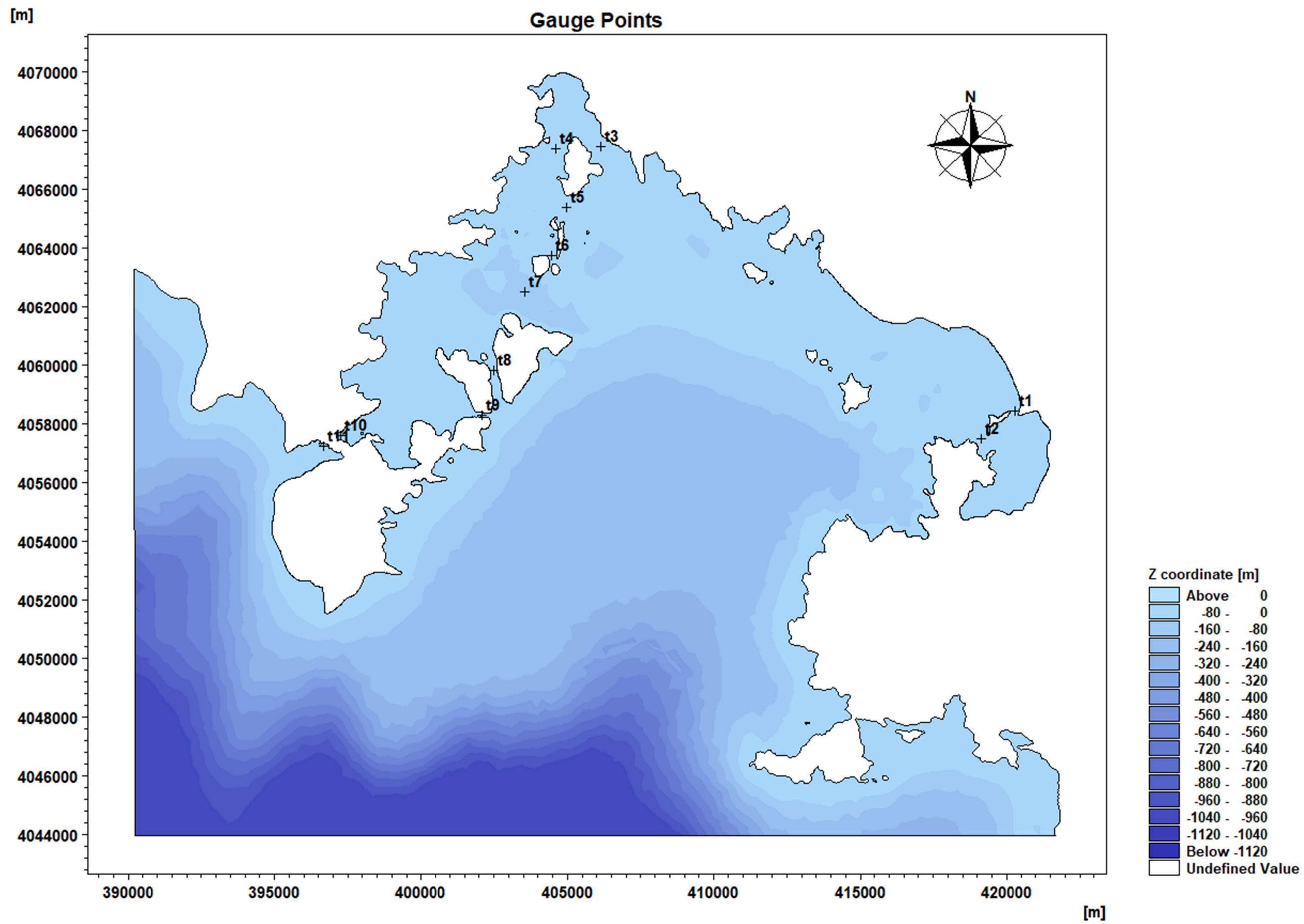


Figure 6.7. Locations of numerical gauge points

Gauge Point	TM 30 3° - WGS 84		LONGITUDE	LATITUDE	Water Depth at Gauge Points (m)	Cross Sectional Area (m^2)	Location Name
	X (m)	Y (m)	E	N			
1	420278.9082	4058431.978	29.1084	36.6535	11.4	2233	Fethiye Bay
2	419143.3193	4057495.498	29.0958	36.645	28.8	7536	
3	406122.6291	4067476.782	28.949	36.7337	50	26768	Göcek Bay
4	404603.2158	4067379.438	28.932	36.7327	59	26748	
5	404981.6936	4065403.794	28.9365	36.7149	49	23051	Dalaman-Göcek Bays
6	404462.6919	4063743.726	28.9309	36.6999	25.2	5252	
7	403566.5751	4062508.011	28.921	36.6887	100	131916	
8	402489.6311	4059810.077	28.9093	36.6643	15	2628	
9	402108.9372	4058313.942	28.9053	36.6508	11.8	1356	
10	397253.0409	4057603.903	28.851	36.6439	-	-	Kapıdağ Peninsula
11	396684.935	4057232.508	28.8447	36.6405	-	-	

Table 6.1. Coordinates of the numerical gauge points

6.1 Coriolis Effect

Because of the Earth's rotation around its own axis, air enclosing the earth is deflected, that is to say, in air deviates to the west along the equator. In the Northern Hemisphere, the air moves in clockwise circulation and in the Southern Hemisphere the air moves in the counterclockwise direction (Figure 6.8). Therefore, the air motion generates complex global wind patterns. Similarly, the ocean surface moves west at equator faster than the movement at higher latitudes. This difference in the water motion is called "Coriolis Effect". Coriolis force is directly related to geographic latitude, the motion of Earth and motion of the object.

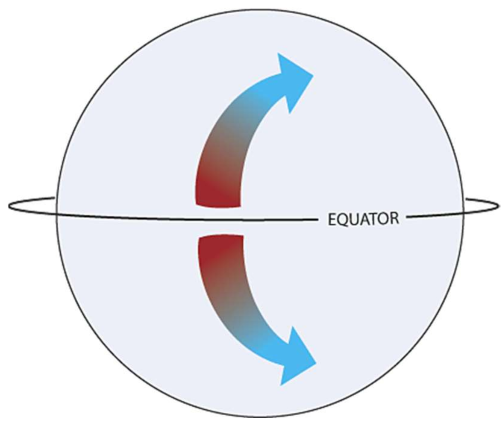


Figure 6.8. The Coriolis effect on air and water (http://oceanservice.noaa.gov/education/kits/currents/media/supp_cur05b.html)

So as to understand the consequence of Coriolis forcing on the water circulation in Fethiye and Göcek Bays, the model is utilized by inputting only the Coriolis condition (without wind and tide) for two scenarios separately. The Coriolis force is calculated based on the geographical information given in the model with a simulation period of 24-hours.

The polar scatter plots of computed current speed and current direction at the middle layer (3rd layer from bottom) at nine numerical gauge points in the study domain are shown in Figure 6.9 to Figure 6.13. The results at each numerical gauge point are given for only 3rd layer (middle layer), since there is no significant change between the current speeds and directions in upper, middle and bottom layers at all the gauge points. The same condition is also valid for tide and wind simulations at all gauge points. As an example, in order to show that there is a little variation of current speeds and directions in five layers, the polar plots only at Gauge Point-1 are provided for the wind simulation.

The accumulated discharges that pass through these cross-sections and flow directions for the total simulation period are given in Table 6.2. The summary of the calculated total volume of water entered or left Fethiye, Göcek and Dalaman-Göcek Bays during 24-hour under only Coriolis force are also given in Table 6.3 with percentages.

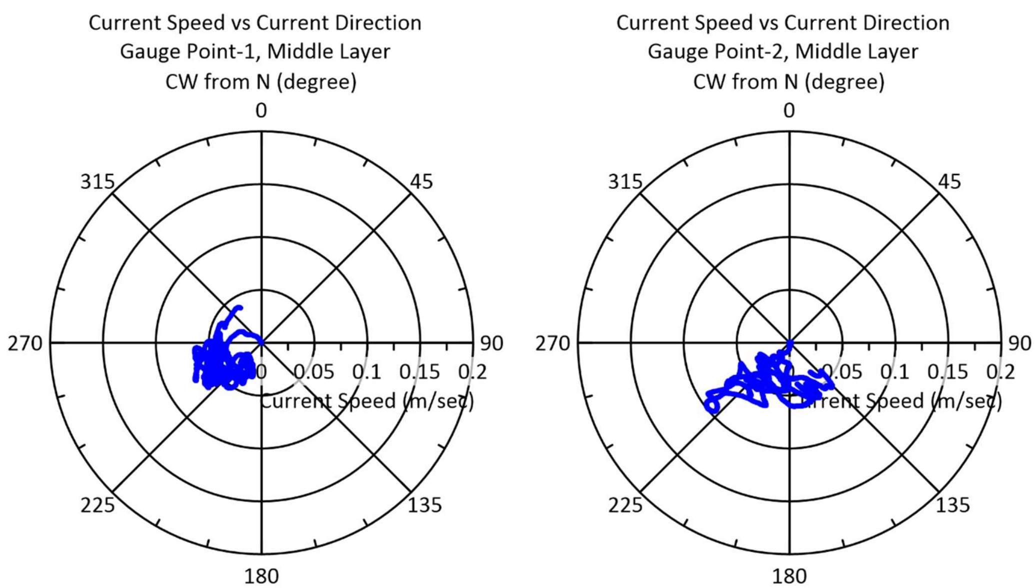


Figure 6.9. Current speed and current direction at Gauge Point 1 and Gauge Point 2 (24-hours simulation of Coriolis force only)

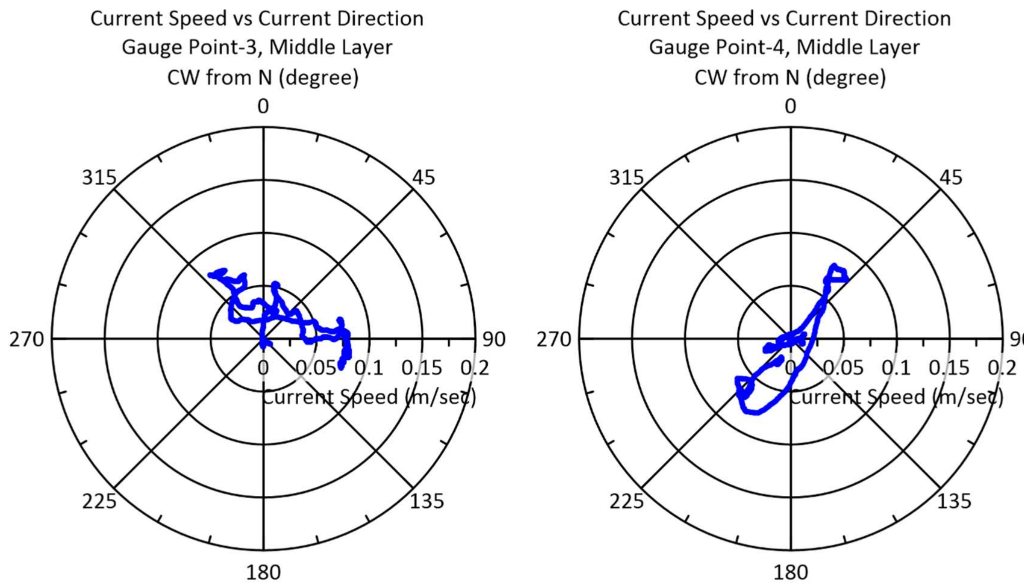


Figure 6.10. Current speed and current direction at Gauge Point 3 and Gauge Point 4 (24-hours simulation of Coriolis force only)

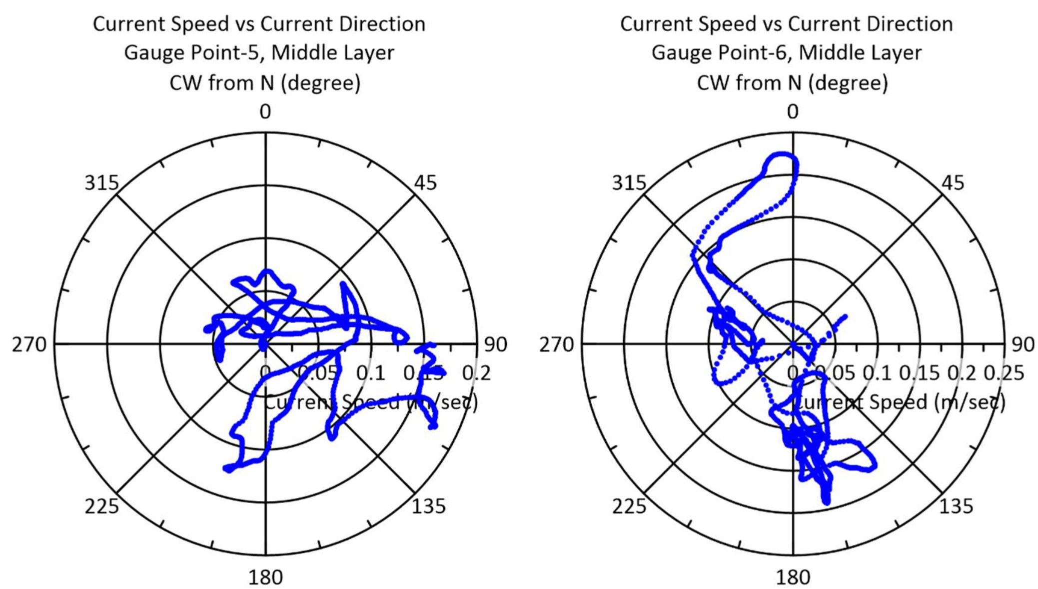
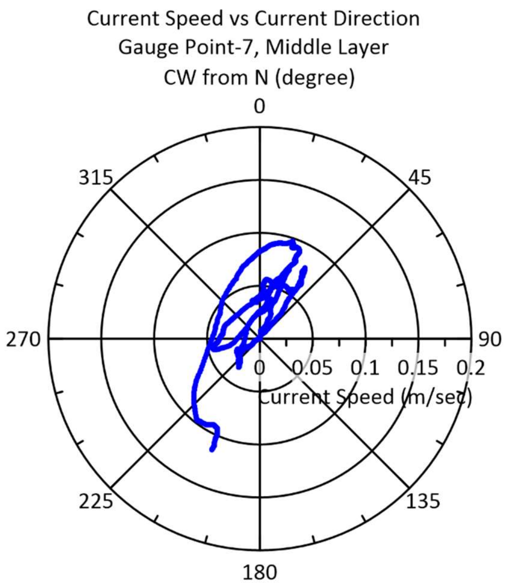


Figure 6.11. Current speed and current direction at Gauge Point 5 and Gauge Point 6 (24-hours simulation of Coriolis force only)



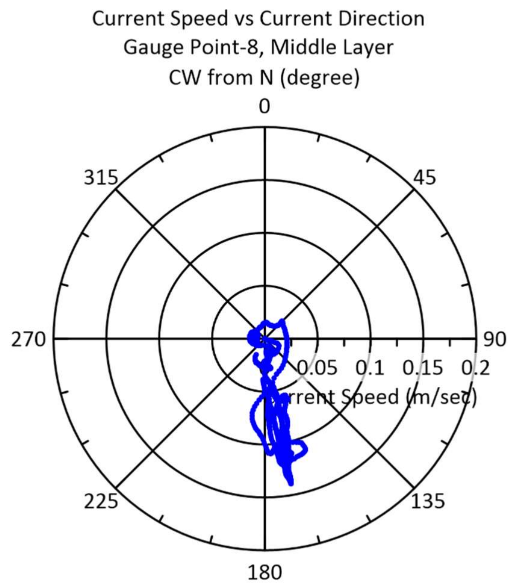


Figure 6.12. Current speed and current direction at Gauge Point 7 and Gauge Point 8 (24-hours simulation of Coriolis force only)

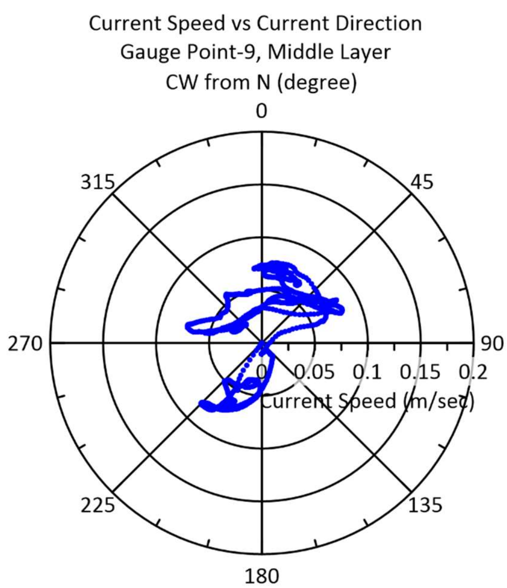


Figure 6.13. Current speed and current direction at Gauge Point 9 (24-hours simulation of Coriolis force only)

Table 6.2. Computed volumetric discharges during 24-hours Coriolis forcing only

Gauge Point	Water Depth at Gauge Points (m)	Cross Sectional Area (m^2)	Volumetric Discharge (10^6 m^3)	Flow Direction	Location Name
1	11.4	2233	-2.04	Outflow	Fethiye Bay
2	28.8	7536	2.08	Inflow	
3	50.0	26768	3.35	Inflow	Göcek Bay
4	59.0	26748	-3.35	Outflow	
5	49.0	23051	-2.46	Outflow	Dalaman-Göcek Bays
6	25.2	5252	0.16	Inflow	
7	100.0	131916	-0.16	Outflow	
8	15.0	2628	-0.80	Outflow	
9	11.8	1356	-0.07	Outflow	

Table 6.3. Total water exchange volumes and percentages in Fethiye, Göcek and Dalaman-Göcek Bays

Name of the Bay	Total volume of water in the bay (10^6 m^3)	Total volume of water **entered** the bay (10^6 m^3)	Total volume of water **left** the bay (10^6 m^3)	% Exchanged Volume
Fethiye	67.65	2.08	-2.04	3.04
Göcek	132.73	3.35	-3.35	2.52
Dalaman - Göcek	1147.58	3.51	-3.50	0.31

It is seen from the figures that, when only Coriolis force is existent in the study region, the mean current speeds at the entrance channels of Fethiye Bay vary between 0 and 10 cm/sec. The average current speed at Gauge Point 1 is higher than at Gauge Point 2. Because the cross-sectional area at the Gauge Point 1 is smaller than the cross-sectional area at Gauge Point 2. The mean direction of the current at these gauge points are in reverse direction which means Coriolis force causes water input to Fethiye Bay at the South-West entrance of Şövalye Island and water output from Fethiye Bay at the North-East entrance of Şövalye Island. The discharge that passes through these channels is also calculated. The total volume of water exchanged during Coriolis force is 2 million m^3 (~3 % of the total water volume in Fethiye Bay).

There are two channels on each side of Göcek Island and these channels enable currents to follow these paths (Gauge Point 3 and Gauge Point 4). If there is only Coriolis force acting on the bay, the mean current speeds at the entrance channels Göcek Bay vary between 0 and 10 cm/sec. As seen from Figure 6.10, Coriolis force pushes water into the Göcek Bay from the East of Göcek Island and pushes water out of Göcek Bay from the West of Göcek Island. At the end of a 24-hour simulation, approximately 3.4 million m^3 (~2.52 % of the total water volume in Göcek Bay) water enters Göcek Bay from East of Göcek Island, circulates inside the bay and similar amount of water goes out from West of Göcek Island.

Gauge Points 5, 6, 7, 8, 9 are located in the channels connecting Dalaman-Göcek Bays and open sea. The cross-sectional areas of these straits are different. The current speed is related to the cross-sectional area of the straits. If the gaps are narrow, the current speeds increase, and current flows along the channel axis. The orientation of the straits between the islands is also important. For example, if straits lay in North-South direction, the main directions for the currents can be North or South. Similar condition holds for the East-West direction.

Coriolis force pushes 2.4 million m^3 of water out of Dalaman-Göcek Bays along the channel 5 during 24-hours. Gauge Point 6 is placed between one of the narrowest channels of Yassıca Islands. Under the effect of Coriolis force, 0.16 million m^3 water entered the bay from channel 6. 0.15 million m^3 of water left Dalaman-Göcek Bays from channel 7 due to the Coriolis force acting on the study domain. As it is expected, in channel 8, the currents are directed to South which means there is an outward flow from the Dalaman-Göcek Bays to the offshore region. By the end of 24-hours, 0.8 million m^3 water is discharged from the bay in channel 8. It is also seen from Figure 6.13 that the water in Dalaman-Göcek Bays is discharged out of the bay with an amount of 0.07 million m^3 from channel 9 during 24 hours of Coriolis forcing only.

Near Kapıdağ Peninsula, two measurement points are selected. Due to the geographical location of these two-gauge points, if there exists only Coriolis force, Gauge Point 10 and 11, which are located in a sheltered bay, have very low current speeds. Therefore, according to the simulation results, Coriolis is not effective at inner points of Dalaman-Göcek Bays.

As seen from Table 6.3, the total volume of exchanged water is computed as 3.5 million m^3 (0.31 % of the total volume of water) in Dalaman-Göcek Bays during 24-hour simulation of Coriolis forcing.

As the summary, the results of the simulation indicate that Coriolis forcing has a weak contribution to water exchange and circulation in Fethiye Bay, Göcek Bay and Dalaman-Göcek Bays. There must be other forces that facilitate the circulation inside the bay.

6.2 Tidal Effect

Tidal forces are generated by the gravitational attraction of the bodies between Earth-Sun and between Earth-Moon. Tide is the movement of water towards the shore and the developing “flood currents” are also directed to the shore. Ebb means that the water moves away from the shore, this movement of water forms an “ebb current”. As it can be seen from Figure 6.14, the ebb and flood currents are in reverse direction. In other words, this periodic movement of the water due to the attractive forces of Moon and Sun on rotating Earth constitutes the “Tidal Potential”.

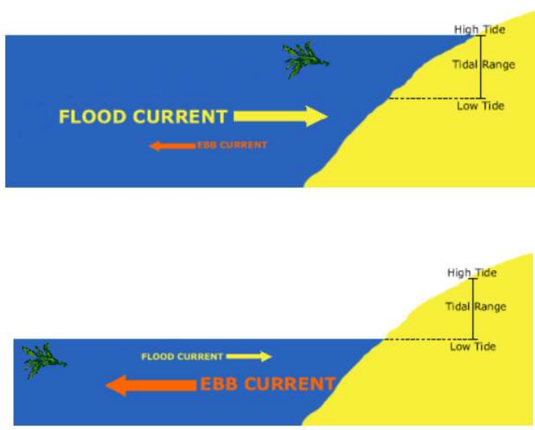


Figure 6.14. Flood Current and Ebb Current
(http://oceanservice.noaa.gov/education/tutorial_currents/media/supp_cur02a.html)

In Turkish coasts, the amplitudes of the tides are relatively low compared to the other parts of the world. Regarding this, it is stated that the Aegean Sea has low tidal amplitudes and the primary tidal component is M2 – Semidiurnal Lunar constituent and the secondary tidal component is S2 – Semidiurnal Solar being typical Mediterranean (Alpar et al., 2000). The peak amplitude of the tide observed in Göcek and Fethiye Bays is 20-30 cm.

To see the individual effect of tidal potential on current speeds, current directions and water exchange capacity in Göcek and Fethiye Bays, the model is used with only tidal case (without wind and Coriolis). A tidal potential which has an amplitude of 24 cm and period of 12 hours is included in the model.

The current speeds and directions are computed at nine numerical gauge points and polar scatter graphs for a simulation duration of 24-hours of tidal action in the 3rd layer (middle layer) are presented in Figure 6.15 to Figure 6.19. Since tidal wave is a long wave, there is no significant difference between the current speeds and directions in upper, middle and bottom layers for the locations.

The overall computed volumetric discharges and flow directions under tidal forcing are given in Table 6.4. The summary of the calculated total volume of water entered to or discharged from Fethiye, Göcek and Dalaman-Göcek Bays during 24-hour tidal action are also given in Table 6.5 with percentages.

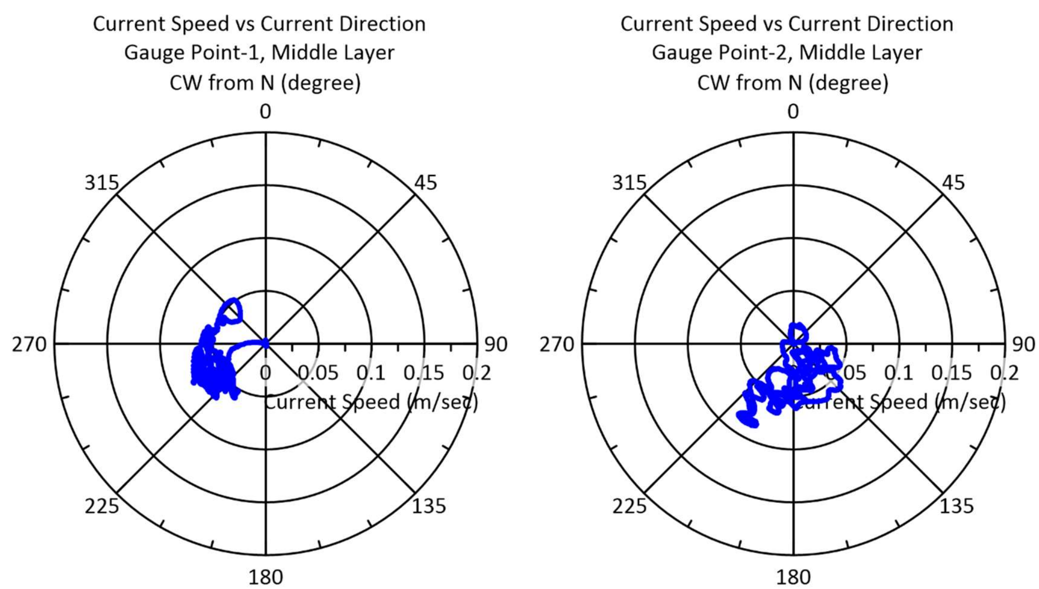


Figure 6.15. Current speed and current direction at Gauge Point 1 and Gauge Point 2 (24-hour simulation of tidal wave only)

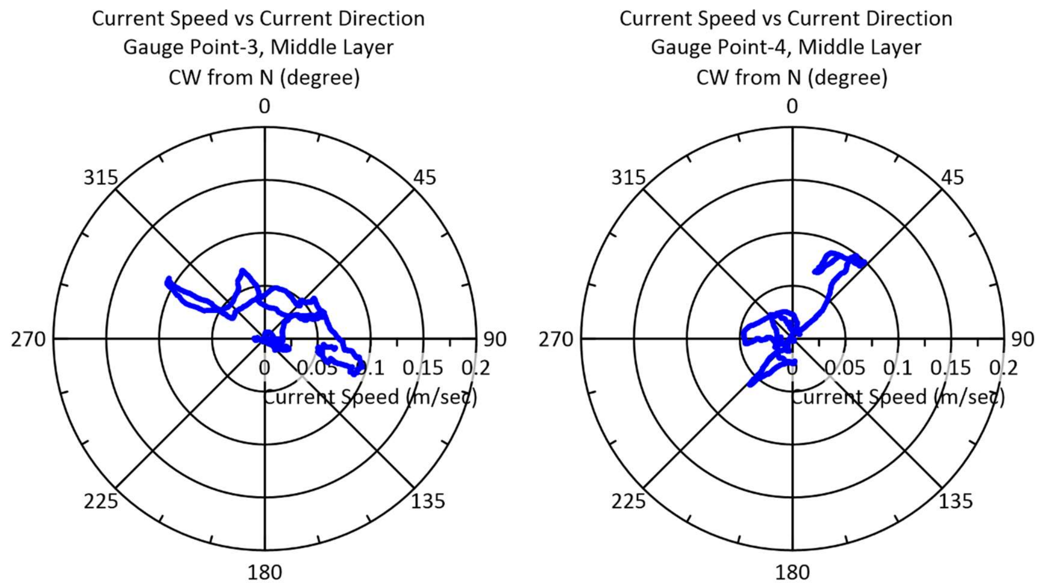


Figure 6.16. Current speed and current direction at Gauge Point 3 and Gauge Point 4 (24-hour simulation of tidal wave only)

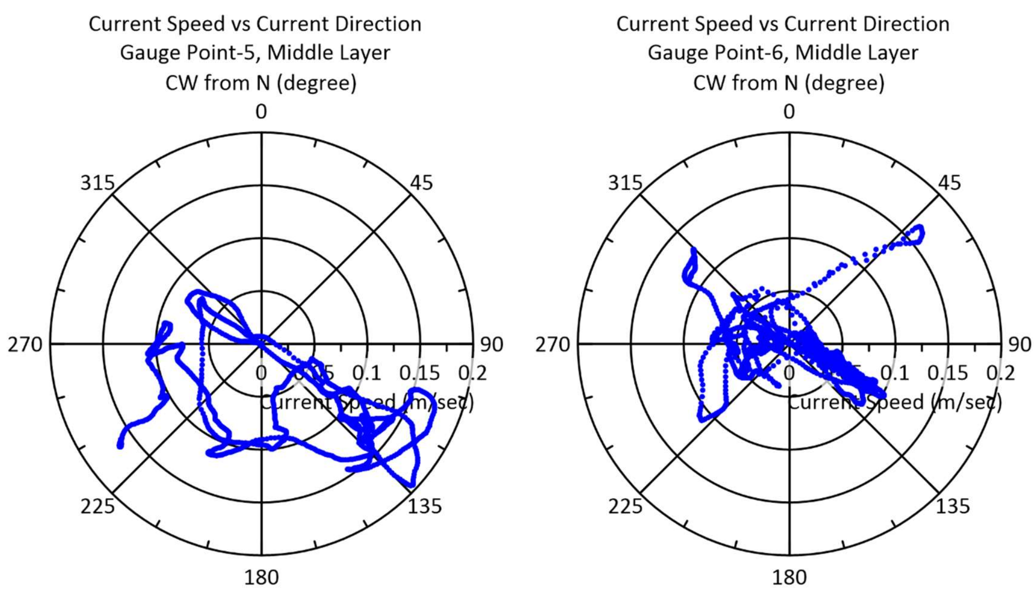
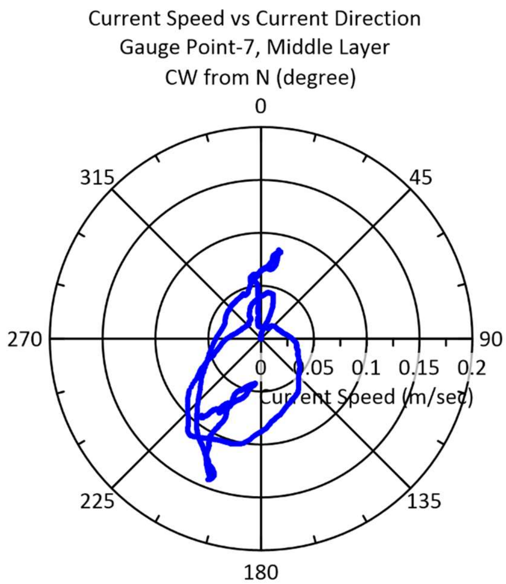


Figure 6.17. Current speed and current direction at Gauge Point 5 and Gauge Point 6 (24-hour simulation of tidal wave only)



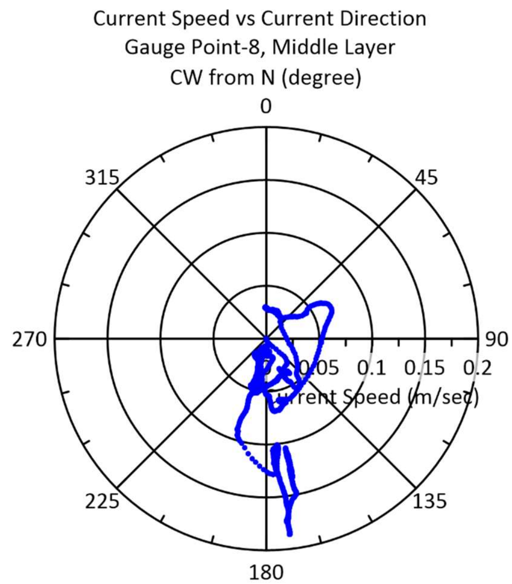


Figure 6.18. Current speed and current direction at Gauge Point 7 and Gauge Point 8 (24-hour simulation of tidal wave only)

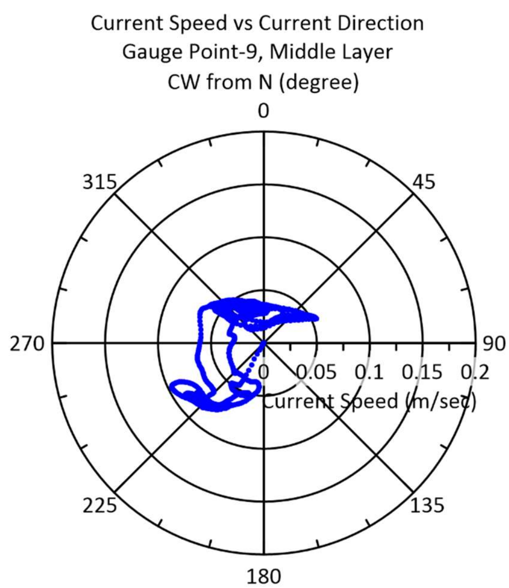


Figure 6.19. Current speed and current direction at Gauge Point 9 (24-hour simulation of tidal wave only)

Table 6.4. Computed volumetric discharges during 24-hour tidal action

Gauge Point	Water Depth at Gauge Points (m)	Cross Sectional Area (m^2)	Volumetric Discharge (10^6 m^3)	Flow Direction	Location Name
1	11.4	2233	-2.18	Outflow	Fethiye Bay
2	28.8	7536	2.19	Inflow	
3	50.0	26768	-0.75	Outflow	Göcek Bay
4	59.0	26748	0.77	Inflow	
5	49.0	23051	-4.73	Outflow	Dalaman-Göcek Bays
6	25.2	5252	-0.28	Outflow	
7	100.0	131916	15.59	Inflow	
8	15.0	2628	-7.95	Outflow	
9	11.8	1356	-1.71	Outflow	

Table 6.5. Total volumes and percentages of water exchanged in Fethiye, Göcek and Dalaman-Göcek Bays during 24-hour tidal action

Name of the Bay	Total volume of water in the bay (10^6 m^3)	Total volume of water **entered** the bay (10^6 m^3)	Total volume of water **left** the bay (10^6 m^3)	% Exchanged Volume
Fethiye	67.65	2.19	-2.18	3.23
Göcek	132.73	0.77	-0.75	0.57
Dalaman - Göcek	1147.58	15.59	-15.42	1.35

As seen from Figure 6.15, the maximum current speed is computed as 9 cm/sec at the straits (Gauge 1 and 2) of Fethiye Bay during the simulated tidal action. According to the computed mean current directions at these gauge points, it is observed that the tidal waves cause water input to Fethiye Bay at the entrance South-West of Şövalye Island and water output from Fethiye Bay at the entrance North-East of Şövalye Island. Throughout 24-hour simulation of the tidal wave, the total volume of water flowed along these channels (exchanged in Fethiye Bay) are computed as 2.2 million $m^3$and presented in Table 6.4 and Table 6.5 (~3.2 % of the total water volume in Fethiye Bay).

To obtain the water exchange in Göcek Bay during the 24 hours of tidal action, the computed current velocities at channels 3 and 4 are analyzed. The current speeds at the middle layer of these entrance channels (3 and 4) of Göcek Bay do not exceed 11 cm/sec. As a summary, the tidal force pushes water into the Göcek Bay from the West of Göcek Island (channel 4) and water is pushed out from the Göcek Bay from the East of Göcek Island (channel 3). As seen from Table 6.5, throughout 24 hours of tidal action 0.7 million m^3 (~0.57 % of the total water volume in Göcek Bay) water enters Göcek Bay from West of Göcek Island, circulates inside the bay and similar amount of water goes out from East of Göcek Island.

In order to obtain the water exchange in Dalaman-Göcek-Bays during 24-hours of tidal action, channels 3, 5, 6, 7, 8 and 9 are analyzed. The amounts of water inflow and outflow at these channels are given in Table 6.4. 4.7 million m^3 water left the Dalaman-Göcek Bays from channel 5. The tidal force causes 0.27 million m^3 water to leave Dalaman-Göcek Bays at channel 6. At channel 7, 15.5 million m^3 water entered to Dalaman-Göcek Bays. 7.9 million m^3 water left Dalaman-Göcek Bays from channel 8. During the tidal action, 1.7 million m^3 water is discharged from Dalaman-Göcek Bays at channel 9.

During 24-hour simulation of the tidal wave, the total volume of water entered to and left from Dalaman-Göcek Bays is 15.5 million m^3. That is, 1.3 % of water volume inside Dalaman-Göcek Bay is exchanged with the offshore.

If the tidal wave is the only forcing mechanism, the current speeds computed near Kapıdağ Peninsula (Gauge Point 10 and 11) are very low.

According to the simulation results due to 24-hour tidal forcing with 24 cm amplitude, and it can be concluded that the water exchange in the bays are about 3% (or less) of total volume of the water in each bay.

In the following section, the effect of wind forcing (without Coriolis and tidal effects) on water exchange and circulation in Fethiye Bay, Göcek Bay and Dalaman-Göcek Bays are examined and presented in detail.

6.3 Wind-Induced Circulation

The currents are in general the horizontal movements of water and its magnitude can vary between few centimeters per second to 4 meters per second depending on forcing mechanisms. Typical surface speeds can be 5 to 50 cm per second. However, the intensity of the currents is inversely proportional to depth (Rafferty, 2011).

Wind is one of the triggering factors for the formation of currents and circulation in the nearshore zone. In this study, the effects of wind on the circulation in Fethiye, Göcek and Dalaman-Göcek Bays are investigated using circulation model MIKE 3 HD FM. The simulations are performed without taking into consideration of the effect of Coriolis force and tidal action. Therefore, the simulation results show the effect of only wind condition blowing from specified direction with specified constant speed in the model domain.

As stated in Chapter 5, the wind data for the model area for Fethiye and Dalaman Meteorological Stations have already been processed by Akbaşoğlu, (2011). According to the results in Akbaşoğlu, (2011), Fethiye is generally exposed to the winds from ENE, E, ESE, WSW, SSW and WNW. The annual dominant wave direction is ENE with more than 14 % of all year wind distribution. Other dominant wave directions are WSW, SSW and E with nearly 10 % for each direction. Meanwhile, the dominant wind blowing directions for Dalaman Meteorological Station are S and NNW with nearly 16 % of all year wind distribution.

After evaluating the analysis and results of Akbaşoğlu, (2011), the representative wind speed is selected as 5 m/sec for 12 hours' duration blowing from ENE, SSE, WSW and NNW directions in a year for the simulation of Fethiye-Göcek Bays.

Four perpendicular wind directions are used in four different scenarios in which the wind duration is selected as 12 hours. First 2 hours are used as ramping of wind speed from calm to the specified speed. Two different average wind speeds are selected as 5 m/sec and 10 m/sec separately (Table 6.6). The results due to constant wind speeds of

5 m/sec and 10 m/sec are analyzed and presented in this thesis. The direction of the wind is in degrees represents clockwise from the North.

To observe the individual effect of wind force on the water circulation and water exchange in Fethiye and Göcek Bays from prevailing wind directions, several simulations are performed. The input parameters of each scenario (wind speed, direction and duration) are listed in Table 6.6. The simulation results are presented in polar scatter graphs (showing the distribution of the wind speed and direction at each gauge point) in the following sections for each scenario.

Table 6.6. Wind simulation scenarios

Scenario		Wind Speed (m/s)	Wind Direction	Wind Direction ° clockwise from North
01	a	5	ENE	67.5
	b	10	ENE	67.5
02	a	5	SSE	157.5
	b	10	SSE	157.5
03	a	5	WSW	247.5
	b	10	WSW	247.5
04	a	5	NNW	337.5
	b	10	NNW	337.5

The polar scatter plots of computed current speed and current direction at the middle layer (3^{rd} layer from bottom) at nine numerical gauge points in the study domain are shown in below figures under wind forcing. In Figure 6.20, winds blowing from ENE direction for 12 hours (including 2 hours ramping) with a constant wind speed of 5 m/sec is applied to the model and current speed-current direction polar plot at Gauge Point 1 is drawn. 5 layers are shown with different colors. As it can be seen from the figure that there is a little variation of current speeds and directions in five layers. Therefore, the results at each numerical gauge point are given for only 3^{rd} layer (middle layer), because there is no significant change between the current speeds and directions in upper, middle and bottom layers at all the gauge points.

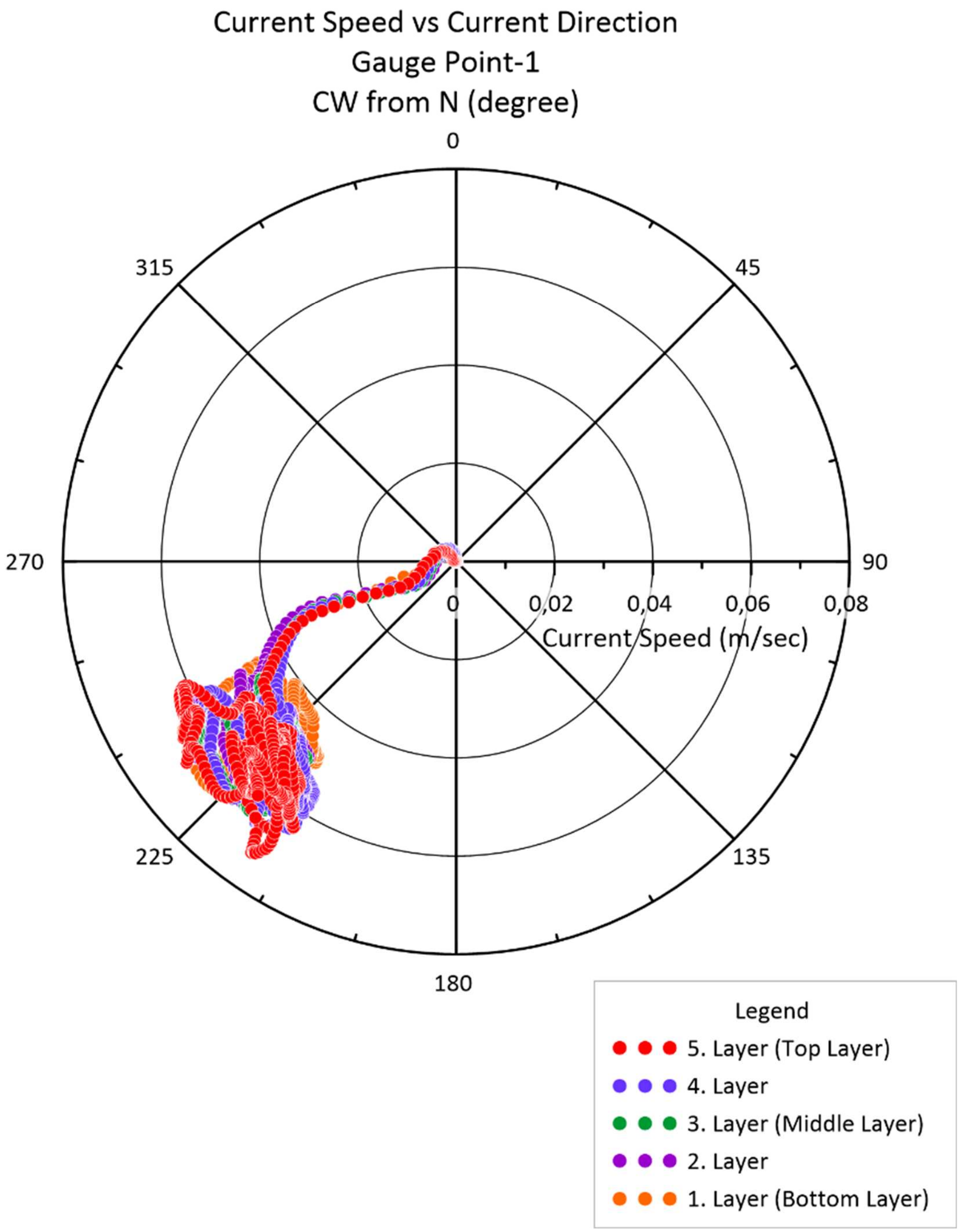


Figure 6.20. Current speed and current direction in each layer at Gauge Point 1 (5 m/sec wind blowing from ENE direction)

6.3.1 Scenario 01 (a and b)

In scenario 01, winds from ENE direction blowing 12 hours with a constant wind speed of 5 m/sec (a) and 10 m/sec (b) are studied. Wind speed is increased from 0 to specified wind speeds within 2 hours. The polar plots showing current speed vs current direction are presented in the following sections for only 5 m/sec wind speed condition. However, the results are presented and shown in tabular format (Table 6.7 to Table 6.10) for all scenarios including 5 m/sec and 10 m/sec wind speed conditions to understand the circulation in the region by analyzing the effect of wind speed on water exchange, volumetric discharges that pass between Fethiye, Göcek and Dalaman-Göcek Bays and the open sea.

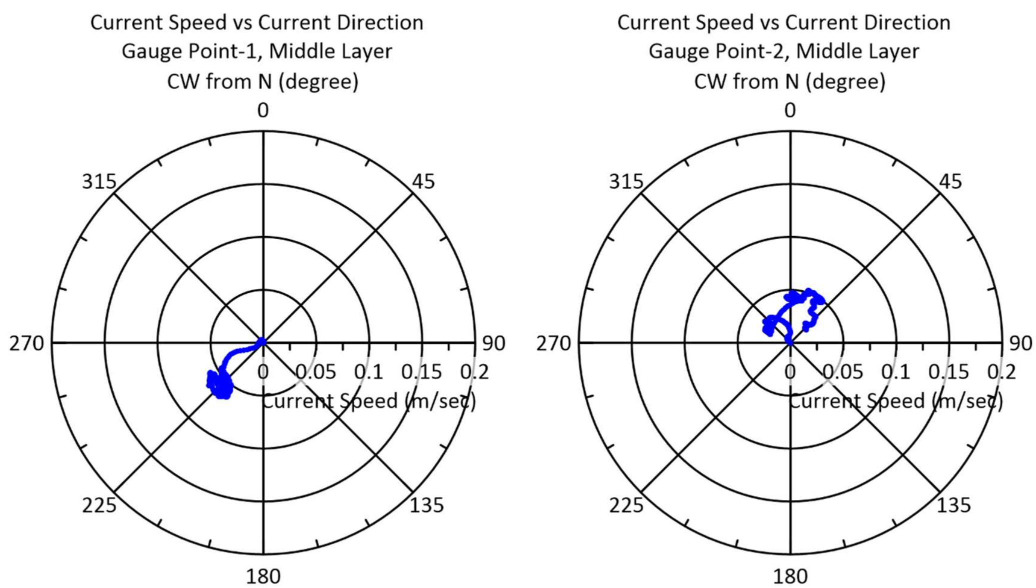


Figure 6.21. Current speed and current direction at Gauge Point 1 and Gauge Point 2 (5 m/sec wind blowing from ENE direction)

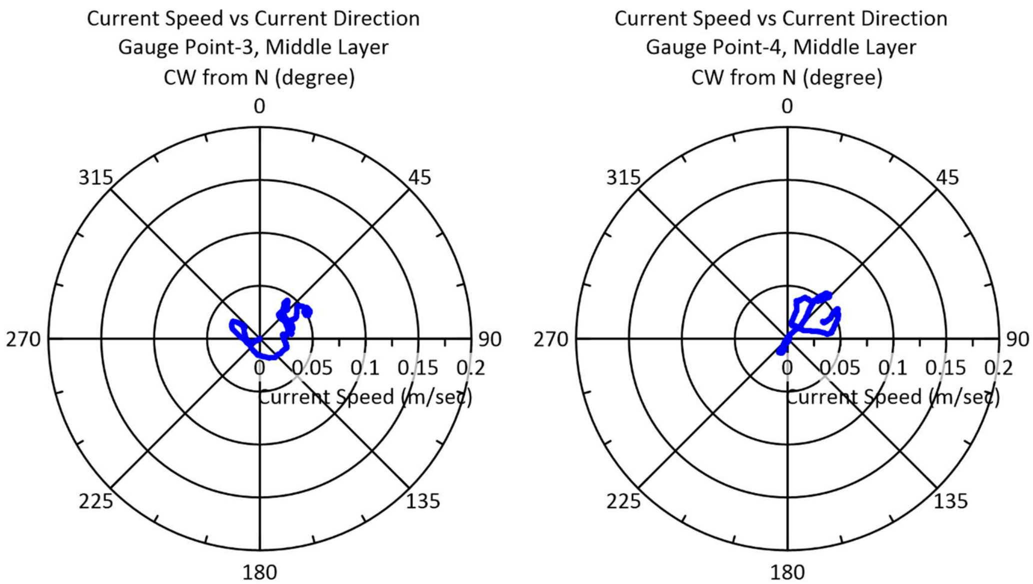


Figure 6.22. Current speed and current direction at Gauge Point 3 and Gauge Point 4 (5 m/sec wind blowing from ENE direction)

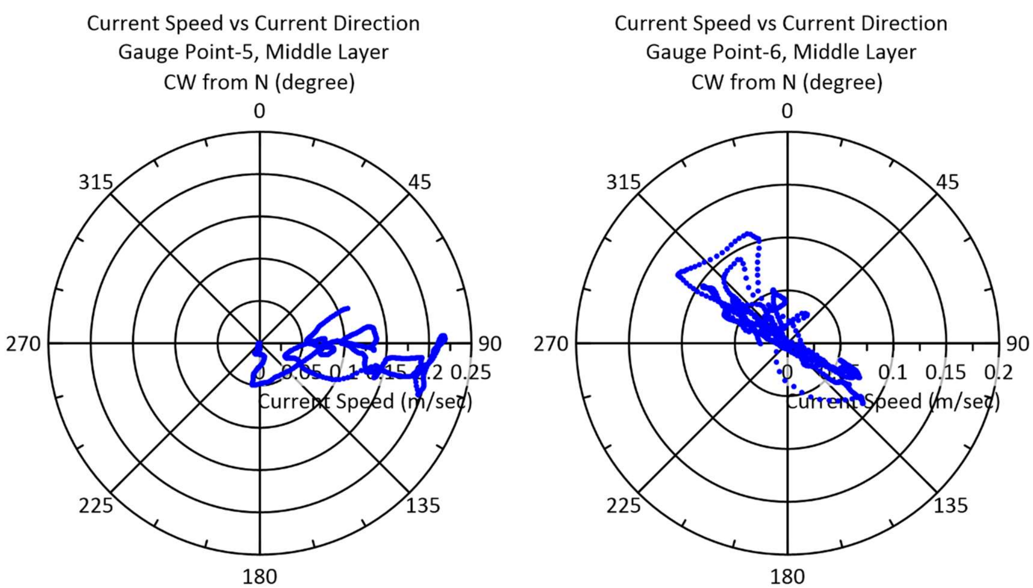


Figure 6.23. Current speed and current direction at Gauge Point 5 and Gauge Point 6 (5 m/sec wind blowing from ENE direction)

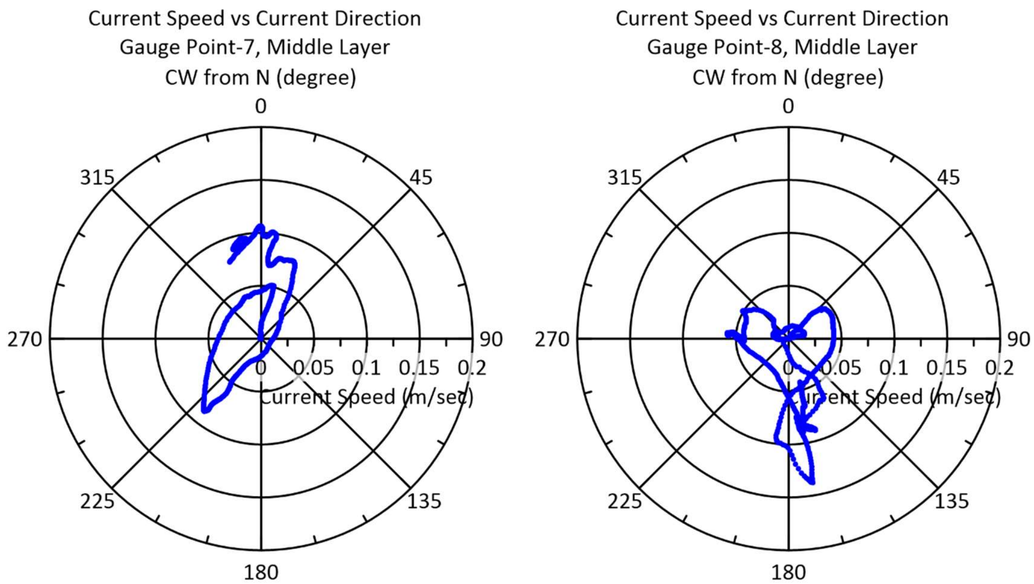


Figure 6.24. Current speed and current direction at Gauge Point 7 and Gauge Point 8 (5 m/sec wind blowing from ENE direction)

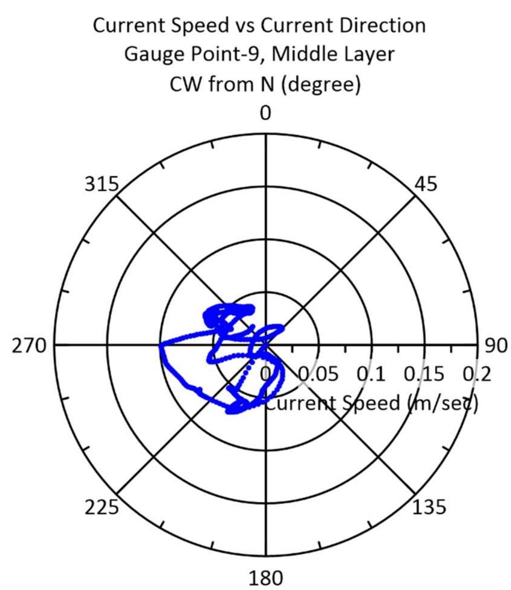


Figure 6.25. Current speed and current direction at Gauge Point 9 (5 m/sec wind blowing from ENE direction)

Table 6.7. Computed volumetric discharges during 5 m/sec wind blowing from ENE direction

Gauge Point	Water Depth at Gauge Points (m)	Cross Sectional Area (m^2)	Volumetric Discharge (10^6 m^3)	Flow Direction	Location Name
1	11.4	2233	0.71	Inflow	Fethiye Bay
2	28.8	7536	-0.69	Outflow	
3	50.0	26768	-6.28	Outflow	Göcek Bay
4	59.0	26748	6.29	Inflow	
5	49.0	23051	-59.97	Outflow	Dalaman-Göcek Bays
6	25.2	5252	0.48	Inflow	
7	100.0	131916	68.99	Inflow	
8	15.0	2628	-2.60	Outflow	
9	11.8	1356	-0.35	Outflow	

Table 6.8. Total volumes and percentages of water exchanged in Fethiye, Göcek and Dalaman-Göcek Bays 5 m/sec wind blowing from ENE direction

Name of the Bay	Total volume of water in the bay (10^6 m^3)	Total volume of water **entered** the bay (10^6 m^3)	Total volume of water **left** the bay (10^6 m^3)	% Exchanged Volume
Fethiye	67.65	0.71	-0.69	1.03
Göcek	132.73	6.29	-6.28	4.74
Dalaman - Göcek	1147.58	69.47	-69.21	6.04

According to the polar plots and tables, 5 m/sec ENE directed winds pushes water into Fethiye Bay from strait 1 and due to conservation of mass, same amount of water is discharged out of the bay from strait 2, after circulating inside the bay. According to the simulation results, 6.28 million m^3 (4.74 % of total water volume in Göcek Bay) is exchanged during 10 hours wind condition blowing from ENE direction with 5 m/sec speed.

In Dalaman-Göcek Bays, the water entering from channels 6 and 7 due to the wind blowing from ENE direction, discharges from channels 3, 5, 8 and 9.

Table 6.9. Computed volumetric discharges during 10 m/sec wind blowing from ENE direction

Gauge Point	Water Depth at Gauge Points (m)	Cross Sectional Area (m^2)	Volumetric Discharge (10^6 m^3)	Flow Direction	Location Name
1	11.4	2233	-0.20	Outflow	Fethiye Bay
2	28.8	7536	0.19	Inflow	
3	50.0	26768	-8.91	Outflow	Göcek Bay
4	59.0	26748	8.90	Inflow	
5	49.0	23051	-7.38	Outflow	Dalaman-Göcek Bays
6	25.2	5252	2.65	Inflow	
7	100.0	131916	17.93	Inflow	
8	15.0	2628	-3.18	Outflow	
9	11.8	1356	-0.98	Outflow	

Table 6.10. Total volumes and percentages of water exchanged in Fethiye, Göcek and Dalaman-Göcek Bays 10 m/sec wind blowing from ENE direction

Name of the Bay	Total volume of water in the bay (10^6 m^3)	Total volume of water **entered** the bay (10^6 m^3)	Total volume of water **left** the bay (10^6 m^3)	% Exchanged Volume
Fethiye	67.65	0.19	-0.20	0.29
Göcek	132.73	8.90	-8.91	6.71
Dalaman - Göcek	1147.58	20.59	-20.45	1.79

For the scenario 01 (b), wind direction is kept as ENE, just as scenario 01 (a). The simulation results of wind blowing with a speed of 10 m/sec are presented in Table 6.9 and Table 6.10.

Increasing wind speed from 5 m/sec to 10 m/sec resulted in an increased water exchange value for both Fethiye and Dalaman-Göcek Bays. However, increasing wind speed had an in exact opposite affect at Göcek Bay. In this scenario, it is concluded that the relationship between wind speed and water exchange is not linear. In other words, even if the wind speed is doubled, water exchange values do not increase with the same proportion.

6.3.2 Scenario 02 (a and b)

In scenario 02, winds from SSE direction, blowing 12 hours with a constant wind speed of 5 m/sec (a) and 10 m/sec (b) are studied. For this scenario, 2 hours of ramping time is defined. Only for 5 m/sec wind speed; current speed vs current direction polar plots are presented, however, the results for 10 m/sec wind speed are presented in tabular form. By comparing the simulation results of 5 m/sec and 10 m/sec, the relationship between wind speed, water exchange and circulation can be observed.

For Fethiye, Göcek and Dalaman-Göcek Bays, the average volumetric discharges, water exchange and flow directions for SSE direction are presented in Table 6.11 to Table 6.15.

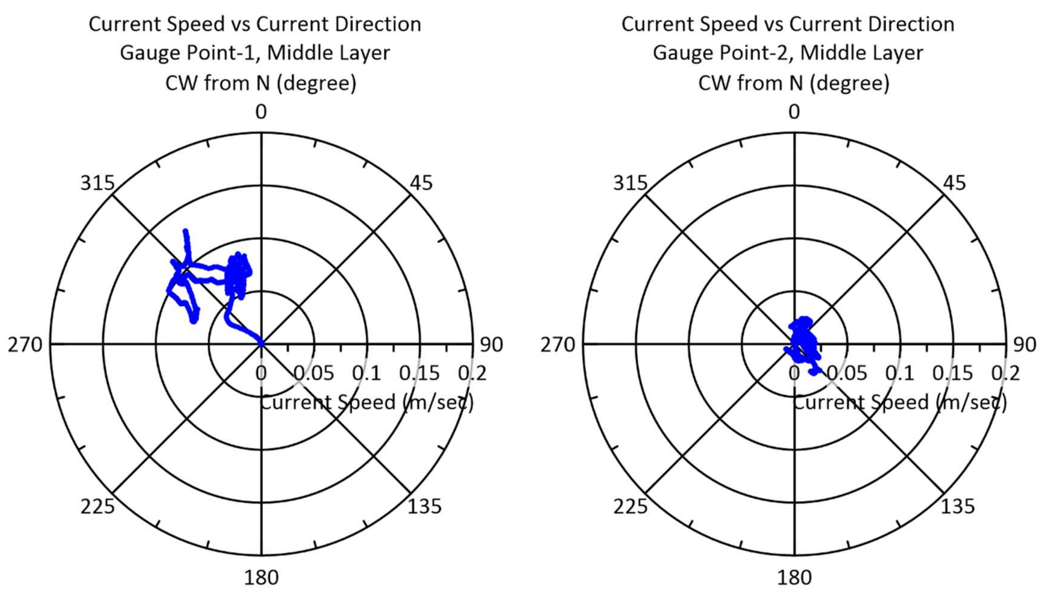


Figure 6.26. Current speed and current direction at Gauge Point 1 and Gauge Point 2 (5 m/sec wind blowing from SSE direction)

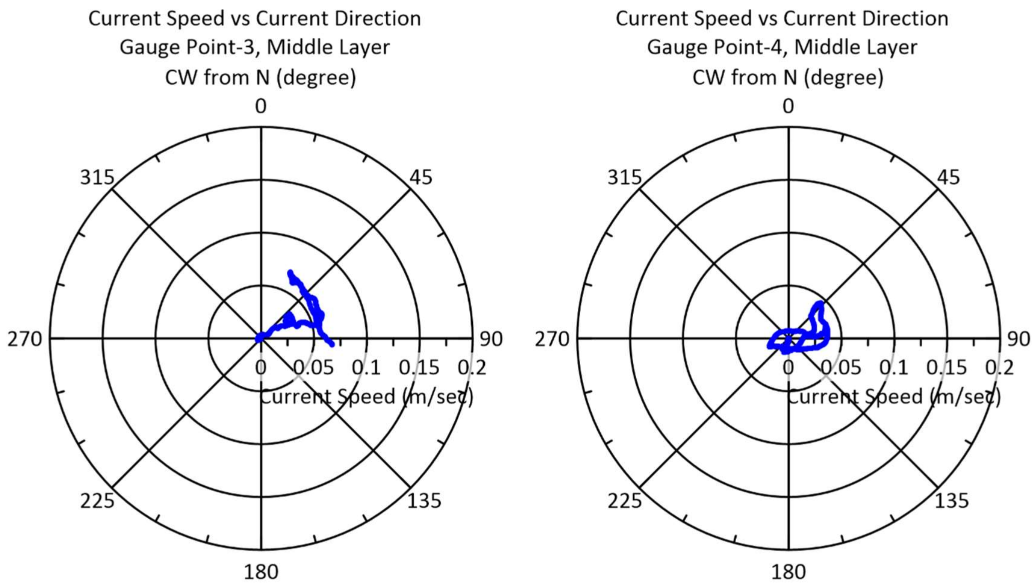


Figure 6.27. Current speed and current direction at Gauge Point 3 and Gauge Point 4 (5 m/sec wind blowing from SSE direction)

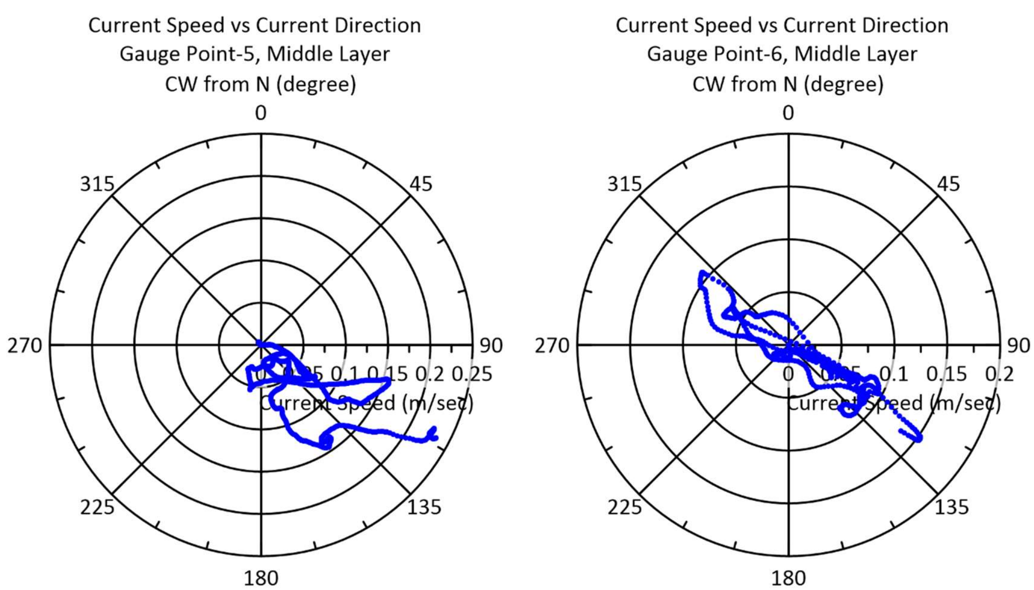


Figure 6.28. Current speed and current direction at Gauge Point 5 and Gauge Point 6 (5 m/sec wind blowing from SSE direction)

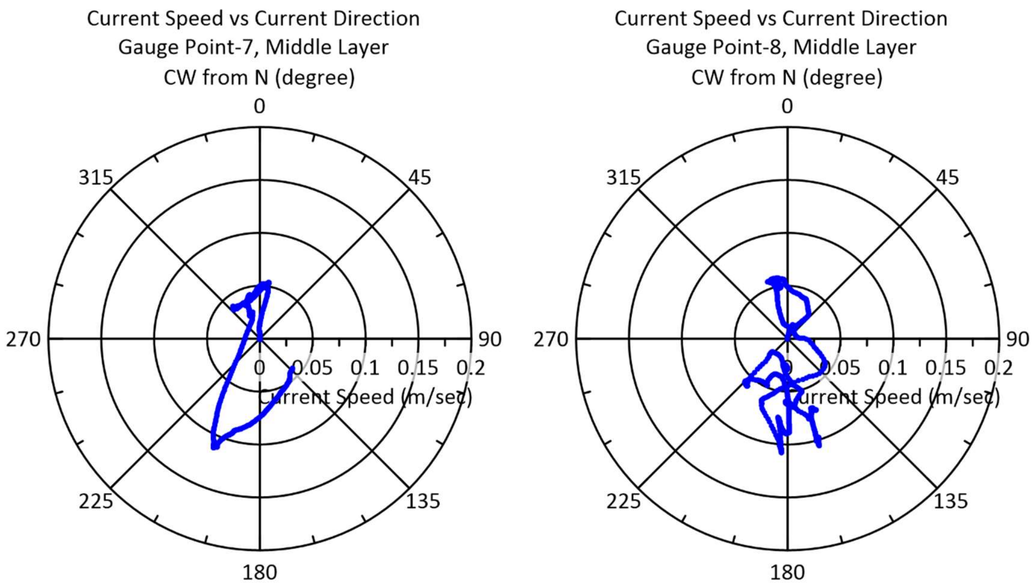


Figure 6.29. Current speed and current direction at Gauge Point 7 and Gauge Point 8 (5 m/sec wind blowing from SSE direction)

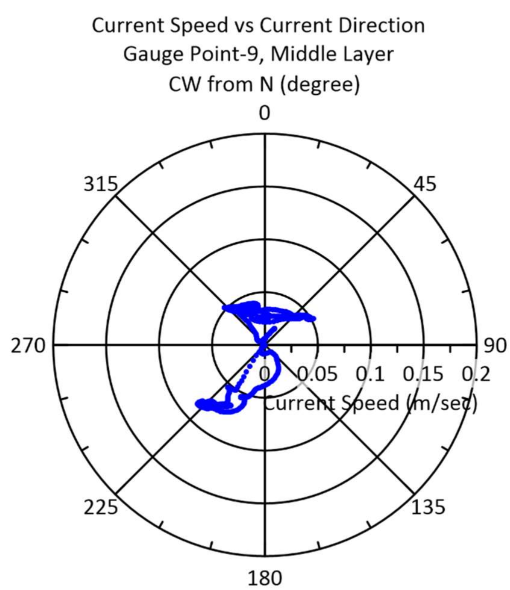


Figure 6.30. Current speed and current direction at Gauge Point 9 (5 m/sec wind blowing from SSE direction)

Table 6.11. Computed volumetric discharges during 5 m/sec wind blowing from SSE direction

Gauge Point	Water Depth at Gauge Points (m)	Cross Sectional Area (m^2)	Volumetric Discharge (10^6 m^3)	Flow Direction	Location Name
1	11.4	2233	-4.62	Outflow	Fethiye Bay
2	28.8	7536	4.62	Inflow	
3	50.0	26768	3.49	Inflow	Göcek Bay
4	59.0	26748	-3.48	Outflow	
5	49.0	23051	-21.39	Outflow	Dalaman-Göcek Bays
6	25.2	5252	-2.62	Outflow	
7	100.0	131916	24.57	Inflow	
8	15.0	2628	-2.52	Outflow	
9	11.8	1356	-1.28	Outflow	

Table 6.12. Total volumes and percentages of water exchanged in Fethiye, Göcek and Dalaman-Göcek Bays 5 m/sec wind blowing from SSE direction

Name of the Bay	Total volume of water in the bay (10^6 m^3)	Total volume of water **entered** the bay (10^6 m^3)	Total volume of water **left** the bay (10^6 m^3)	% Exchanged Volume
Fethiye	67.65	4.62	-4.62	6.83
Göcek	132.73	3.49	-3.48	2.62
Dalaman - Göcek	1147.58	28.06	-27.80	2.43

The simulation results demonstrate that if the wind blows for 12 hours from SSE direction, 4.62 million m^3 water is exchanged within the Fethiye Bay. Sea water enters the bay from strait 2 and leaves from strait 1.

According to the simulation results, total water exchange in Göcek Bay is approximately 3.49 million m^3 (2.62 % of total water volume of Göcek Bay) at the end of scenario 02 (a).

In Dalaman-Göcek Bays, sea water entering from the widest channel 7 and channel 3 due to the wind blowing from SSE, discharges from channels 5, 6, 8 and 9.

Table 6.13. Computed volumetric discharges during 10 m/sec wind blowing from SSE direction

Gauge Point	Water Depth at Gauge Points (m)	Cross Sectional Area (m^2)	Volumetric Discharge (10^6 m^3)	Flow Direction	Location Name
1	11.4	2233	-5.12	Outflow	Fethiye Bay
2	28.8	7536	5.15	Inflow	
3	50.0	26768	17.07	Inflow	Göcek Bay
4	59.0	26748	-17.03	Outflow	
5	49.0	23051	52.44	Inflow	Dalaman-Göcek Bays
6	25.2	5252	-1.55	Outflow	
7	100.0	131916	-72.62	Outflow	
8	15.0	2628	3.02	Inflow	
9	11.8	1356	1.98	Inflow	

Table 6.14. Total volumes and percentages of water exchanged in Fethiye, Göcek and Dalaman-Göcek Bays 10 m/sec wind blowing from SSE direction

Name of the Bay	Total volume of water in the bay (10^6 m^3)	Total volume of water **entered** the bay (10^6 m^3)	Total volume of water **left** the bay (10^6 m^3)	% Exchanged Volume
Fethiye	67.65	5.15	-5.12	7.59
Göcek	132.73	17.07	-17.03	12.84
Dalaman - Göcek	1147.58	74.51	-74.16	6.48

In this scenario, 02 (b), the wind blowing direction is again SSE and the wind speed is increased from 5 m/sec to 10 m/sec. The simulation results are presented in Table 6.13 and Table 6.14. Accordingly, the rise in the wind speed yielded similarly in all three bays (Fethiye, Göcek and Dalaman-Göcek Bays) where the water exchange increased.

6.3.3 Scenario 03 (a and b)

In scenario 03, winds blowing from WSW direction for 12 hours with a constant wind speed of 5 m/sec (a) and 10 m/sec (b) are studied. Wind ramping time for scenario 03 is set as 2 hours. Polar plots showing current speed vs current direction are presented only for 5 m/sec wind speed. The simulation results of 5 m/sec and 10 m/sec are analyzed and the relationship between wind speed, water exchange and circulation are examined.

For WSW direction, the average volumetric discharges, total water exchange and flow directions between Fethiye, Göcek and Dalaman-Göcek Bays, are shown in below tables.

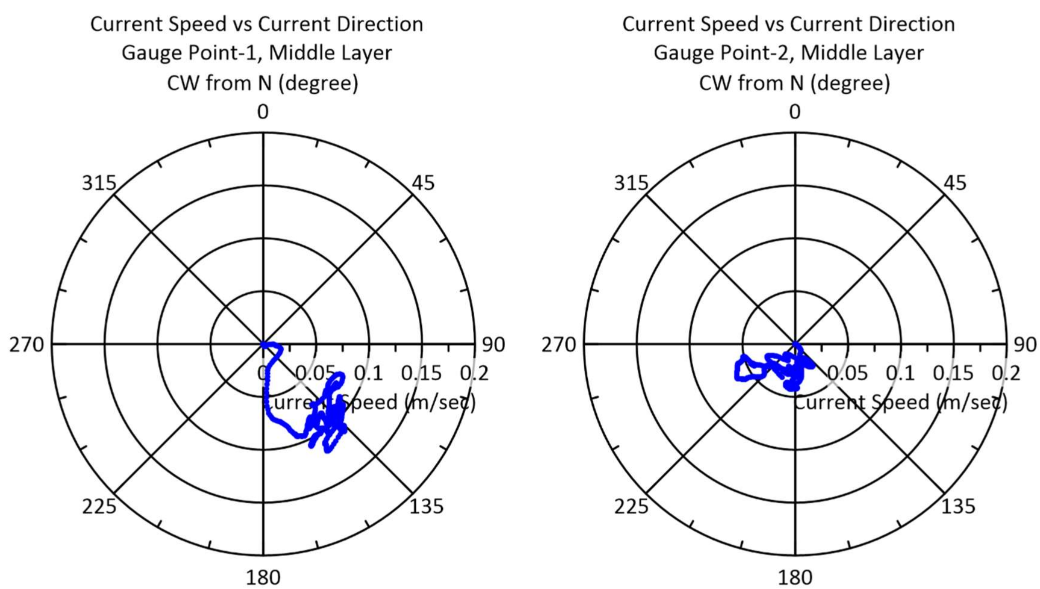


Figure 6.31. Current speed and current direction at Gauge Point 1 and Gauge Point 2 (5 m/sec wind blowing from WSW direction)

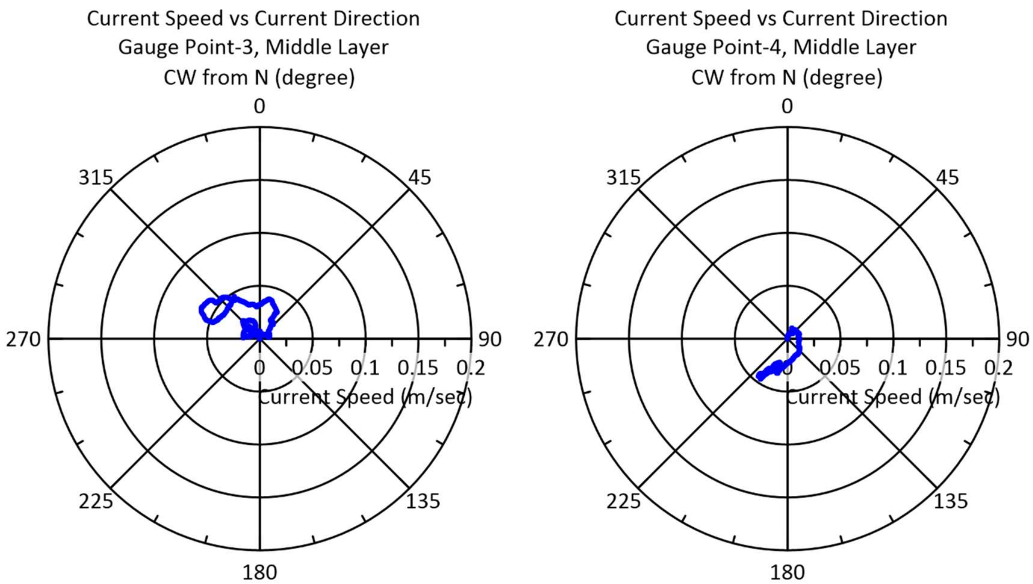


Figure 6.32. Current speed and current direction at Gauge Point 3 and Gauge Point 4 (5 m/sec wind blowing from WSW direction)

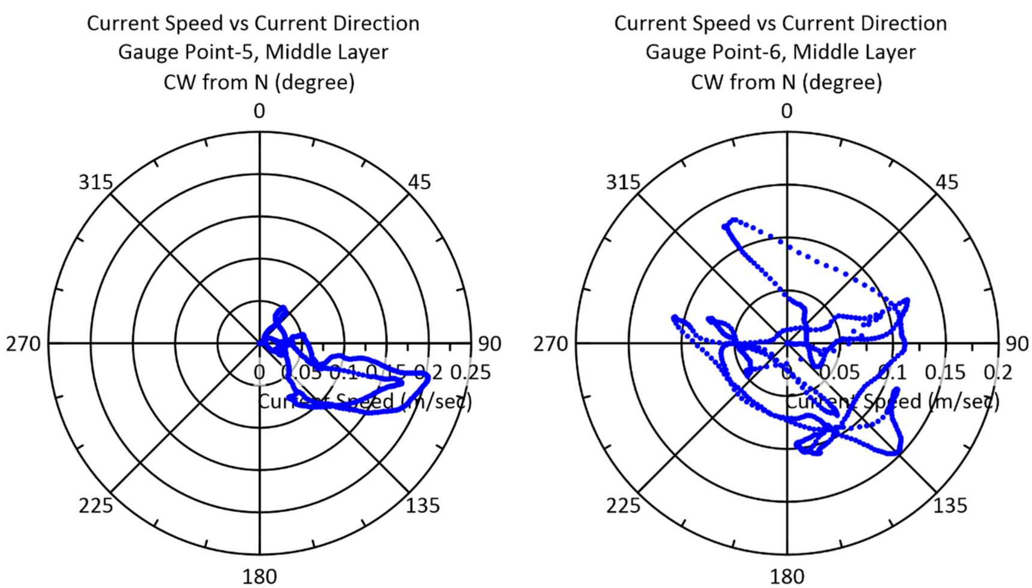
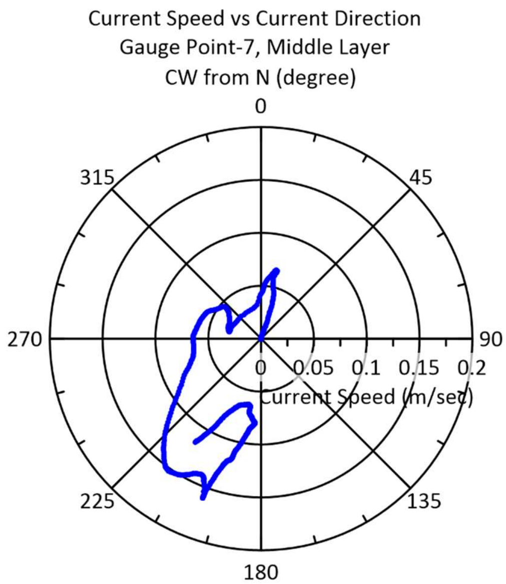


Figure 6.33. Current speed and current direction at Gauge Point 5 and Gauge Point 6 (5 m/sec wind blowing from WSW direction)



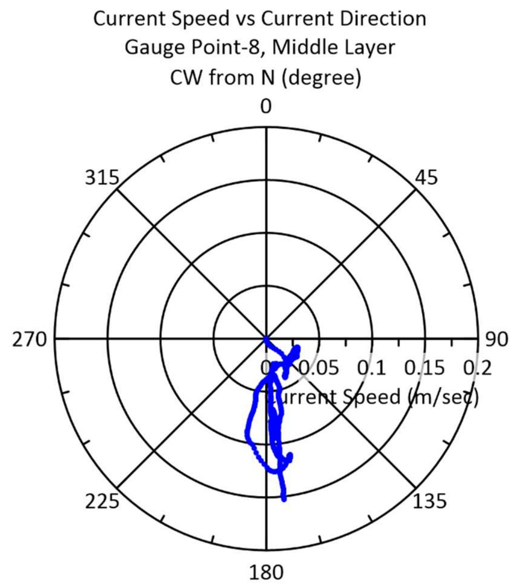


Figure 6.34. Current speed and current direction at Gauge Point 7 and Gauge Point 8 (5 m/sec wind blowing from WSW direction)

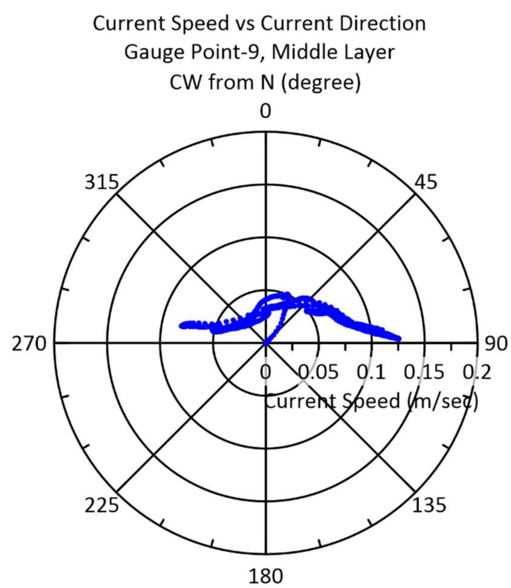


Figure 6.35. Current speed and current direction at Gauge Point 9 (5 m/sec wind blowing from WSW direction)

Table 6.15. Computed volumetric discharges during 5 m/sec wind blowing from WSW direction

Gauge Point	Water Depth at Gauge Points (m)	Cross Sectional Area (m^2)	Volumetric Discharge (10^6 m^3)	Flow Direction	Location Name
1	11.4	2233	1.86	Inflow	Fethiye Bay
2	28.8	7536	-1.84	Outflow	
3	50.0	26768	16.64	Inflow	Göcek Bay
4	59.0	26748	-16.63	Outflow	
5	49.0	23051	-35.59	Outflow	Dalaman-Göcek Bays
6	25.2	5252	2.07	Inflow	
7	100.0	131916	19.82	Inflow	
8	15.0	2628	-3.07	Outflow	
9	11.8	1356	0.30	Inflow	

Table 6.16. Total volumes and percentages of water exchanged in Fethiye, Göcek and Dalaman-Göcek Bays 5 m/sec wind blowing from WSW direction

Name of the Bay	Total volume of water in the bay (10^6 m^3)	Total volume of water **entered** the bay (10^6 m^3)	Total volume of water **left** the bay (10^6 m^3)	% Exchanged Volume
Fethiye	67.65	1.86	-1.84	2.74
Göcek	132.73	16.64	-16.63	12.53
Dalaman - Göcek	1147.58	38.84	-38.66	3.38

As seen from the above tables, this simulation with wind blowing from WSW direction for 12 hours demonstrates that 1.86 million m^3 water is exchanged within the Fethiye Bay. Sea water enters the bay from strait 1 and leaves from strait 2. At the end of scenario 03 (a), total amount of water circulated in Göcek Bay is approximately 16.64 million m^3. In Dalaman-Göcek Bays, the total water exchange is calculated by analyzing the channels 3, 5, 6, 7, 8, and 9. Wind blowing 5 m/sec from WSW direction induces sea water to enter the bay from channel 5 and channel 8, to leave the bay from channels 3, 6, 7 and 9.

Table 6.17. Computed volumetric discharges during 10 m/sec wind blowing from WSW direction

Gauge Point	Water Depth at Gauge Points (m)	Cross Sectional Area (m^2)	Volumetric Discharge (10^6 m^3)	Flow Direction	Location Name
1	11.4	2233	0.34	Inflow	Fethiye Bay
2	28.8	7536	-0.31	Outflow	
3	50.0	26768	-7.73	Outflow	Göcek Bay
4	59.0	26748	7.75	Inflow	
5	49.0	23051	-43.94	Outflow	Dalaman-Göcek Bays
6	25.2	5252	-5.63	Outflow	
7	100.0	131916	59.49	Inflow	
8	15.0	2628	-1.01	Outflow	
9	11.8	1356	-1.06	Outflow	

Table 6.18. Total volumes and percentages of water exchanged in Fethiye, Göcek and Dalaman-Göcek Bays 10 m/sec wind blowing from WSW direction

Name of the Bay	Total volume of water in the bay (10^6 m^3)	Total volume of water **entered** the bay (10^6 m^3)	Total volume of water **left** the bay (10^6 m^3)	% Exchanged Volume
Fethiye	67.65	0.34	-0.31	0.48
Göcek	132.73	7.75	-7.73	5.83
Dalaman - Göcek	1147.58	59.49	-59.38	5.18

In scenario 03 (b), the wind direction is remained constant whereas the wind speed is increased to 10 m/sec. Above tables show the summary of the simulation results for wind force 5 m/sec and 10 m/sec from WSW. If the wind speed is increased from 5 m/sec to 10 m/sec, the water exchange value for Fethiye Bay decreases. On the other hand, increasing wind speed causes an increase in water exchange at Göcek and Dalaman-Göcek Bays.

For this case, it is understood that the relation of wind speed to water exchange is not linear. That is, even if the wind speed is duplicated, measured water exchange values at gauge points do not increase evenly.

6.3.4 Scenario 04 (a and b)

Winds blowing 12 hours from NNW direction with a constant wind speed of 5 m/sec (a) and 10 m/sec (b) are examined in detail. For both scenarios, wind speed is increased from 0 to specific wind speeds within 2 hours. Current speed vs current direction polar plots are presented in the following sections for only 5 m/sec wind speed condition. Yet all simulation results are presented in tabular format (Table 6.7 to Table 6.10) for all scenarios. Both 5 m/sec and 10 m/sec wind speed simulation are performed to understand the circulation in the region by analyzing the effect of wind speed on water exchange, volumetric discharges that pass through Fethiye, Göcek and Dalaman-Göcek Bays.

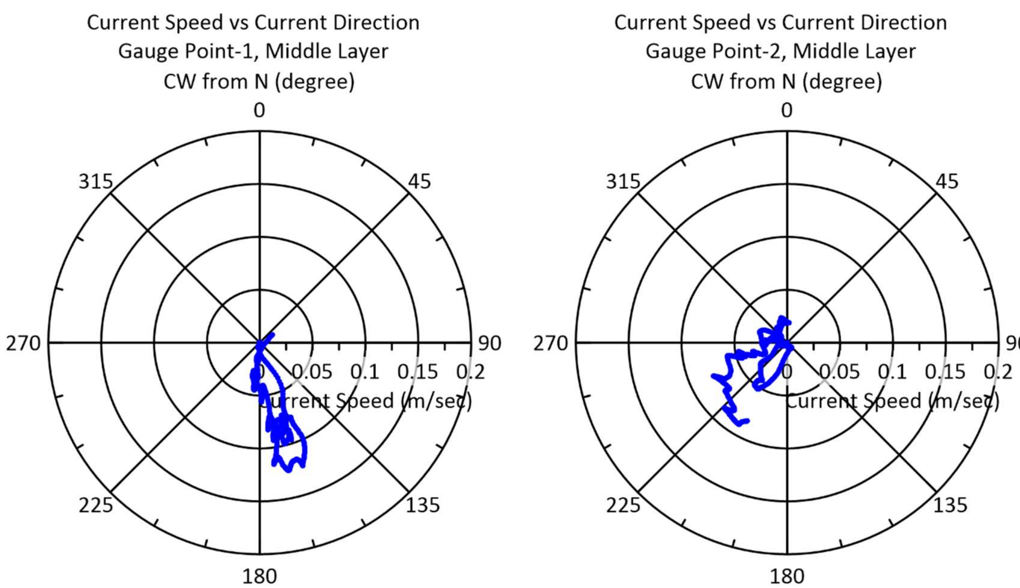


Figure 6.36. Current speed and current direction at Gauge Point 1 and Gauge Point 2 (5 m/sec wind blowing from NNW direction)

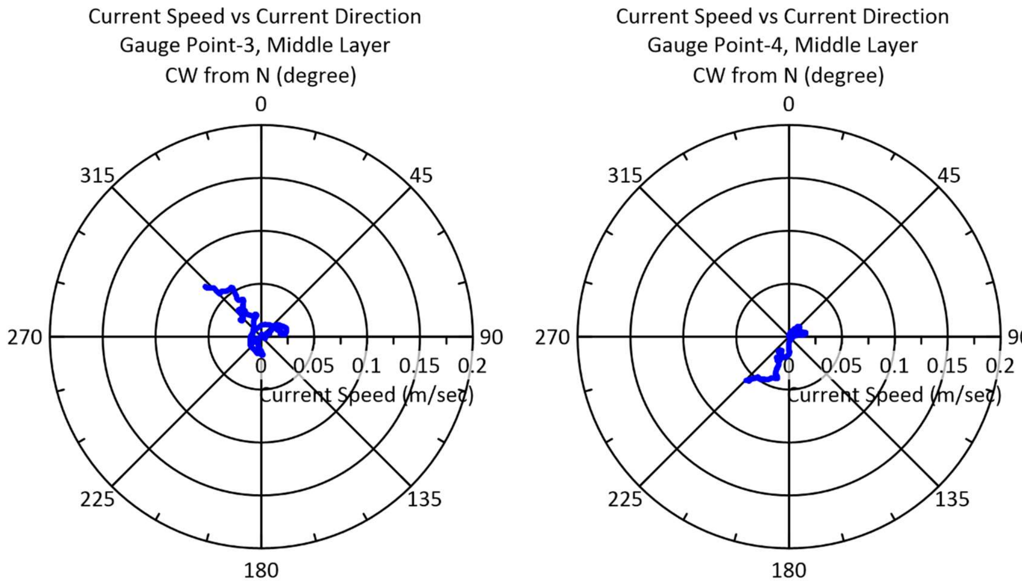


Figure 6.37. Current speed and current direction at Gauge Point 3 and Gauge Point 4 (5 m/sec wind blowing from NNW direction)

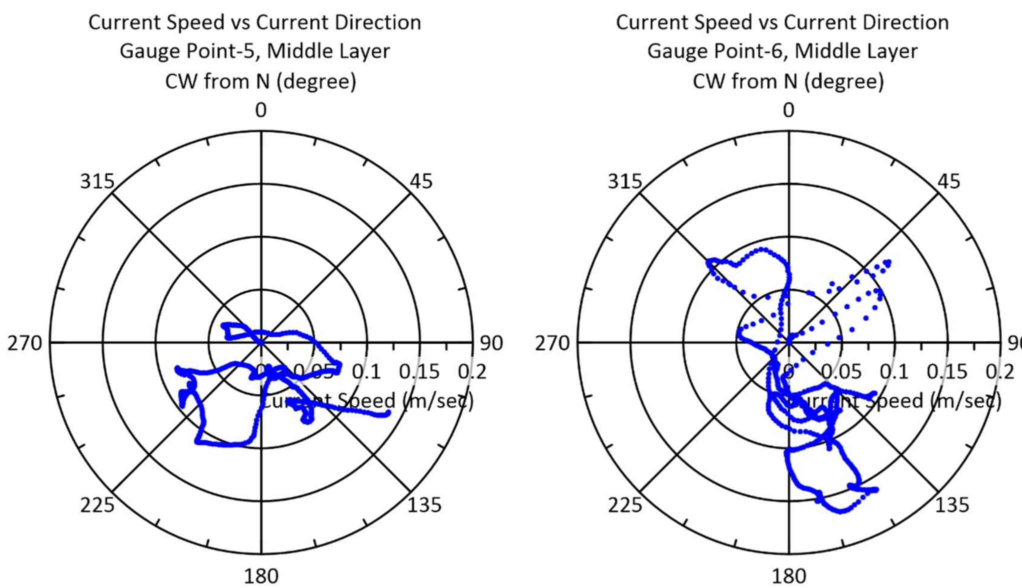


Figure 6.38. Current speed and current direction at Gauge Point 5 and Gauge Point 6 (5 m/sec wind blowing from NNW direction)

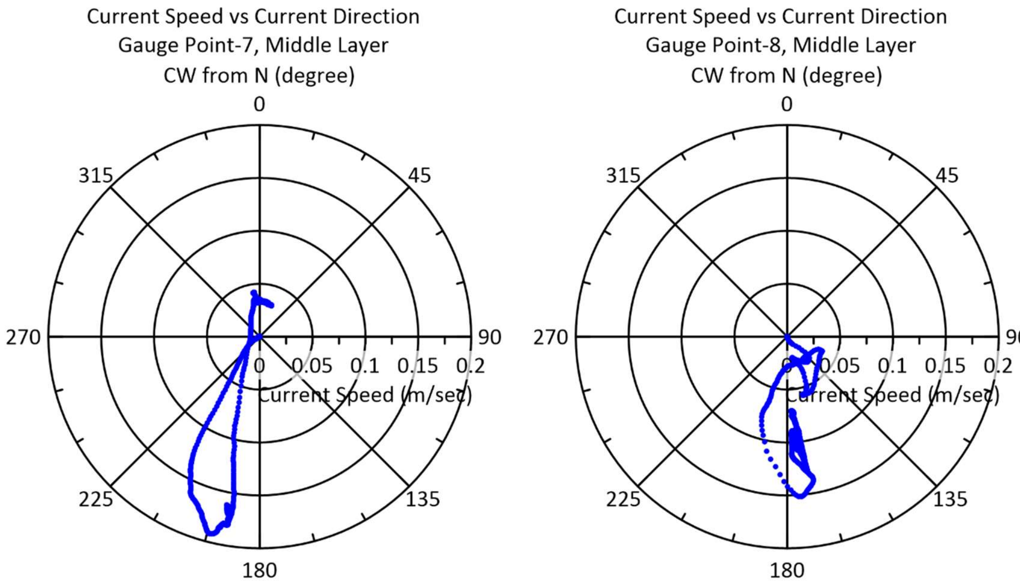


Figure 6.39. Current speed and current direction at Gauge Point 7 and Gauge Point 8 (5 m/sec wind blowing from NNW direction)

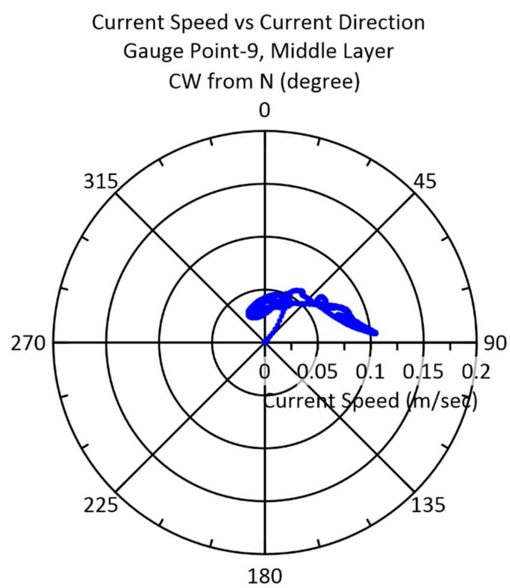


Figure 6.40. Current speed and current direction at Gauge Point 9 (5 m/sec wind blowing from NNW direction)

Table 6.19. Computed volumetric discharges during 5 m/sec wind blowing from NNW direction

Gauge Point	Water Depth at Gauge Points (m)	Cross Sectional Area (m^2)	Volumetric Discharge (10^6 m^3)	Flow Direction	Location Name
1	11.4	2233	3.53	Inflow	Fethiye Bay
2	28.8	7536	-3.49	Outflow	
3	50.0	26768	24.95	Inflow	Göcek Bay
4	59.0	26748	-24.93	Outflow	
5	49.0	23051	-8.39	Outflow	Dalaman-Göcek Bays
6	25.2	5252	0.78	Inflow	
7	100.0	131916	-12.44	Outflow	
8	15.0	2628	-4.94	Outflow	
9	11.8	1356	0.30	Inflow	

Table 6.20. Total volumes and percentages of water exchanged in Fethiye, Göcek and Dalaman-Göcek Bays 5 m/sec wind blowing from NNW direction

Name of the Bay	Total volume of water in the bay (10^6 m^3)	Total volume of water **entered** the bay (10^6 m^3)	Total volume of water **left** the bay (10^6 m^3)	% Exchanged Volume
Fethiye	67.65	3.53	-3.49	5.19
Göcek	132.73	24.95	-24.93	18.79
Dalaman - Göcek	1147.58	26.03	-25.77	2.26

In according with the polar plots and tables, 5 m/sec NNW directed winds pushes 3.5 million m^3 water into Fethiye Bay from channel 1 and same amount of water is discharged out of the bay from channel 2 after circulating inside the bay.

At the end of scenario 04 (a), approximately 24.9 million m^3 water is transferred through the straits of Göcek Bay.

In Dalaman-Göcek Bays, under the effect of the wind blowing from NNW direction, water entering from channels 3, 6 and 9, leaves the bay from channels 5, 7 and 8.

Table 6.21. Computed volumetric discharges during 10 m/sec wind blowing from NNW direction

Gauge Point	Water Depth at Gauge Points (m)	Cross Sectional Area (m^2)	Volumetric Discharge (10^6 m^3)	Flow Direction	Location Name
1	11.4	2233	4.36	Inflow	Fethiye Bay
2	28.8	7536	-4.34	Outflow	
3	50.0	26768	-14.94	Outflow	Göcek Bay
4	59.0	26748	14.93	Inflow	
5	49.0	23051	-42.13	Outflow	Dalaman-Göcek Bays
6	25.2	5252	-1.02	Outflow	
7	100.0	131916	71.94	Inflow	
8	15.0	2628	-11.39	Outflow	
9	11.8	1356	-2.32	Outflow	

Table 6.22. Total volumes and percentages of water exchanged in Fethiye, Göcek and Dalaman-Göcek Bays 10 m/sec wind blowing from NNW direction

Name of the Bay	Total volume of water in the bay (10^6 m^3)	Total volume of water **entered** the bay (10^6 m^3)	Total volume of water **left** the bay (10^6 m^3)	% Exchanged Volume
Fethiye	67.65	4.36	-4.34	6.43
Göcek	132.73	14.93	-14.94	11.25
Dalaman - Göcek	1147.58	71.94	-71.80	6.26

The only difference between two scenarios is the wind speed. In scenario 04 (b), wind speed is selected as 10 m/sec and the simulation results of wind blowing with a speed of 10 m/sec are presented in above tables.

By the time wind speed is increased to 10 m/sec, water exchange values for Fethiye and Dalaman-Göcek Bays increase. On the contrary, with constant wind direction and increasing wind speed, the amount of water exchange through Göcek Bay decreases.

CHAPTER 7

CONCLUSION AND DISCUSSIONS

In this study, the total volume and percentage of water exchanges under three different forcing mechanisms; Coriolis force, tidal wave and wind forcing, are performed individually and compared by using MIKE 3 Flow Model Flexible Mesh – Hydrodynamic Module.

MIKE 3 Flow Model FM – HD solves three-dimensional incompressible Reynolds averaged Navier-Stokes equations (RANS) based on Boussinesq and of hydrostatic pressure assumptions by using a cell-centered technique; Finite Volume Method (FVM).

Firstly, Coriolis force is applied for 24-hours duration by using the latitude of the study area. Secondly, the tidal wave having an amplitude of 24 cm and period of 12 hours is simulated for 24-hours. The primary tidal constituent is selected as M2 – Semidiurnal Lunar. Lastly, for Fethiye-Göcek Bays, four perpendicular wind directions; ENE, SSE, WSW and NNW with a representative constant wind speed of 5 m/sec and 10 m/sec blowing for 12 hours' duration are given as inputs for the simulations. The wind inputs are selected according to the long-term wind statistics analysis.

In order to make better comparisons, a summary table showing the water exchange percentages in Fethiye Bay, Göcek Bay and Dalaman-Göcek Bays for each forcing mechanism is presented in Table 7.1.

Table 7.1. Total percentages of water exchanged in Fethiye, Göcek and Dalaman-Göcek Bays under all forcing mechanisms

Forcing Mechanism	Simulation Duration (hour)	Total Percentage of Water Exchange (%)		
		Fethiye Bay	Göcek Bay	Dalaman-Göcek Bays
Coriolis Force	24	3.04	2.52	0.31
Tidal Wave	24	3.23	0.57	1.35
ENE - 5 m/sec	12	1.03	4.74	6.04
ENE - 10 m/sec	12	0.29	6.71	1.79
SSE - 5 m/sec	12	6.83	2.62	2.43
SSE - 10 m/sec	12	7.59	12.84	6.48
WSW - 5 m/sec	12	2.74	12.53	3.38
WSW - 10 m/sec	12	0.48	5.83	5.18
NNW - 5 m/sec	12	5.19	18.79	2.26
NNW - 10 m/sec	12	6.43	11.25	6.26

Considering the computed current speeds, directions and computed volumetric discharges in Fethiye Bay, it is understood that tidal flushing is weak and therefore the effect of tidal forcing on water exchange and circulation is weak in Fethiye, Göcek and Dalaman-Göcek Bays. Tidal wave simulation results were examined, and it can be concluded that the water exchange depends on the bathymetry, topography of the study domain and tidal wave parameters (tidal period, tidal amplitude and tidal constituents).

When the results of simulations using 24-hours of Coriolis force and tidal wave acting separately on the study domain are compared, it is observed that the amount of total water exchange amount in the straits of the bays are weak (less than 3%) for 24 hours duration.

The results of simulations with 2 different wind speed and 4 different wind directions blowing 10 hours duration after 2 hours ramp, are compared. Due to geographical position of the straits of Fethiye Bay, wind blowing from ENE and WSW, does not have significant impact on water exchange in the bay. On the other hand, under SSE and NNW directed wind conditions, a certain amount of water exchange takes place. In the case of Göcek Bay, all wind directions; ENE, SSE, WSW and NNW, contribute a fair amount of water volume exchanged through the straits (3 and 4) of the bay. Likewise, the geographical location and topography may also have been effective. Yet another bay, the water transfer in Dalaman-Göcek Bays is controlled and dominated by large and small islands scattered in the area. In Dalaman-Göcek Bays, winds blowing from 4 different directions, contribute to water exchange in the range of 1.7 % to 6.5 % of the total volume in the bays.

For all wind directions, changing the wind speed can lead to different consequences. This means that, if the wind speed is increased from 5 m/sec to 10 m/sec (i.e. wind speed is doubled), the water exchange does not necessarily be double, even a decrease can be observed.

When the effect of Coriolis, tidal and wind force on Fethiye, Göcek and Dalaman-Göcek Bays are analyzed, it is obtained that wind forcing is the primary triggering factor for the formation of coastal currents.

The concluding remarks of this thesis study are presented as follows:

- A rise in the wind speed does not guarantee that the water exchange will also increase for every location all the time.
- One of the key factors that affects the amount of water exchange is the wind blowing direction. The topography of the study area also plays an important role in this manner. In other words, at any particular point, for a constant wind speed, the change in wind direction may increase or decrease the amount of water exchange with respect to topography. For instance, while a mountain can block the wind, an open valley can allow the wind to pass.
- In the case of a scenario presented in this study, where the wind blowing direction is kept constant (going from scenario (a) to (b)), increasing the wind speed does not always assures an increase in exchanged water amount.

- The total water exchange under three forcing mechanisms; Coriolis, tide and wind forces, are in the order of 5 % of the total water volume of the bays.

As for the recommendations and suggestions for future studies, the followings are listed;

- In order to look for solutions to increase water circulation inside Dalaman-Göcek Bays and increase of water exchange in these bays with the offshore, an artificial channel can be opened at Kapıdağ Peninsula as a potential future development plan if applicable. The performance of the artificial channel can be investigated under Coriolis, tide and wind scenarios as an alternative case for further research. However, there may be artefacts at the site which may prevent the application of development plans.
- To simplify the wind input (wind speed and direction) for the simulations, constant wind speed and direction is considered. However, it is also possible to consider variable wind speed and direction to investigate the effect of changing wind speed and direction for future studies.
- In this thesis study, water inputs from three streams (Kargı, Murt, T2 DSI) discharging into Fethiye-Göcek Bay is neglected. It is suggested that further studies can be performed by including the discharges from these rivers. The river discharges may affect the temperature and salinity of the area that it flows into the sea. Also, discharges from the rivers may influence and trigger the currents and circulation near the river mouth.
- Instead of barotropic mode, it can be suggested that in further studies, baroclinic mode can be considered to include the effect of salinity and temperature into the model. In baroclinic mode, density is a function of pressure only, but in latter case, it is function of pressure, salinity and temperature.

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APPENDICES

APPENDIX A CIRCULATION PATTERNS AT FETHIYE AND GOCEK BAYS UNDER CORIOLIS FORCE

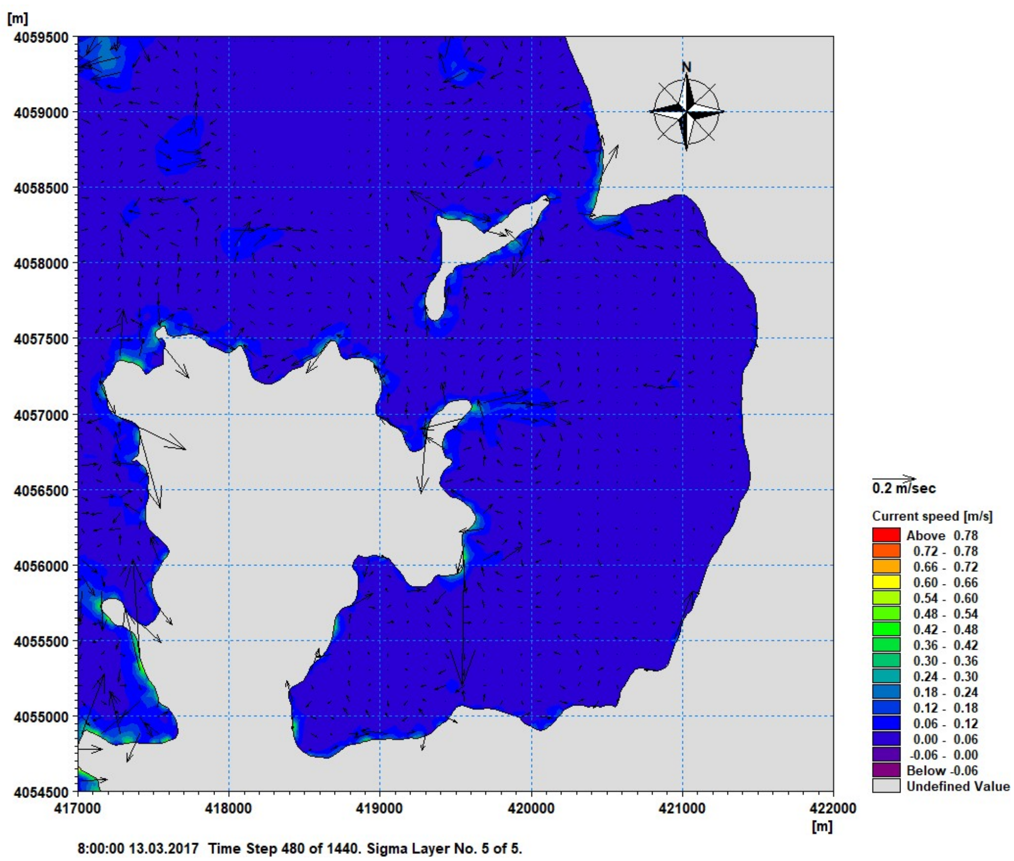


Figure A.1. Circulation pattern at Fethiye Bay at 8th hour under 24 hours of Coriolis forcing

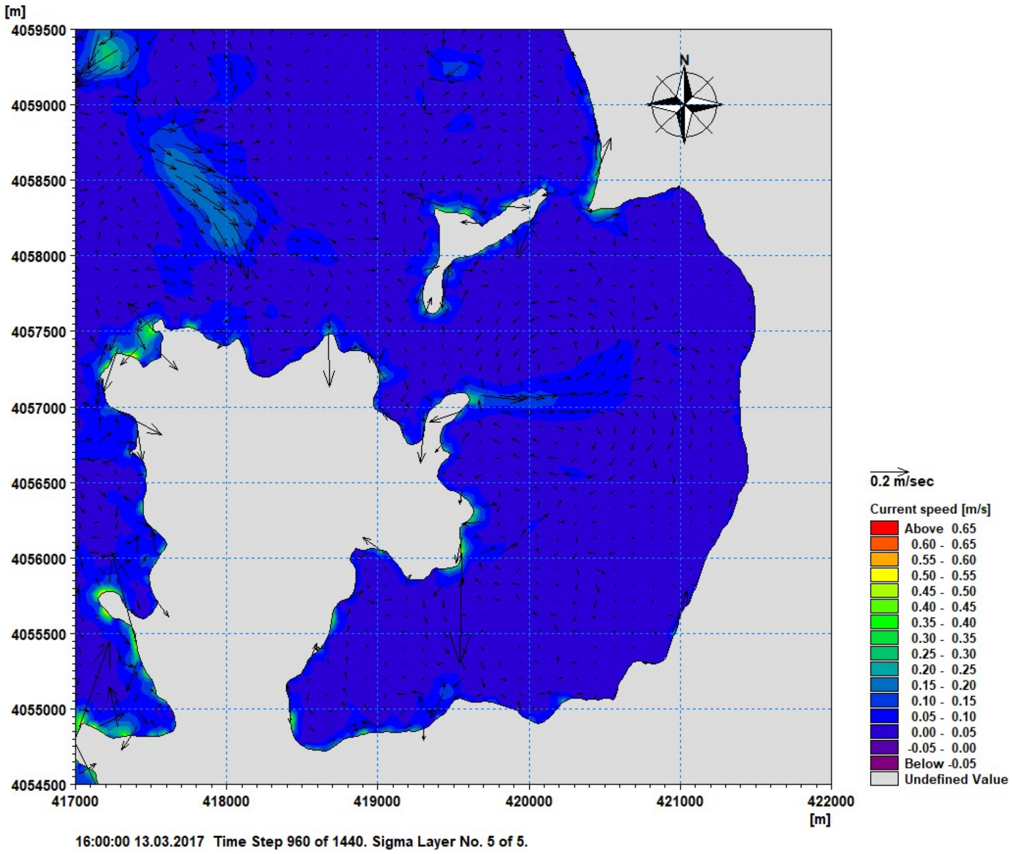


Figure A.2. Circulation pattern at Fethiye Bay at 16th hour under 24 hours of Coriolis forcing

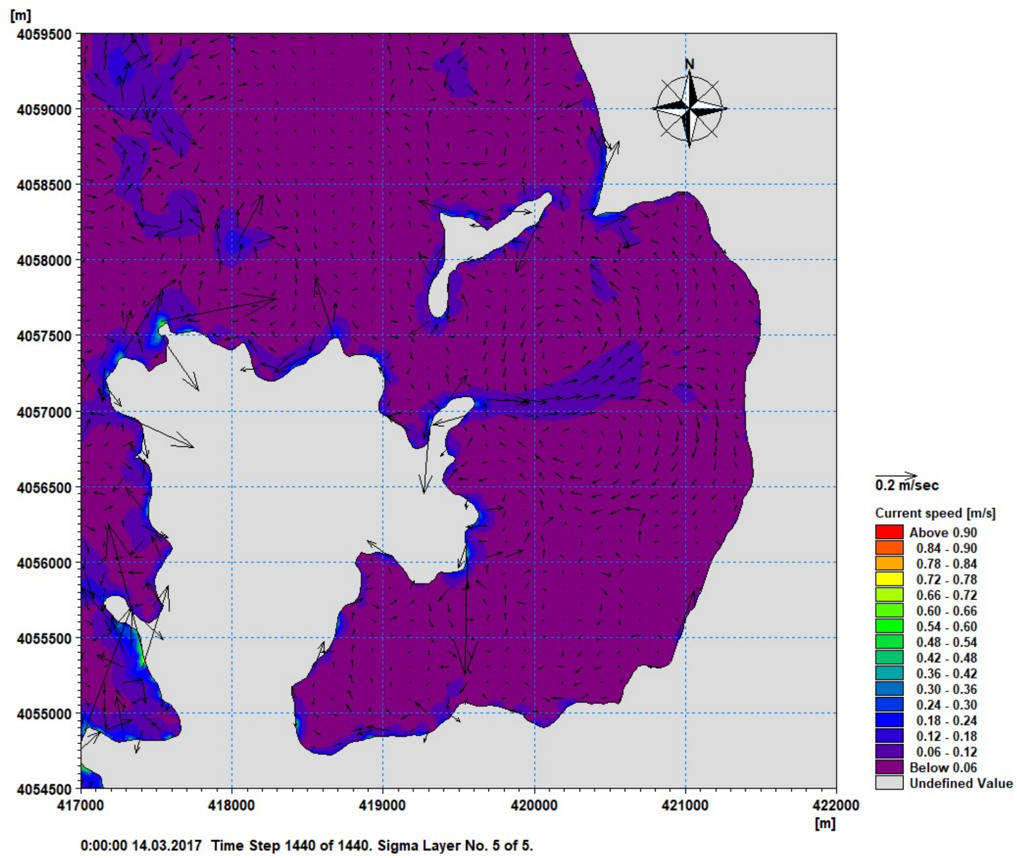


Figure A.3. Circulation pattern at Fethiye Bay at 24th hour under 24 hours of Coriolis forcing

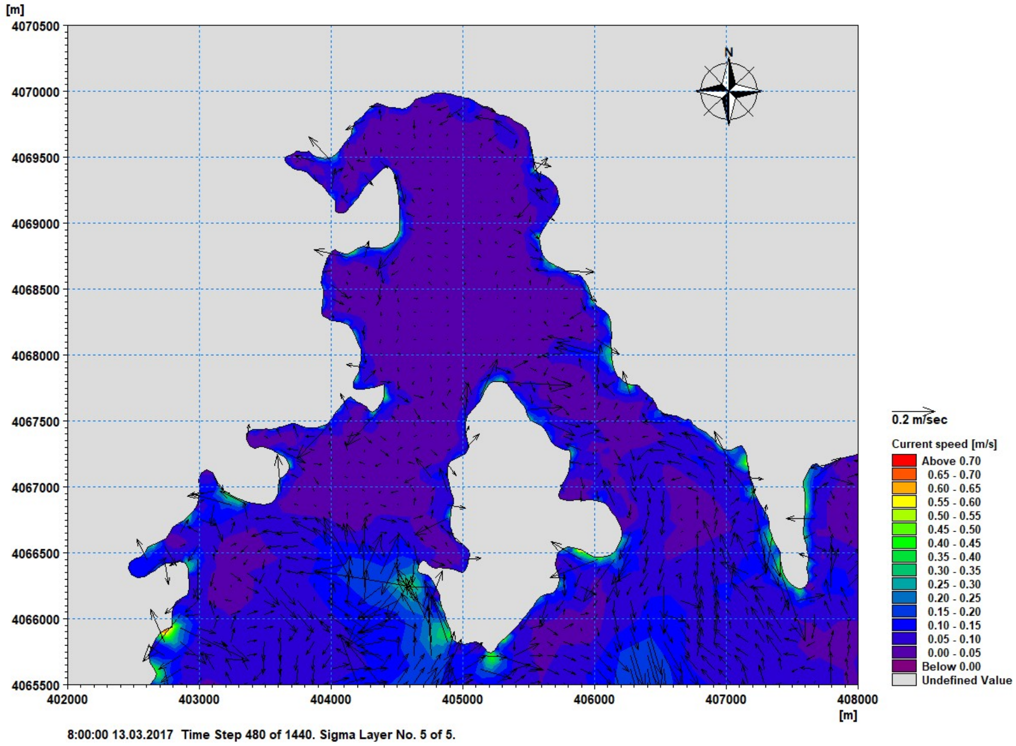


Figure A.4. Circulation pattern at Göcek Bay at 8th hour under 24 hours of Coriolis forcing

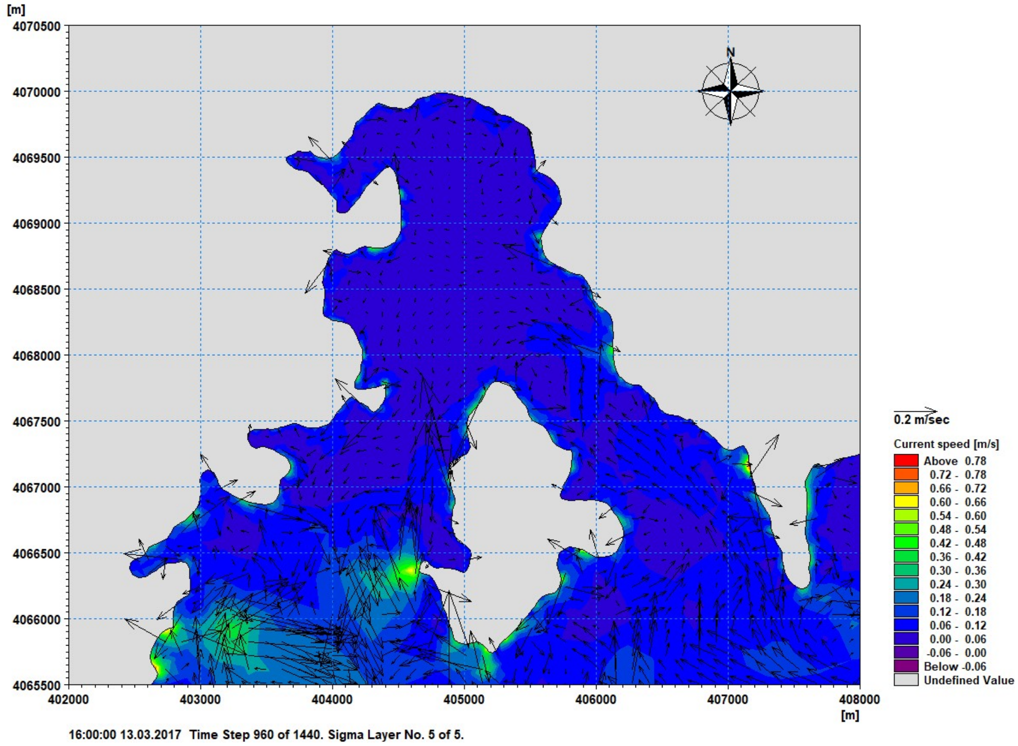


Figure A.5. Circulation pattern at Göcek Bay at 16th hour under 24 hours of Coriolis forcing

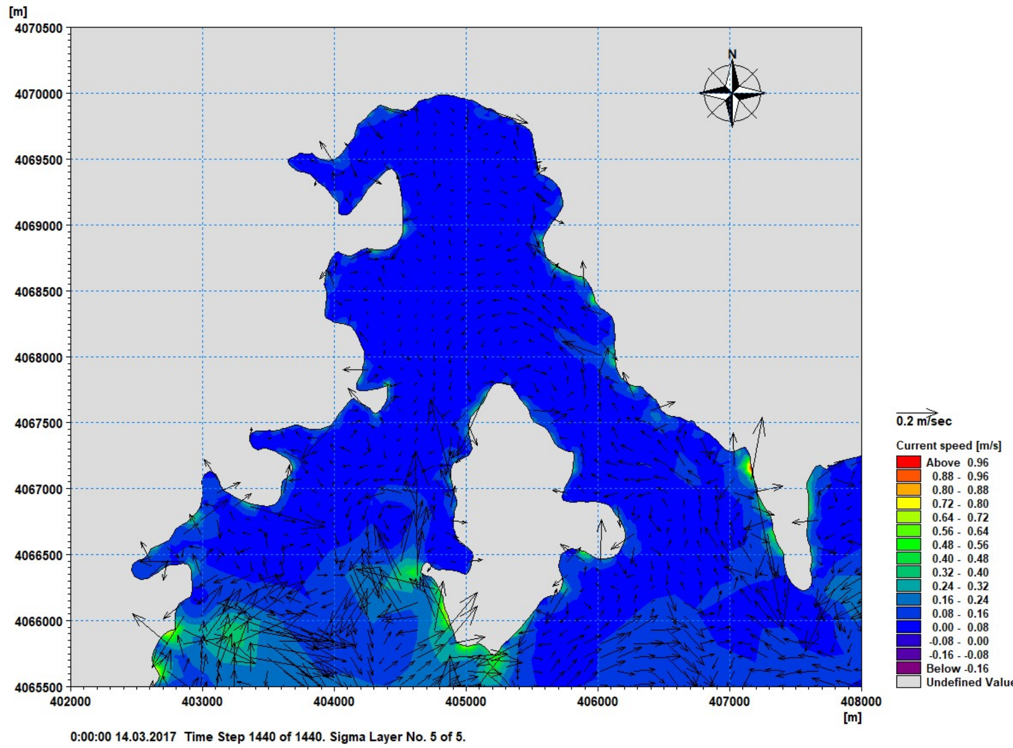


Figure A.6. Circulation pattern at Göcek Bay at 24th hour under 24 hours of Coriolis forcing

APPENDIX B CIRCULATION PATTERNS AT FETHIYE AND GOCEK BAYS UNDER TIDAL FORCE

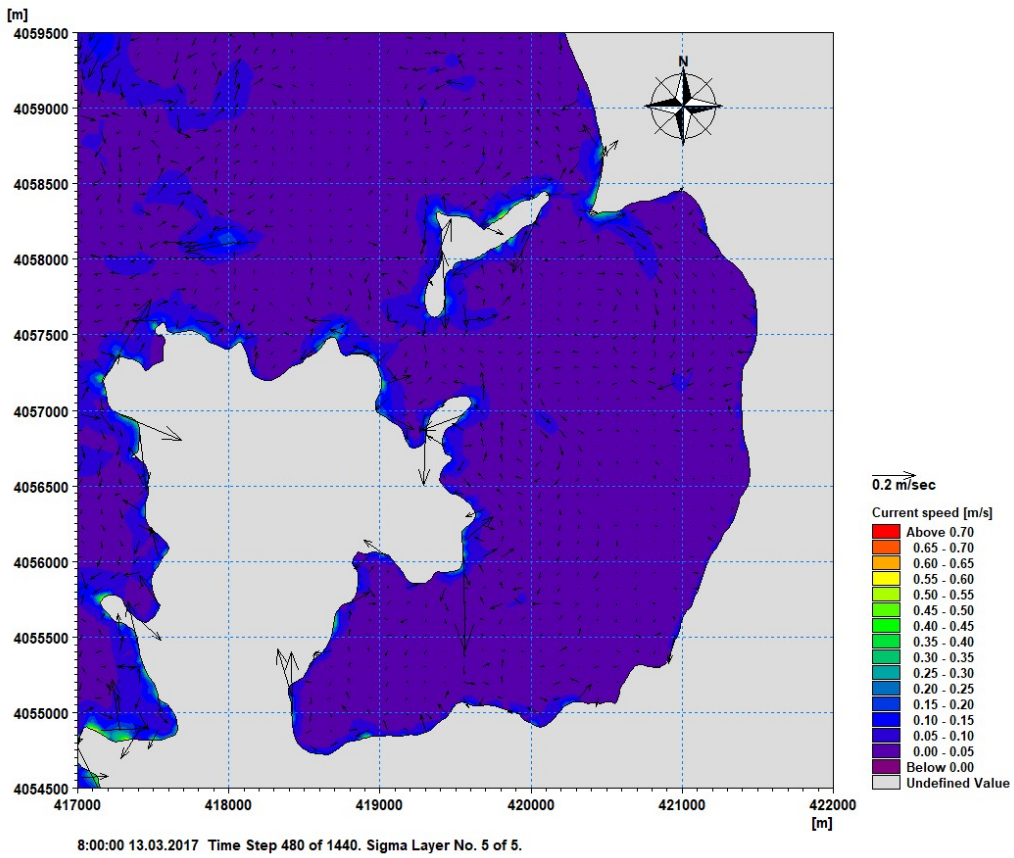


Figure B.1. Circulation pattern at Fethiye Bay at 8th hour under 24 hours of tidal forcing

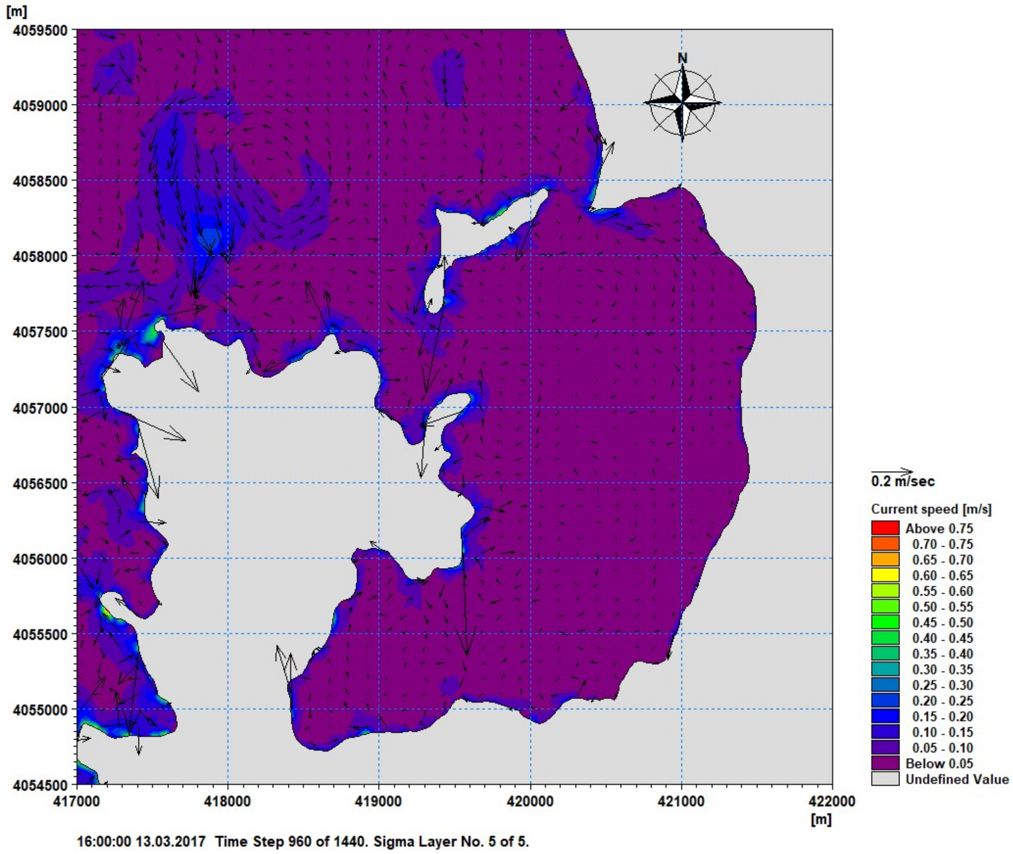


Figure B.2. Circulation pattern at Fethiye Bay at 16th hour under 24 hours of tidal forcing

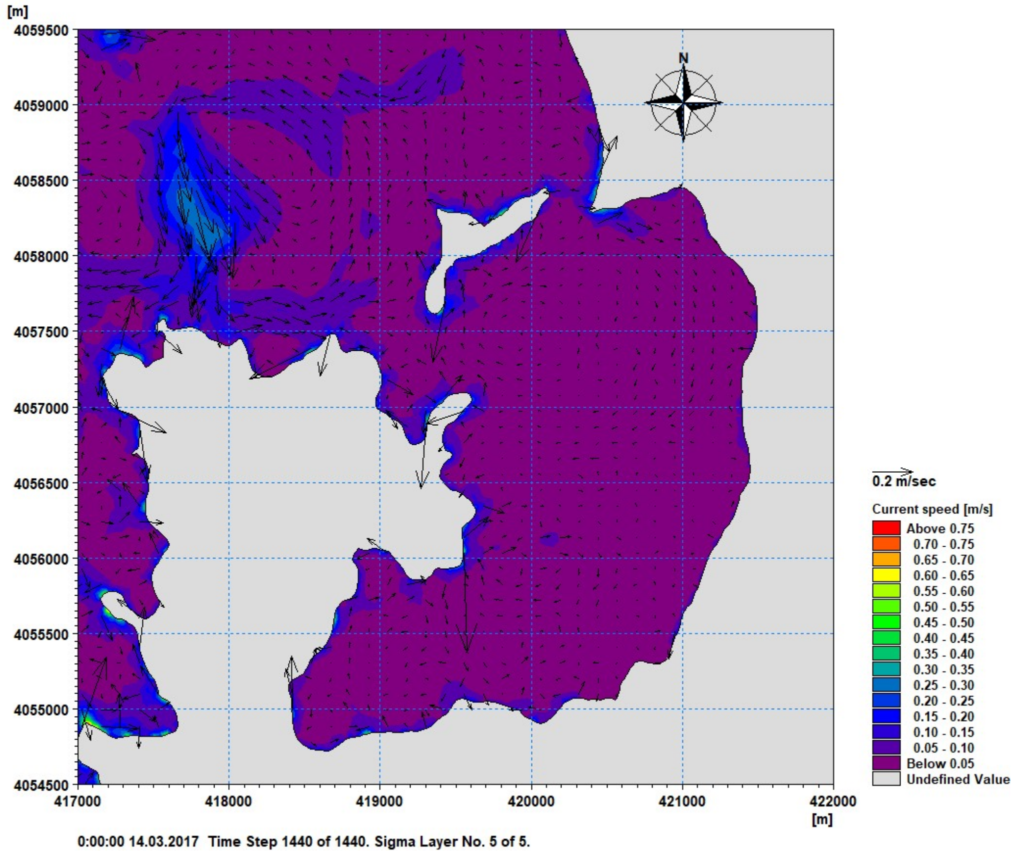


Figure B.3. Circulation pattern at Fethiye Bay at 24th hour under 24 hours of tidal forcing

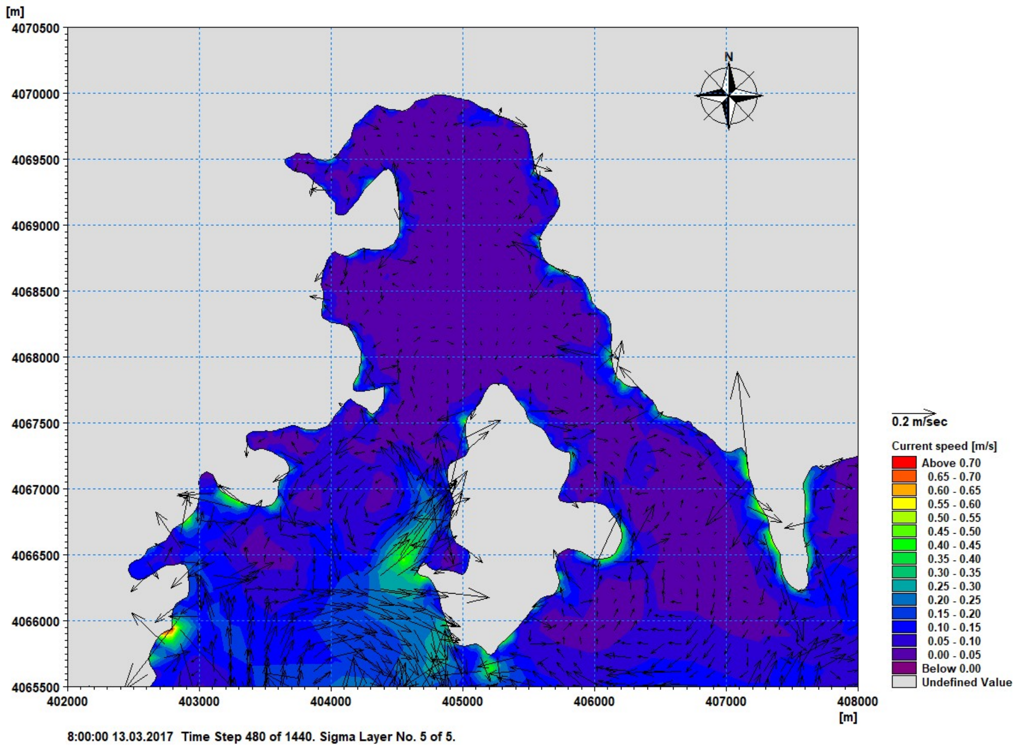


Figure B.4. Circulation pattern at Göcek Bay at 8th hour under 24 hours of tidal forcing

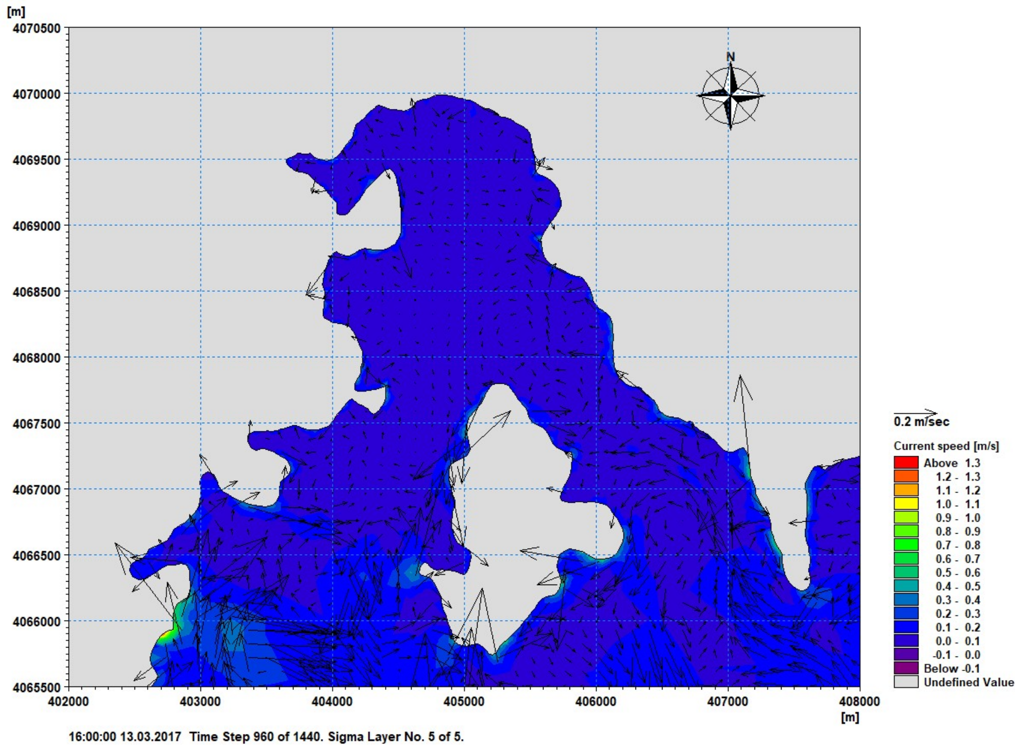


Figure B.5. Circulation pattern at Göcek Bay at 16th hour under 24 hours of tidal forcing

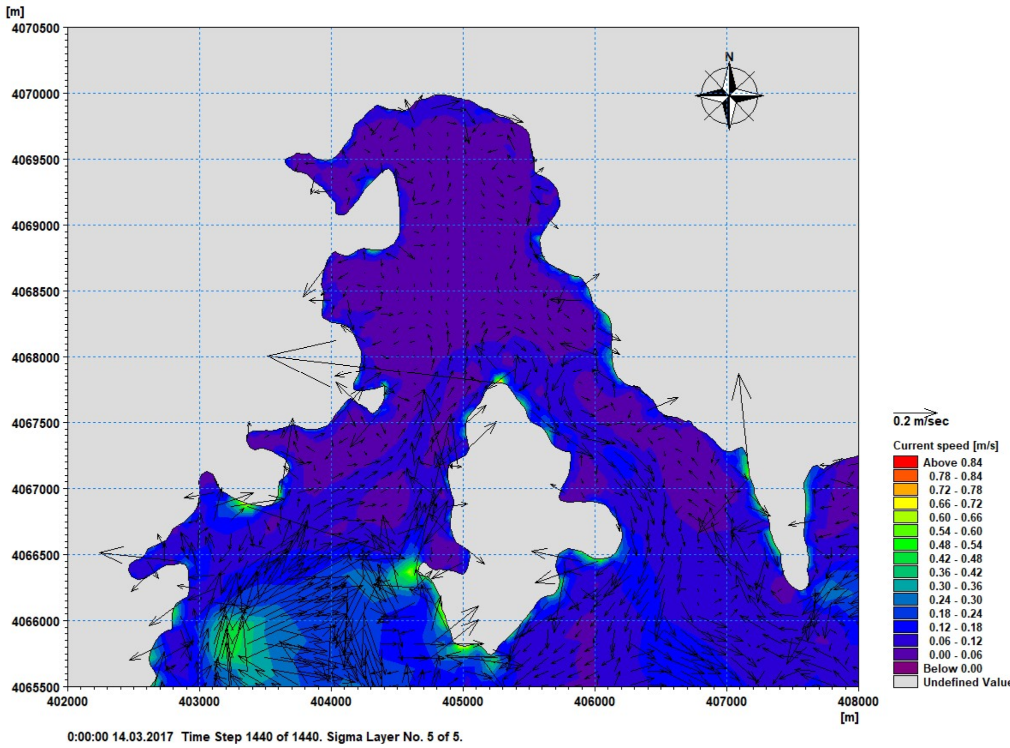


Figure B.6. Circulation pattern at Göcek Bay at 24th hour under 24 hours of tidal forcing

APPENDIX C CIRCULATION PATTERNS AT FETHIYE AND GOCEK BAYS UNDER WIND FORCE (Wind Speed: 5 m/sec-Wind Direction: ENE)

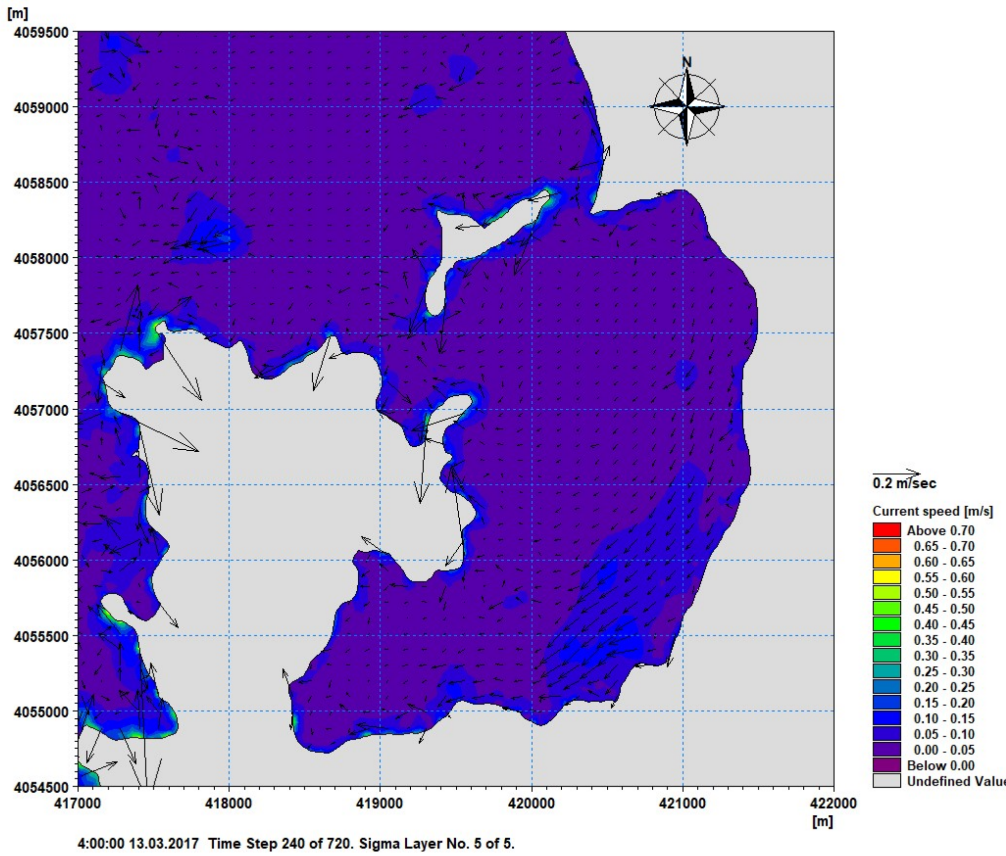


Figure C.1. Circulation pattern at Fethiye Bay at 4th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: ENE)

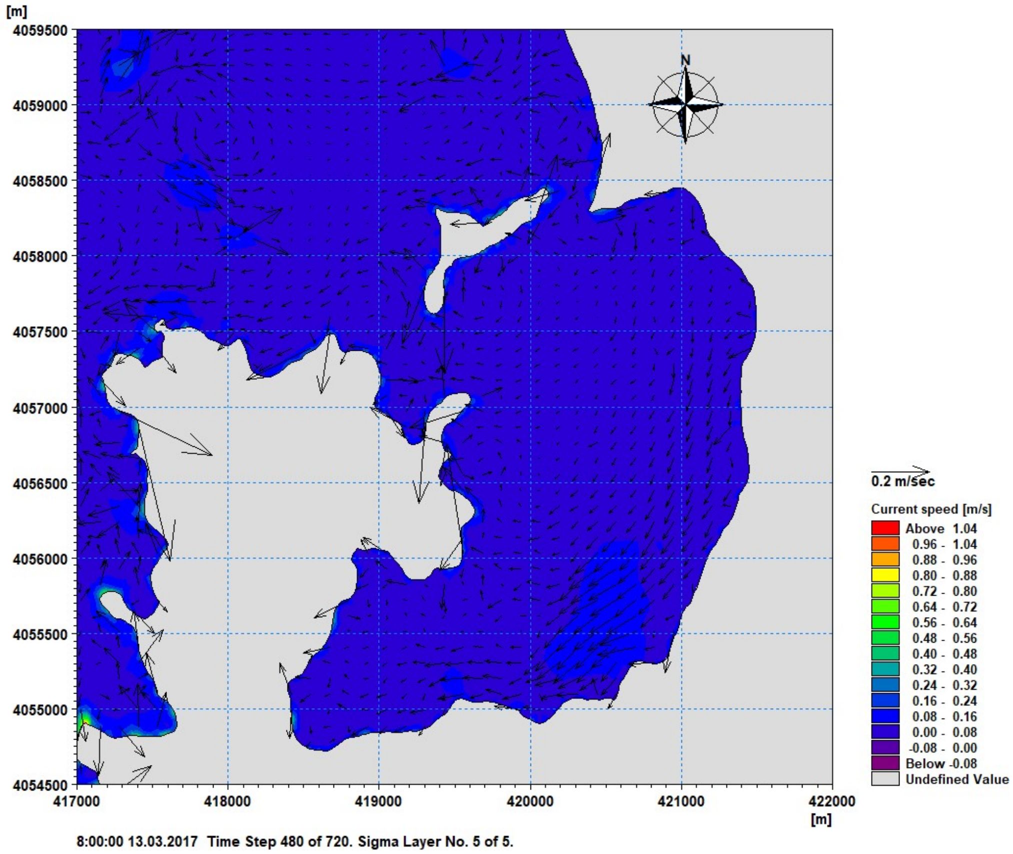


Figure C.2. Circulation pattern at Fethiye Bay at 8th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: ENE)

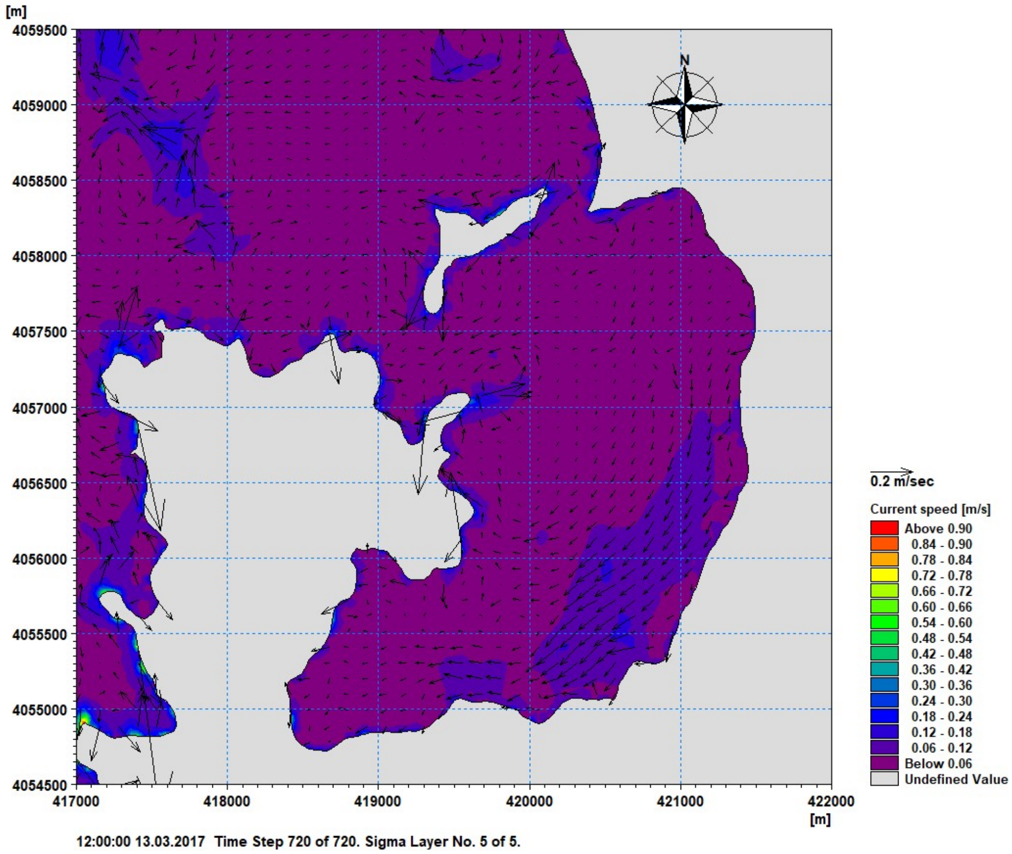


Figure C.3. Circulation pattern at Fethiye Bay at 12th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: ENE)

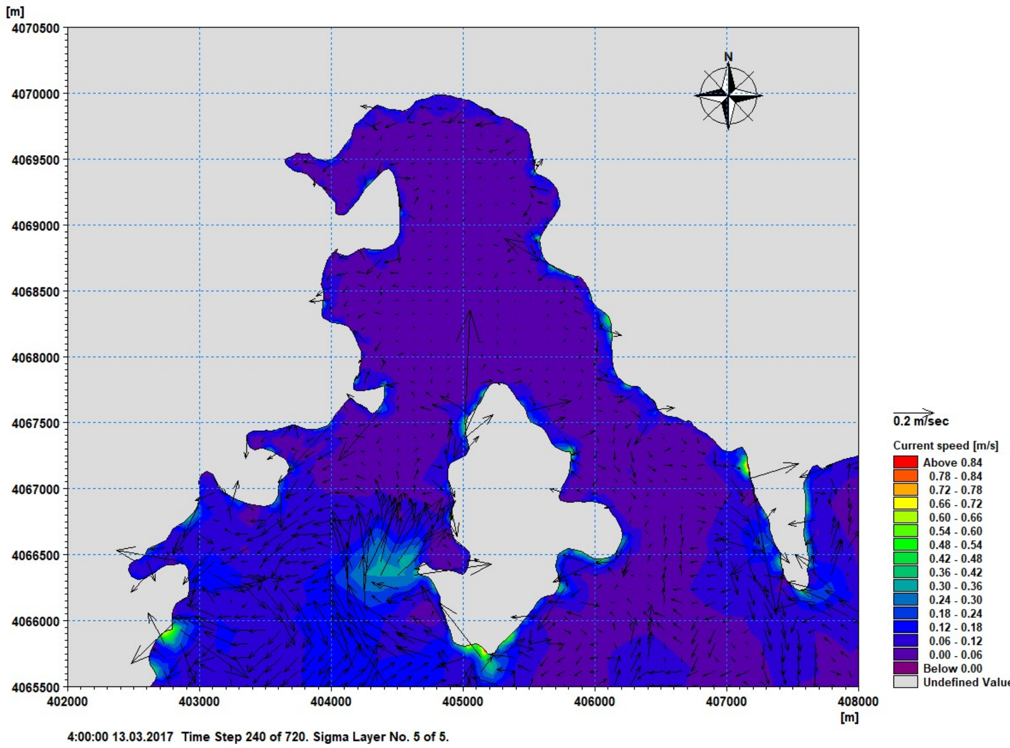


Figure C.4. Circulation pattern at Göcek Bay at 4th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: ENE)

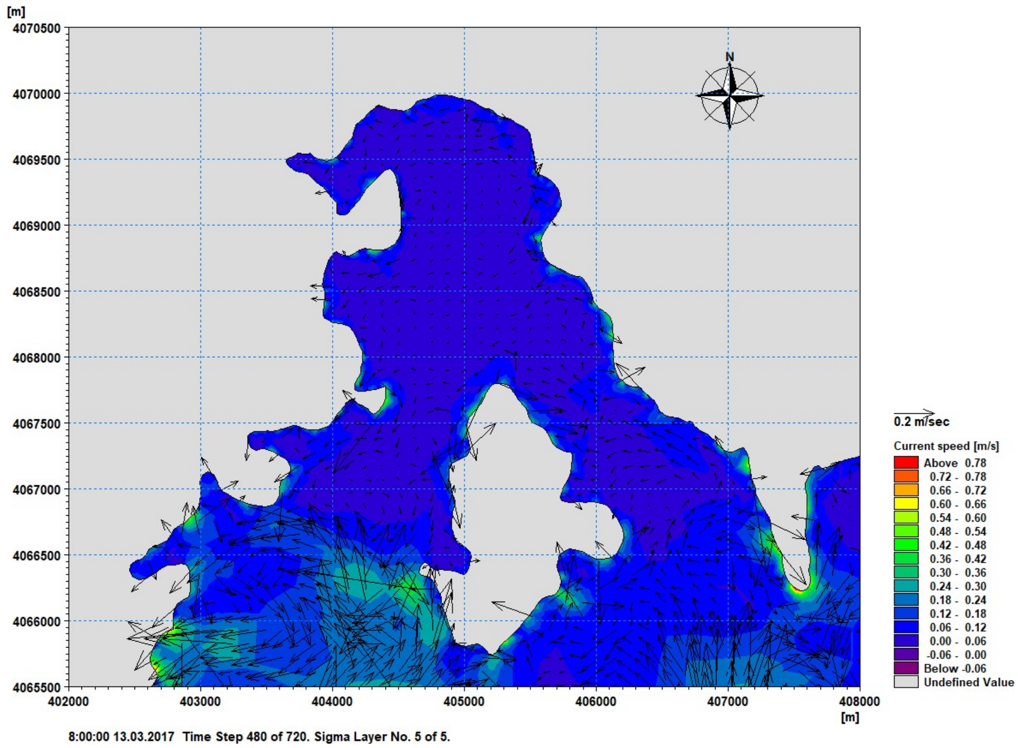


Figure C.5. Circulation pattern at Göcek Bay at 8th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: ENE)

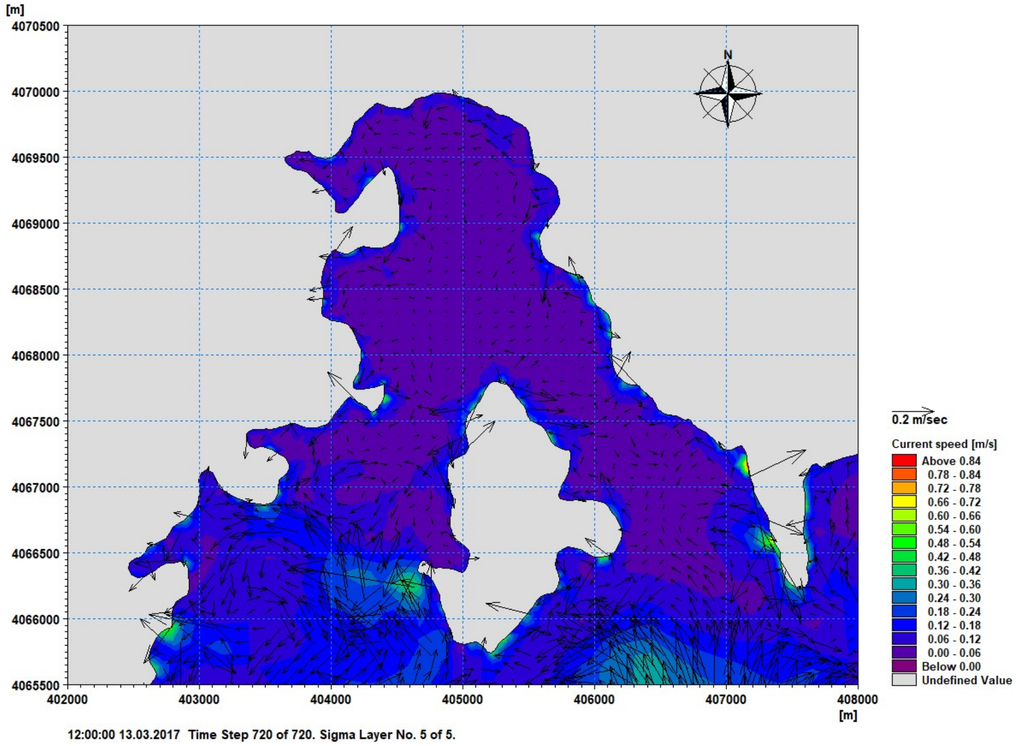


Figure C.6. Circulation pattern at Göcek Bay at 12^{th} hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: ENE)

APPENDIX D CIRCULATION PATTERNS AT FETHIYE AND GOCEK BAYS UNDER WIND FORCE (Wind Speed: 10 m/sec-Wind Direction: ENE)

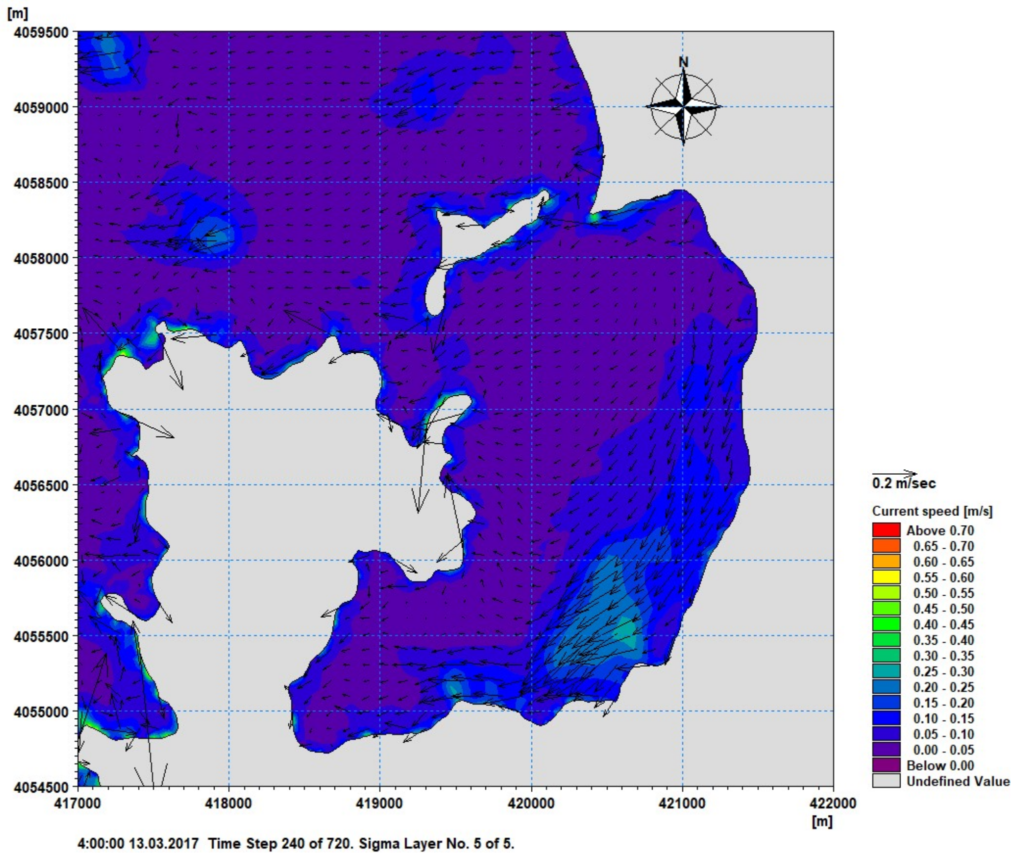


Figure D.1. Circulation pattern at Fethiye Bay at 4th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: ENE)

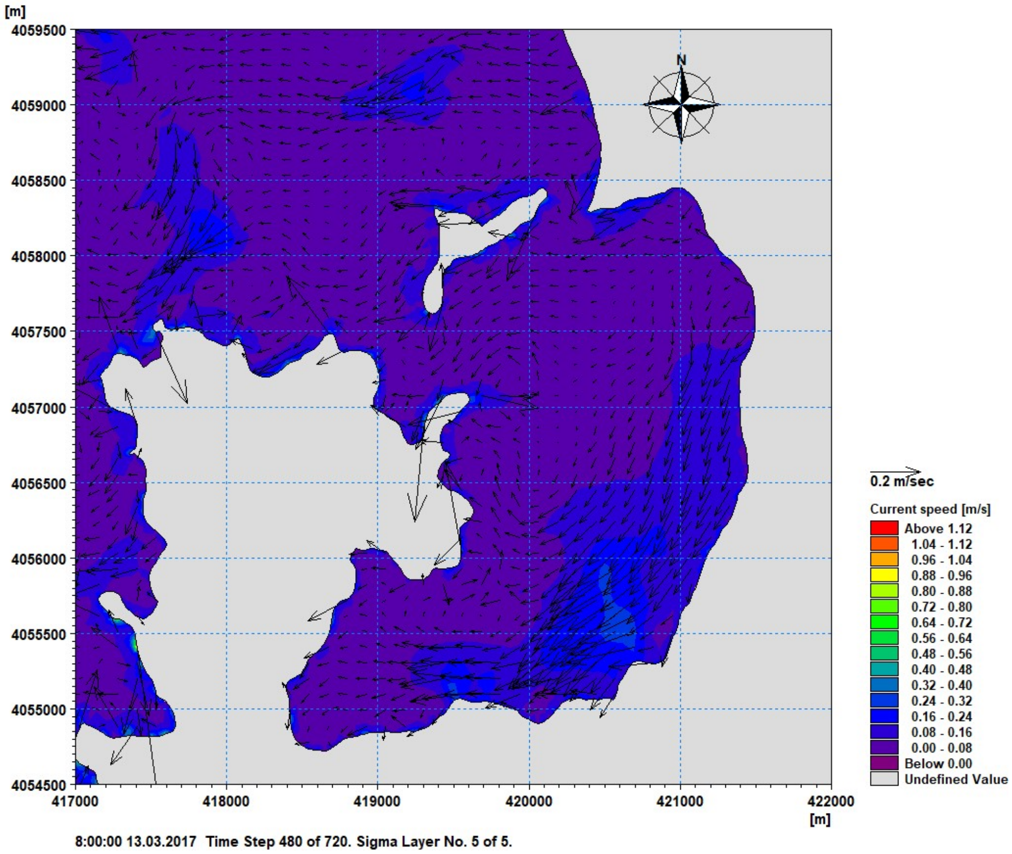


Figure D.2. Circulation pattern at Fethiye Bay at 8th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: ENE)

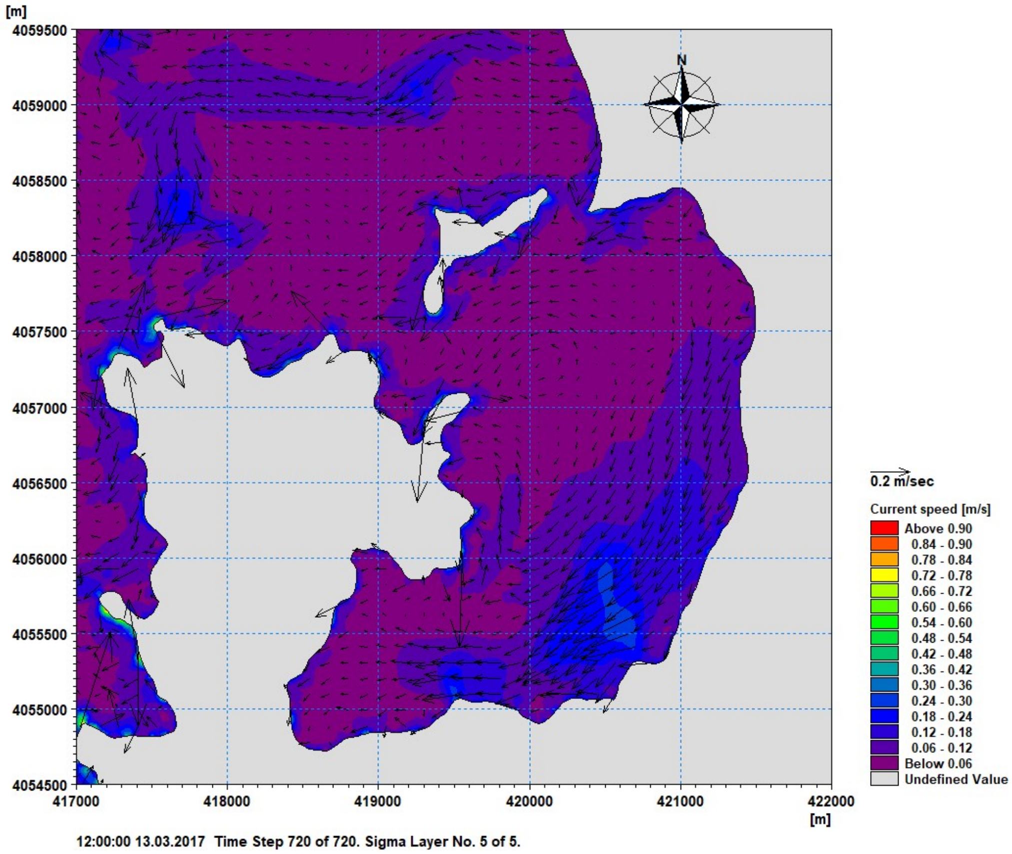


Figure D.3. Circulation pattern at Fethiye Bay at 12th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: ENE)

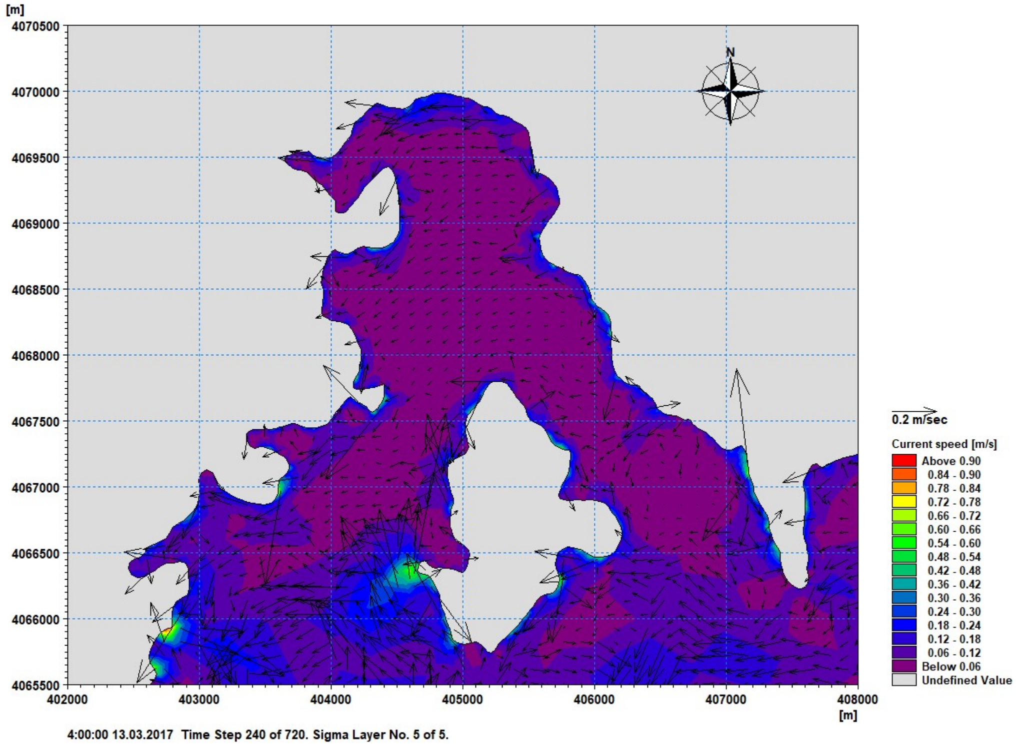


Figure D.4. Circulation pattern at Göcek Bay at 4th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: ENE)

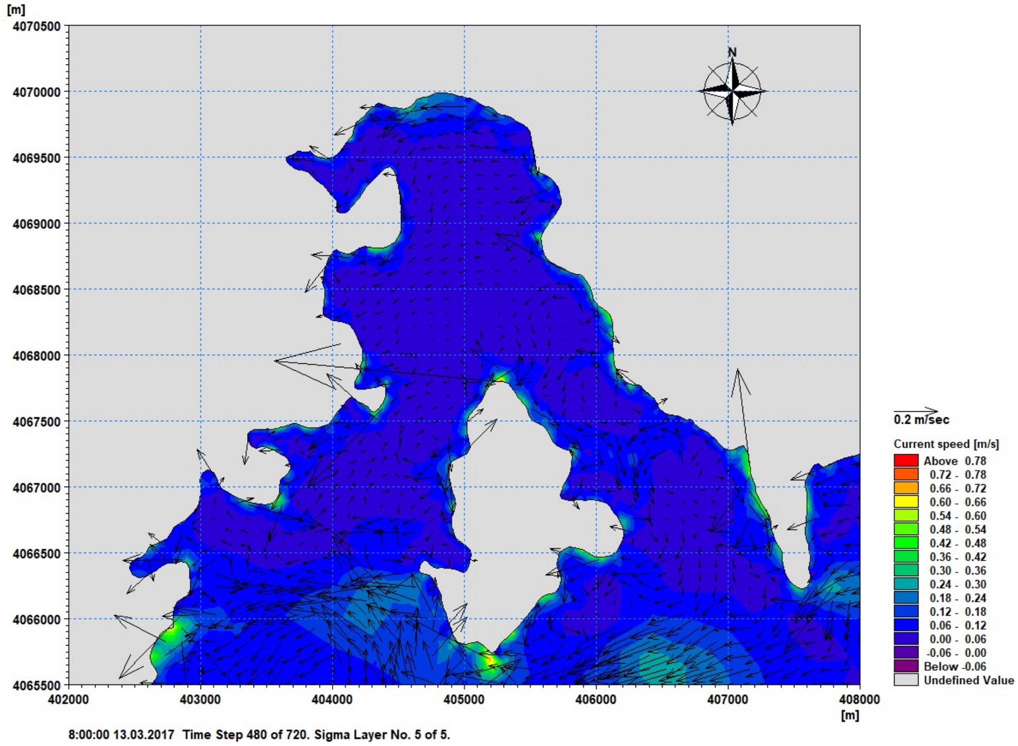


Figure D.5. Circulation pattern at Göcek Bay at 8th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: ENE)

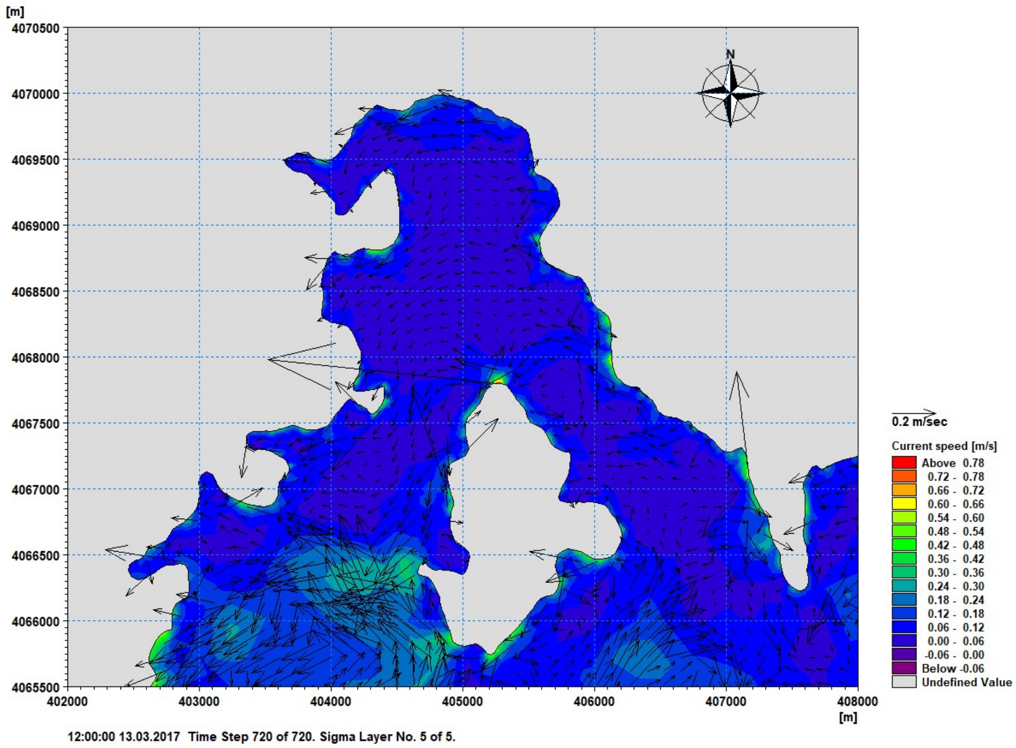


Figure D.6. Circulation pattern at Göcek Bay at 12th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: ENE)

APPENDIX E CIRCULATION PATTERNS AT FETHIYE AND GOCEK BAYS UNDER WIND FORCE (Wind Speed: 5 m/sec-Wind Direction: SSE)

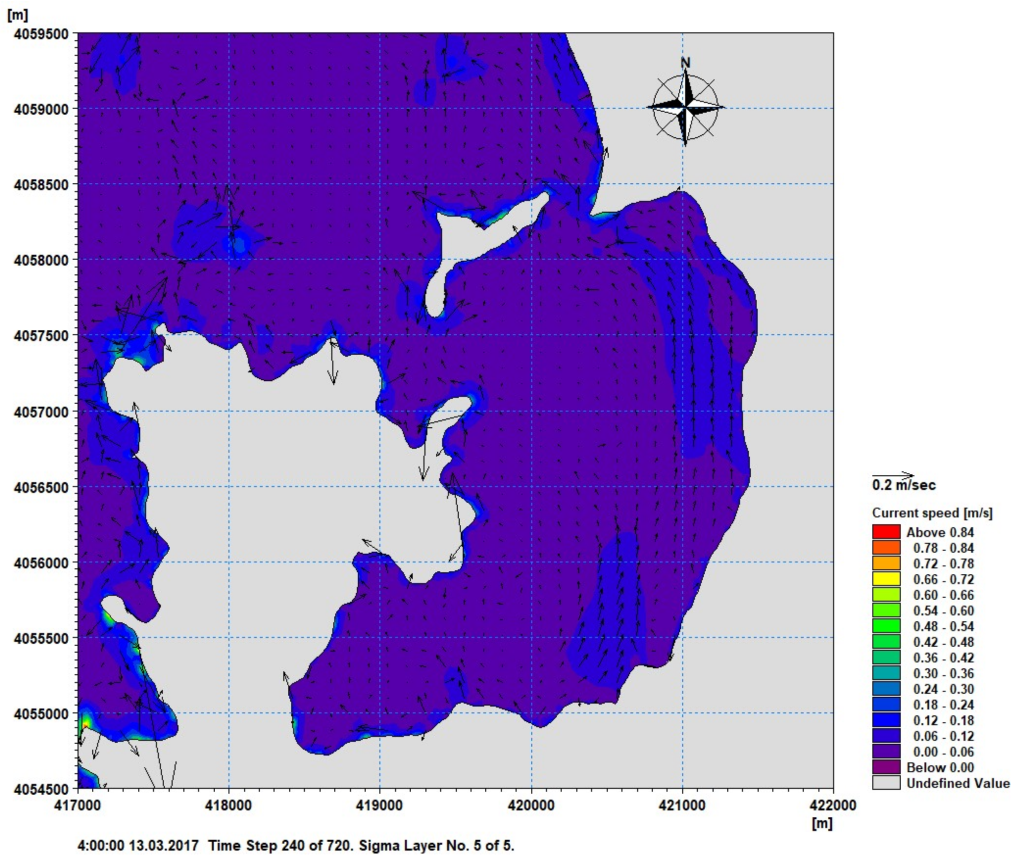
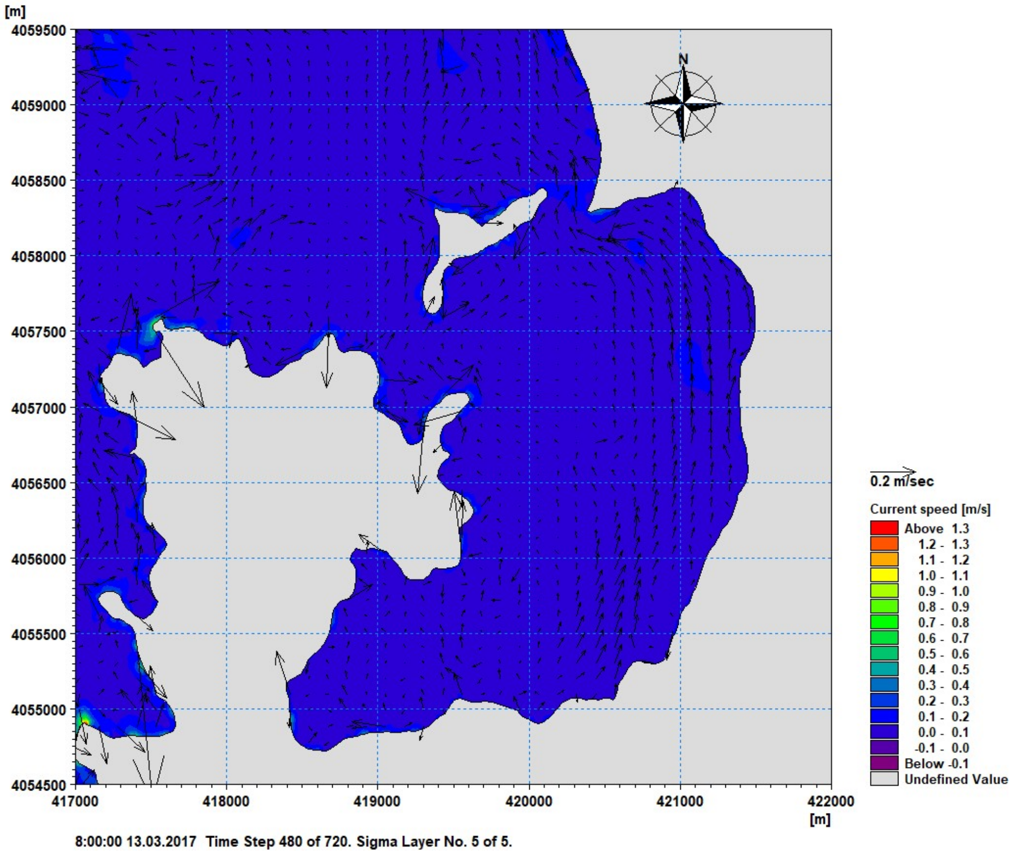


Figure E.1. Circulation pattern at Fethiye Bay at 4th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: SSE)



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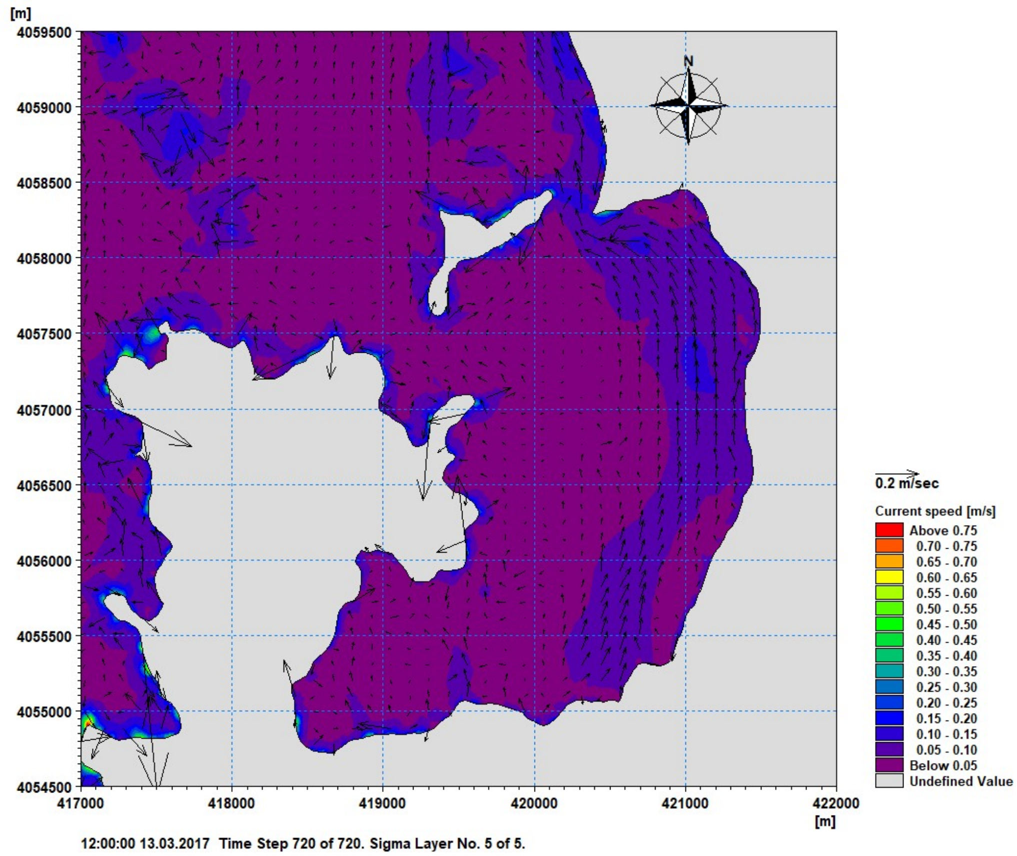

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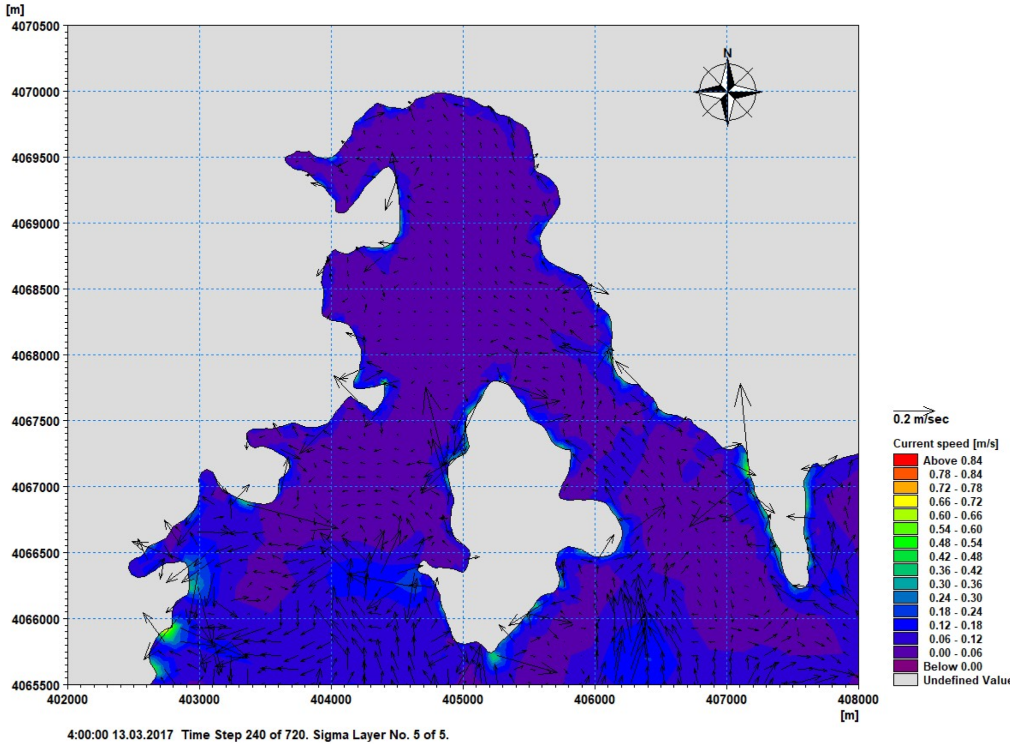

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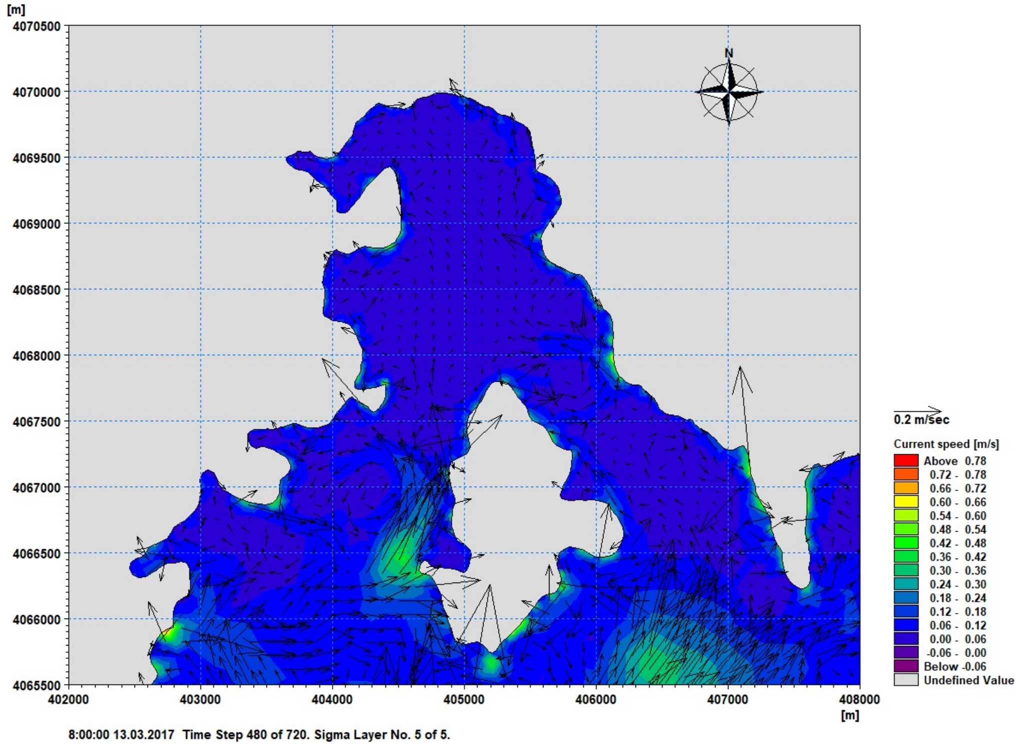

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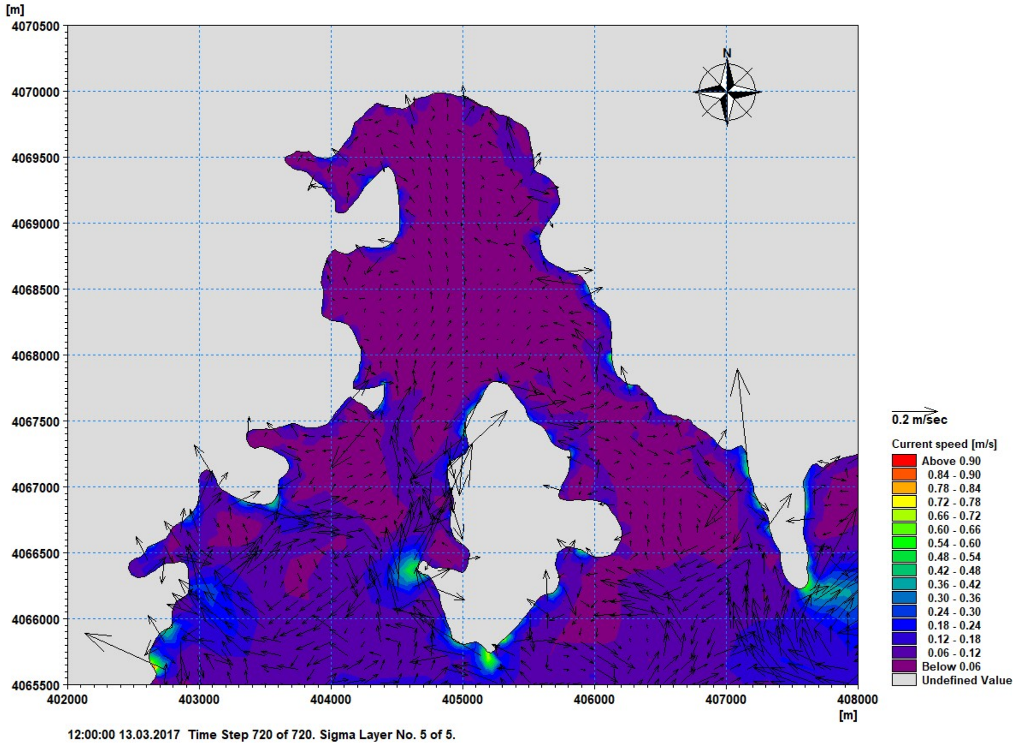
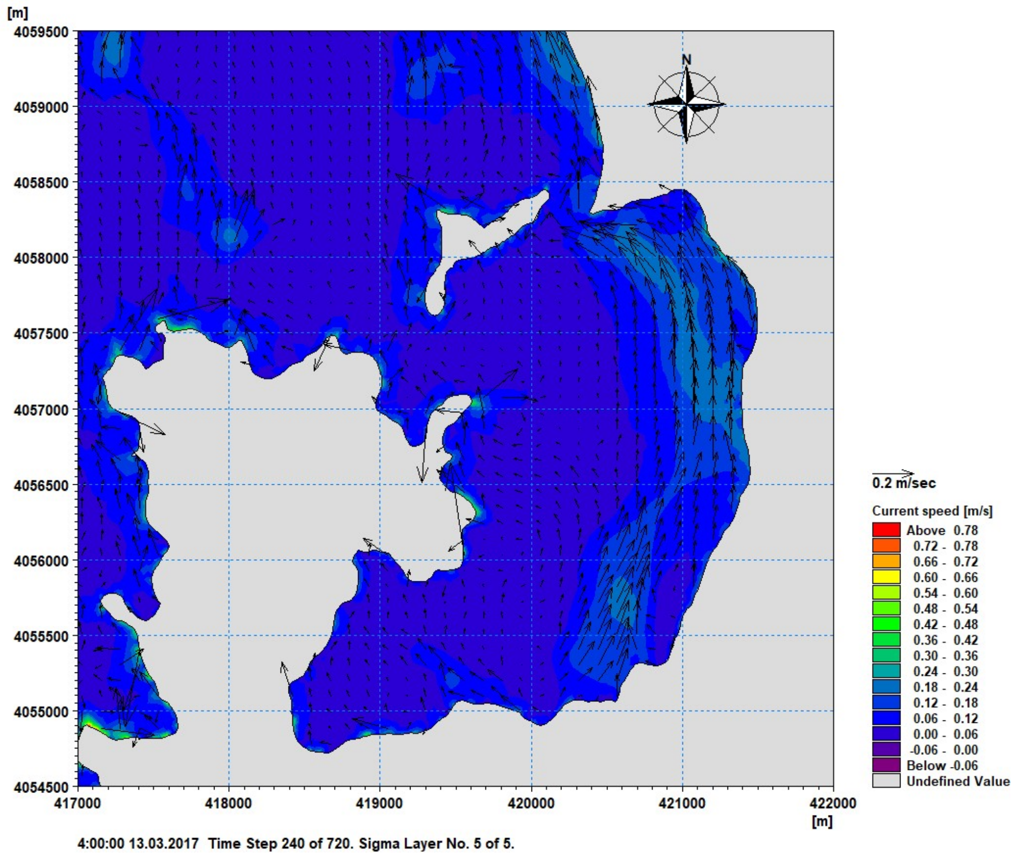


Figure E.6. Circulation pattern at Göcek Bay at 12^{th} hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: SSE)

APPENDIX F CIRCULATION PATTERNS AT FETHIYE AND GOCEK BAYS UNDER WIND FORCE (Wind Speed: 10 m/sec-Wind Direction: SSE)



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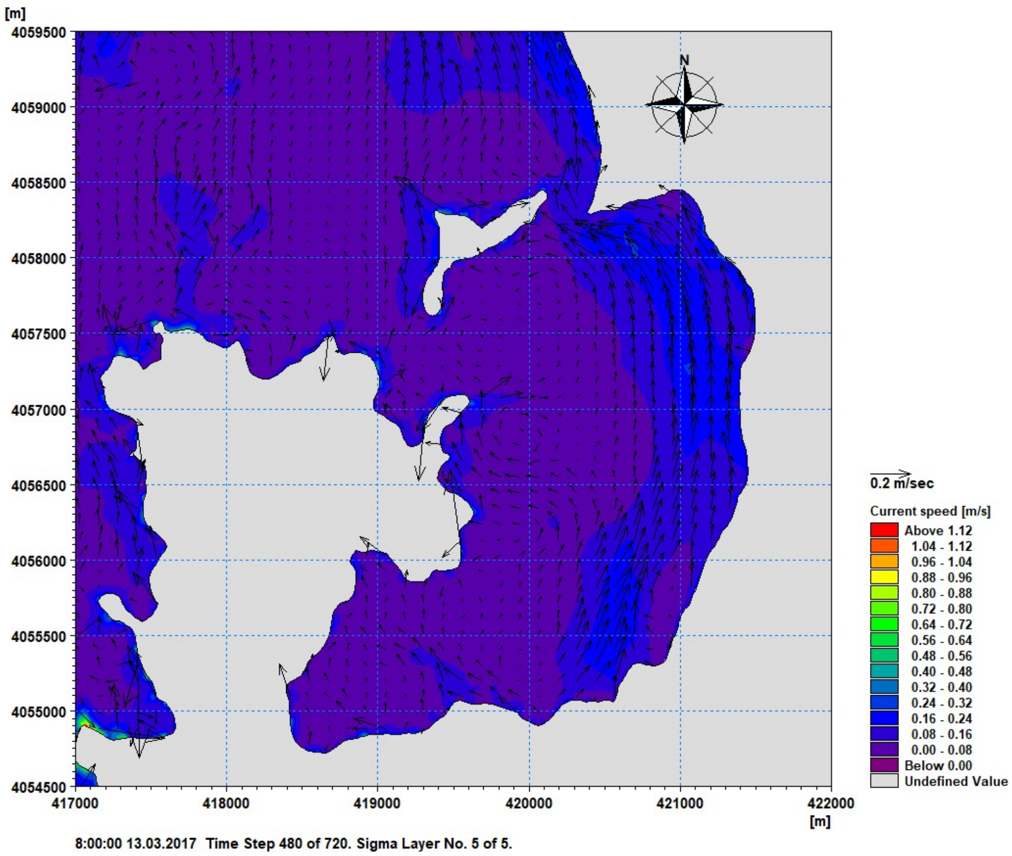

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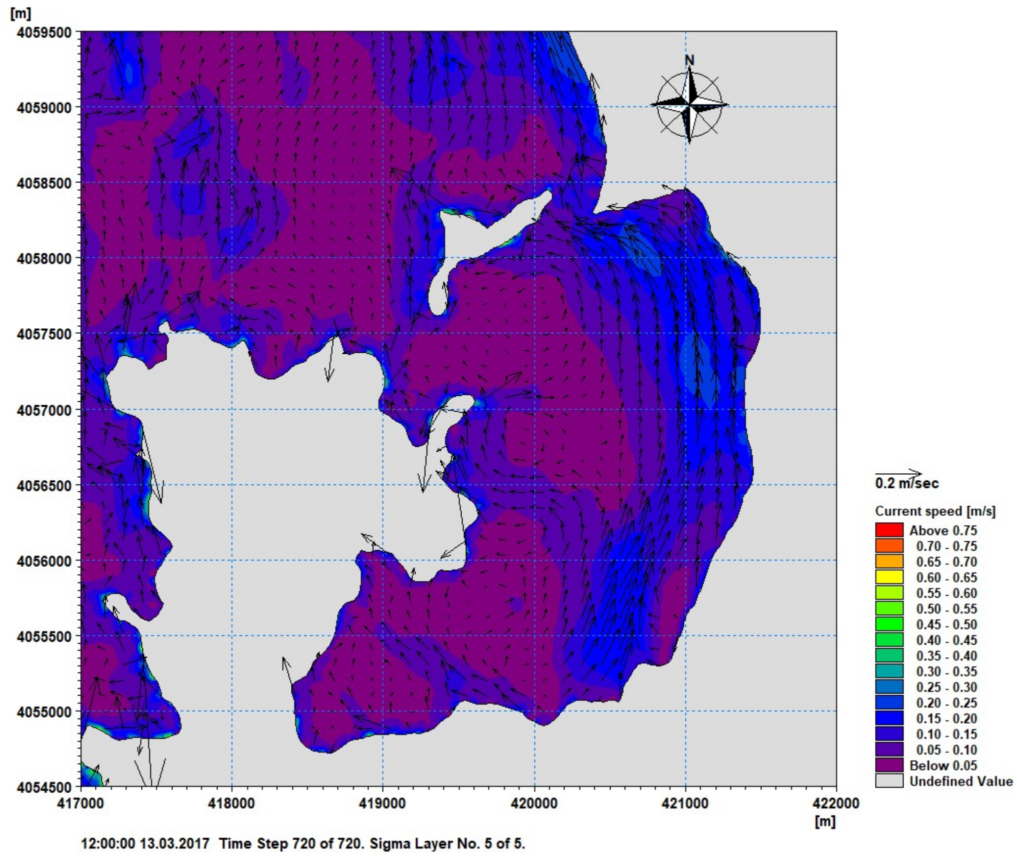
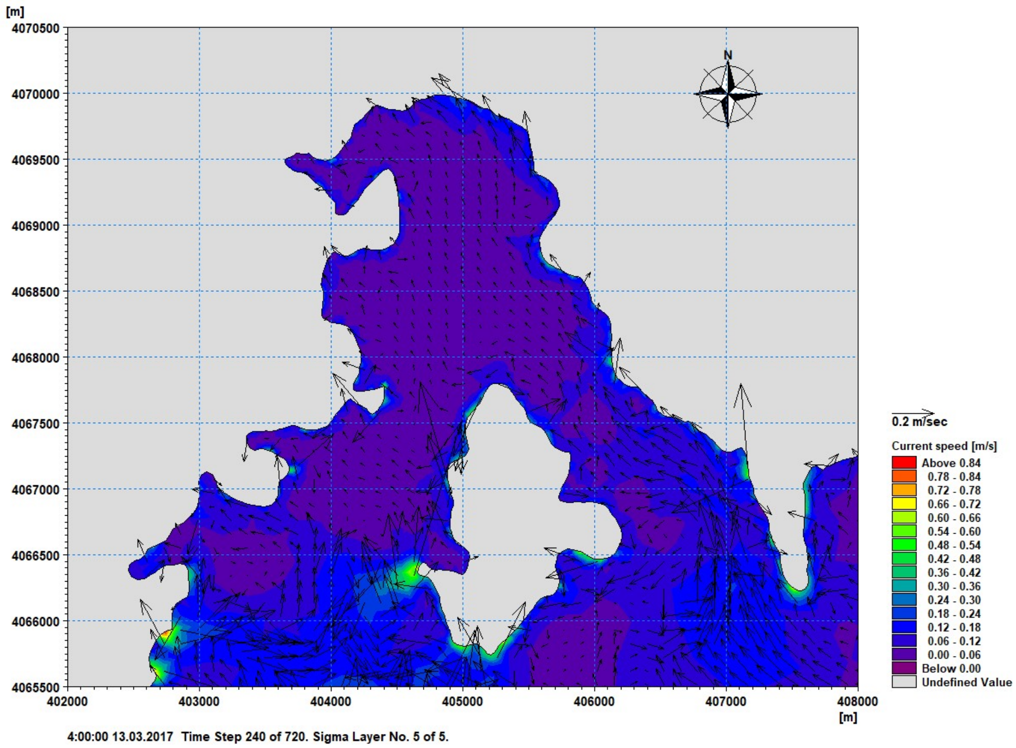


Figure F.3. Circulation pattern at Fethiye Bay at 12th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: SSE)



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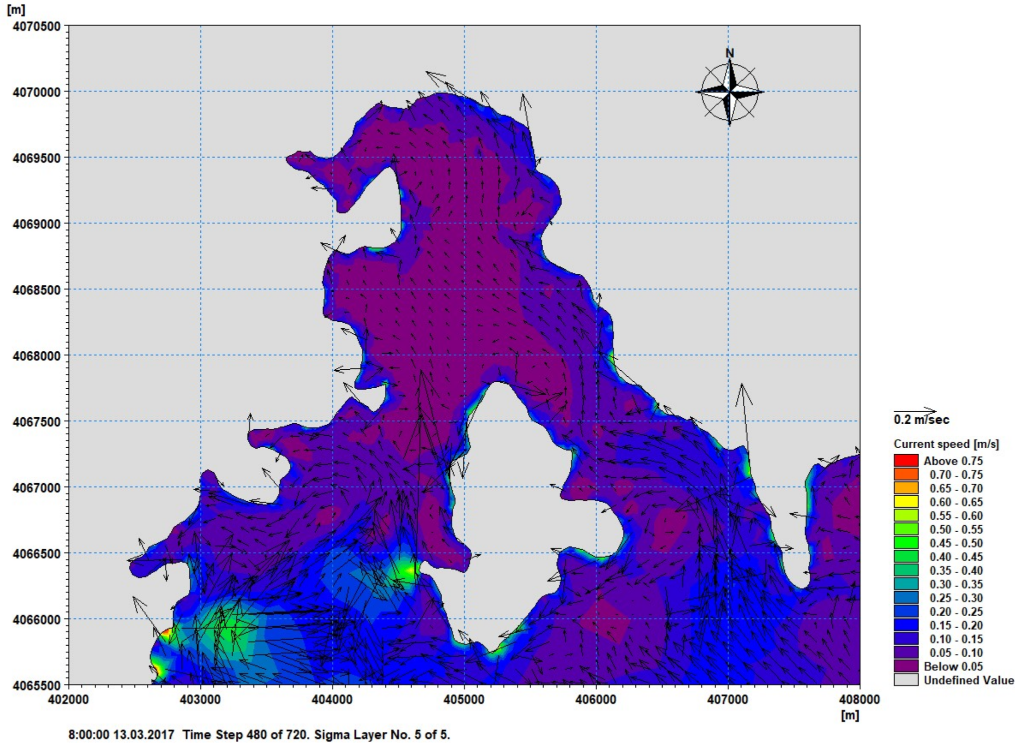

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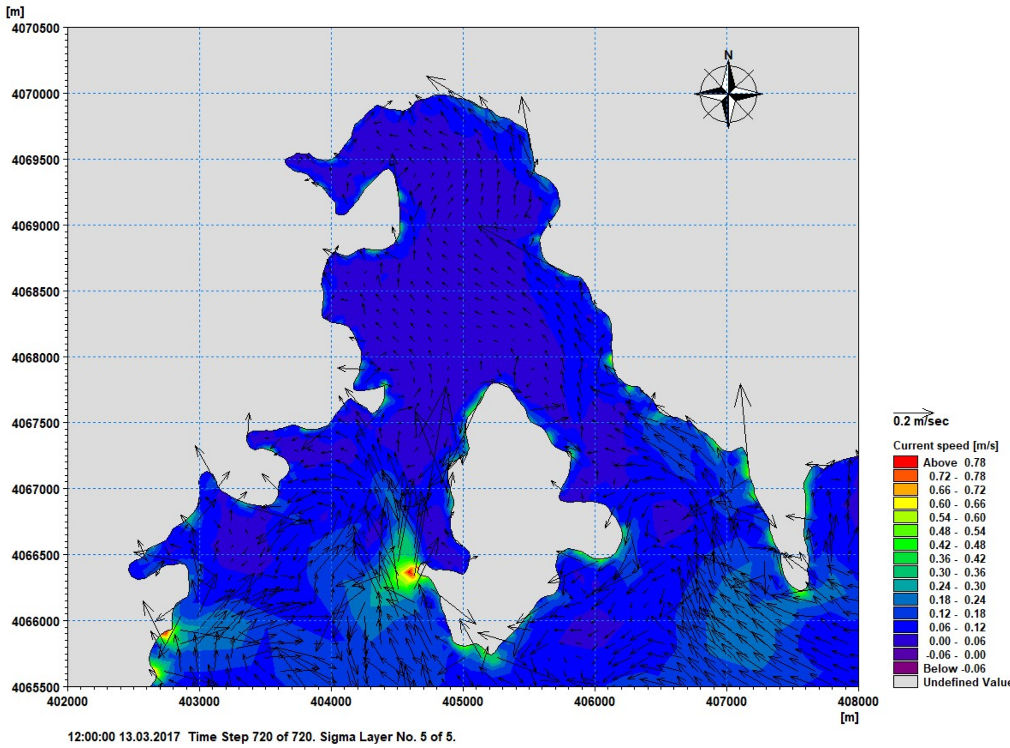


Figure F.6. Circulation pattern at Göcek Bay at 12th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: SSE)

APPENDIX G CIRCULATION PATTERNS AT FETHIYE AND GOCEK BAYS UNDER WIND FORCE (Wind Speed: 5 m/sec-Wind Direction: WSW)

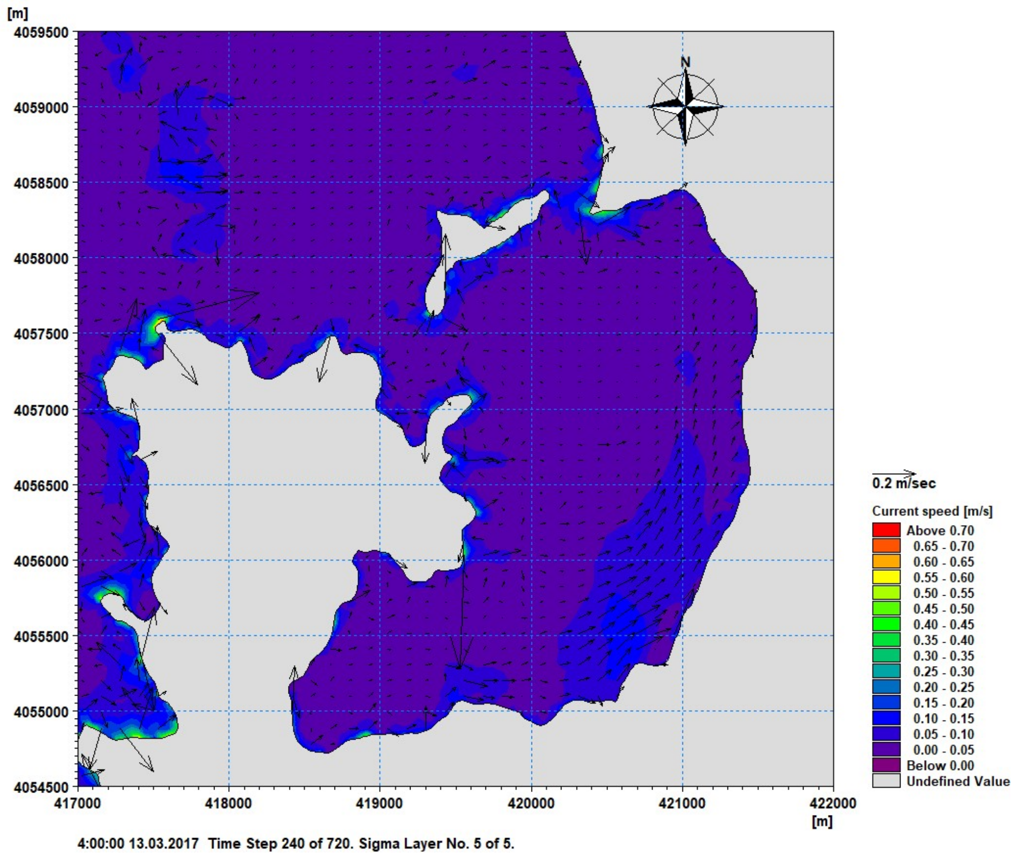


Figure G.1. Circulation pattern at Fethiye Bay at 4th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: WSW)

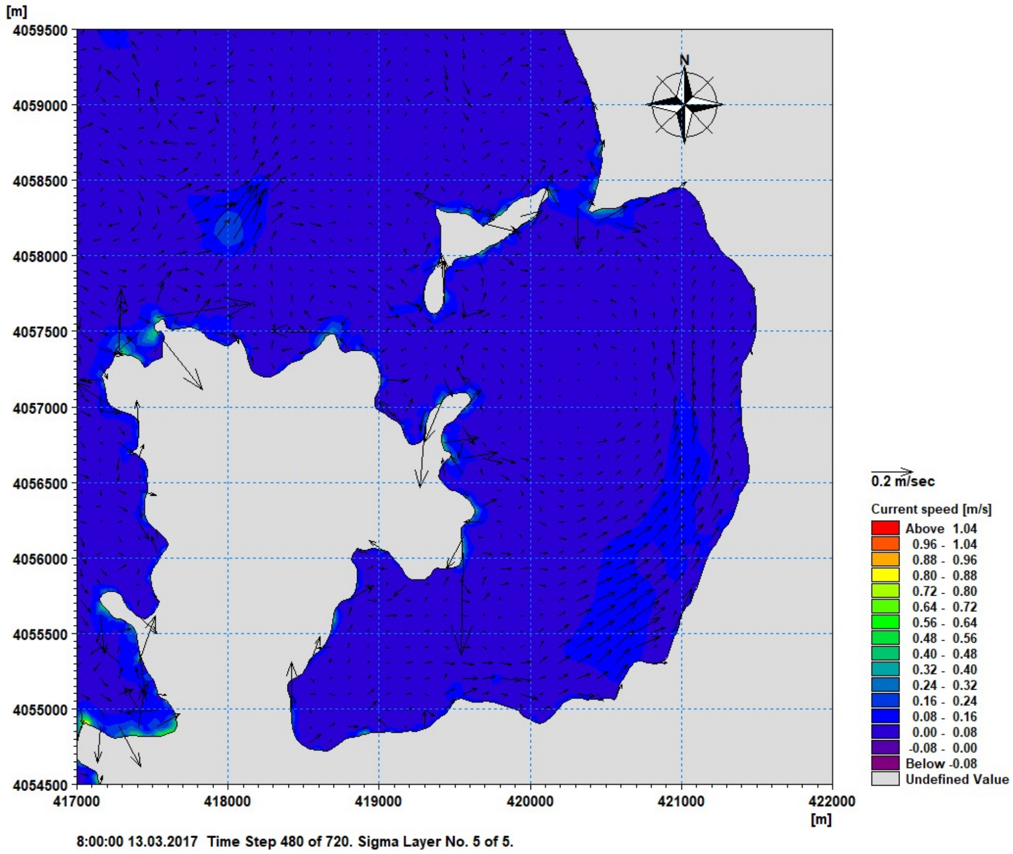
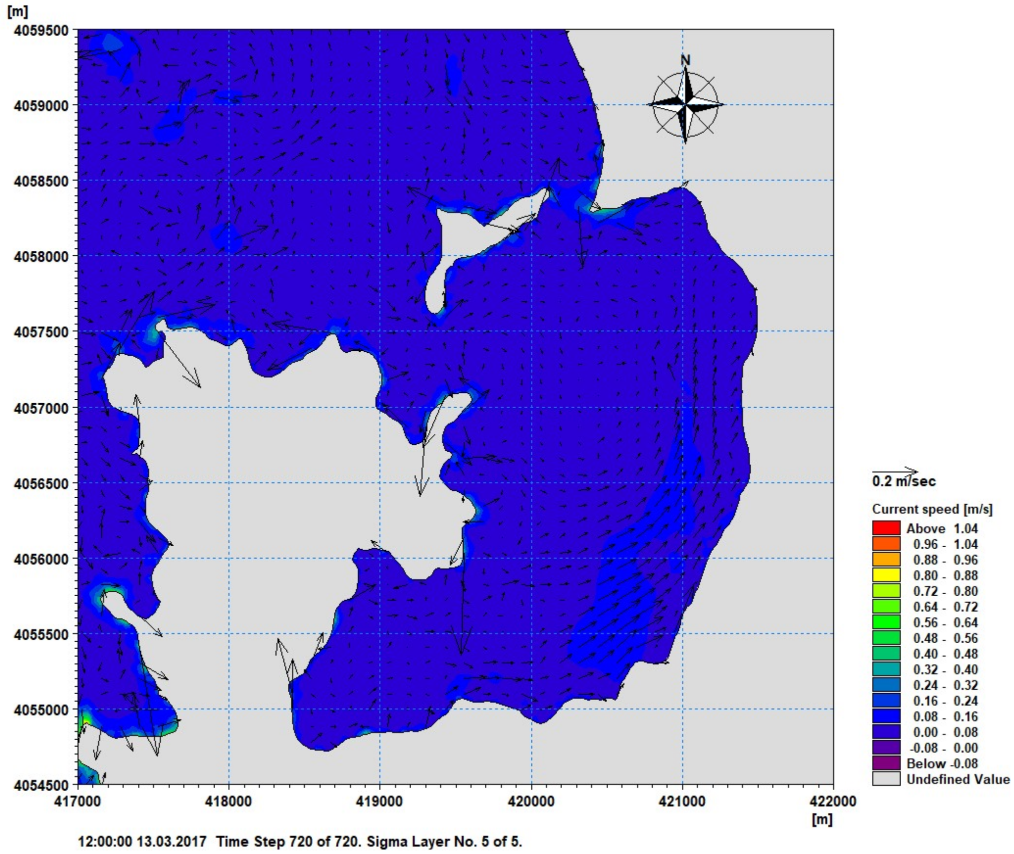


Figure G.2. Circulation pattern at Fethiye Bay at 8th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: WSW)



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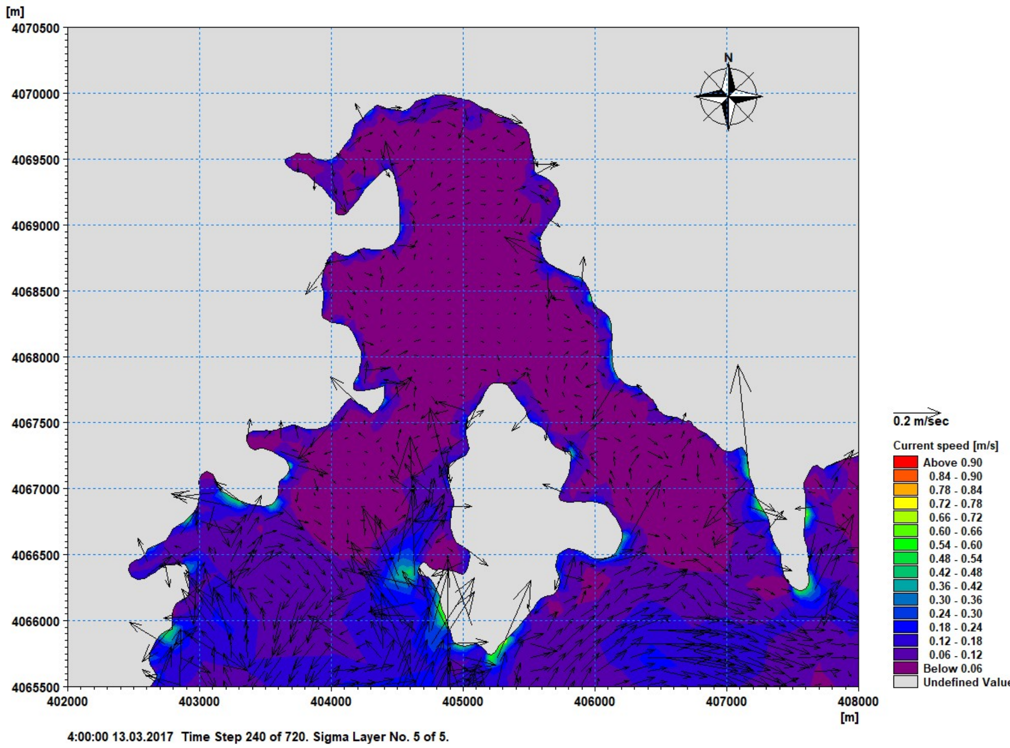

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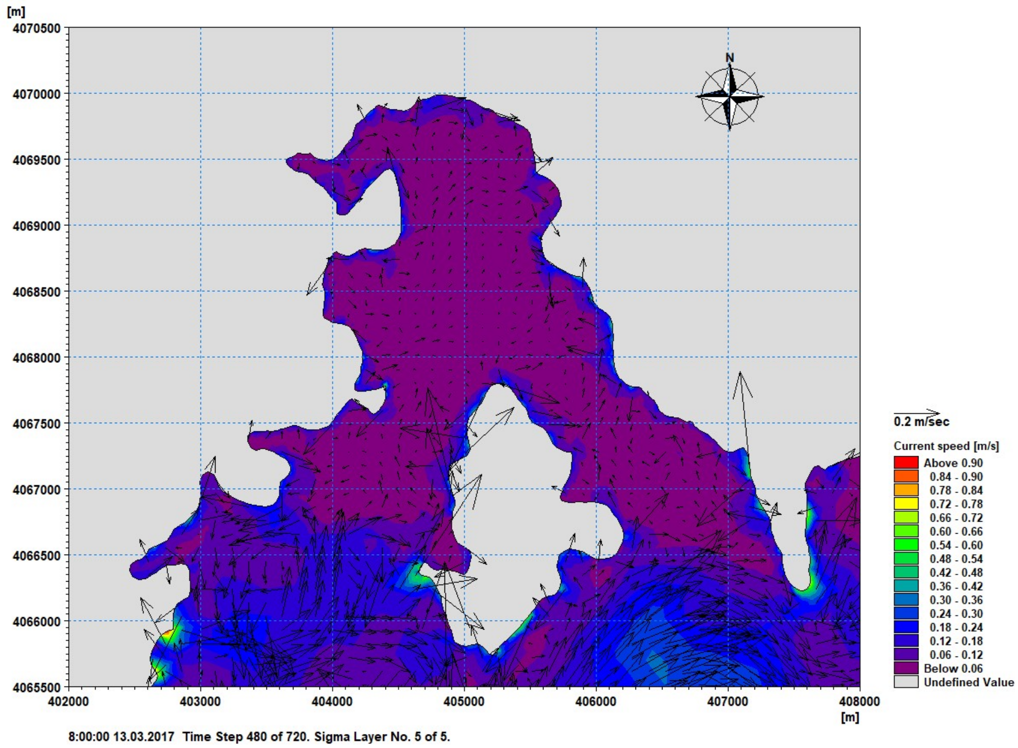

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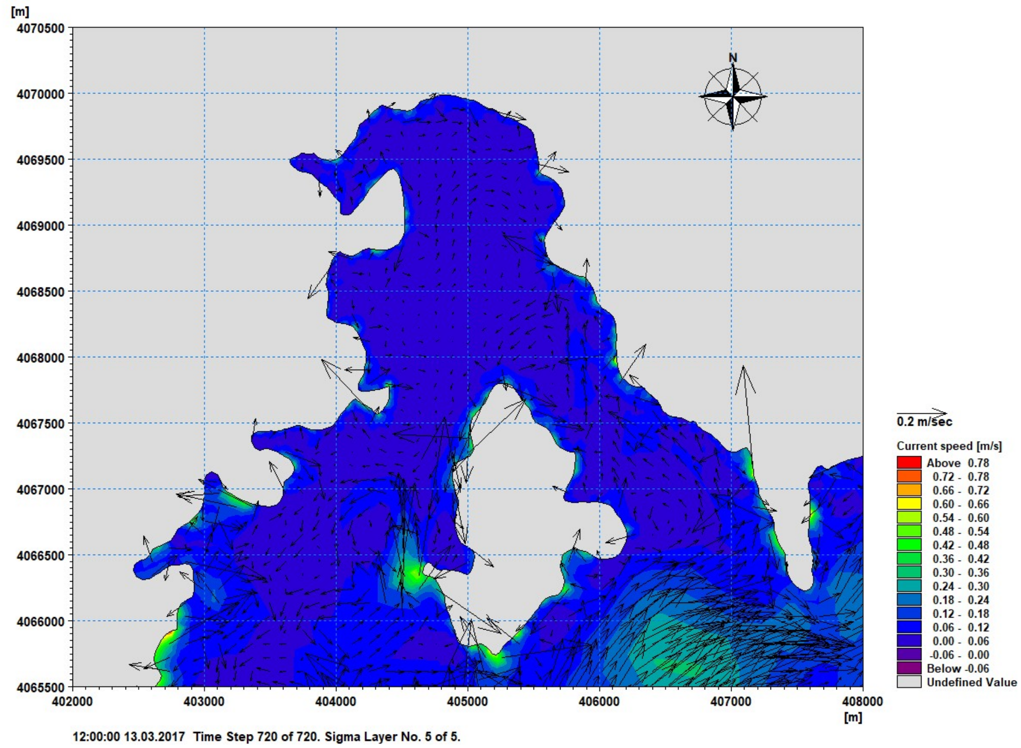


Figure G.6. Circulation pattern at Göcek Bay at 12th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: WSW)

APPENDIX H CIRCULATION PATTERNS AT FETHIYE AND GOCEK BAYS UNDER WIND FORCE (Wind Speed: 10 m/sec-Wind Direction: WSW)

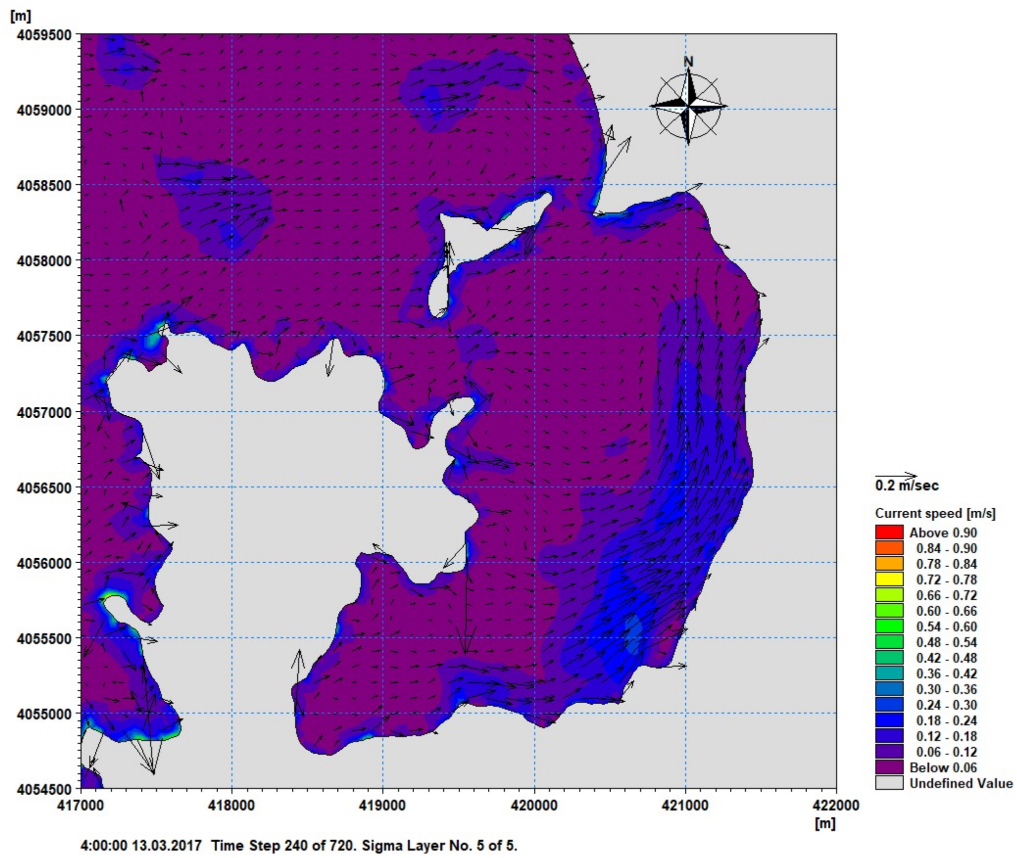


Figure H.1. Circulation pattern at Fethiye Bay at 4th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: WSW)

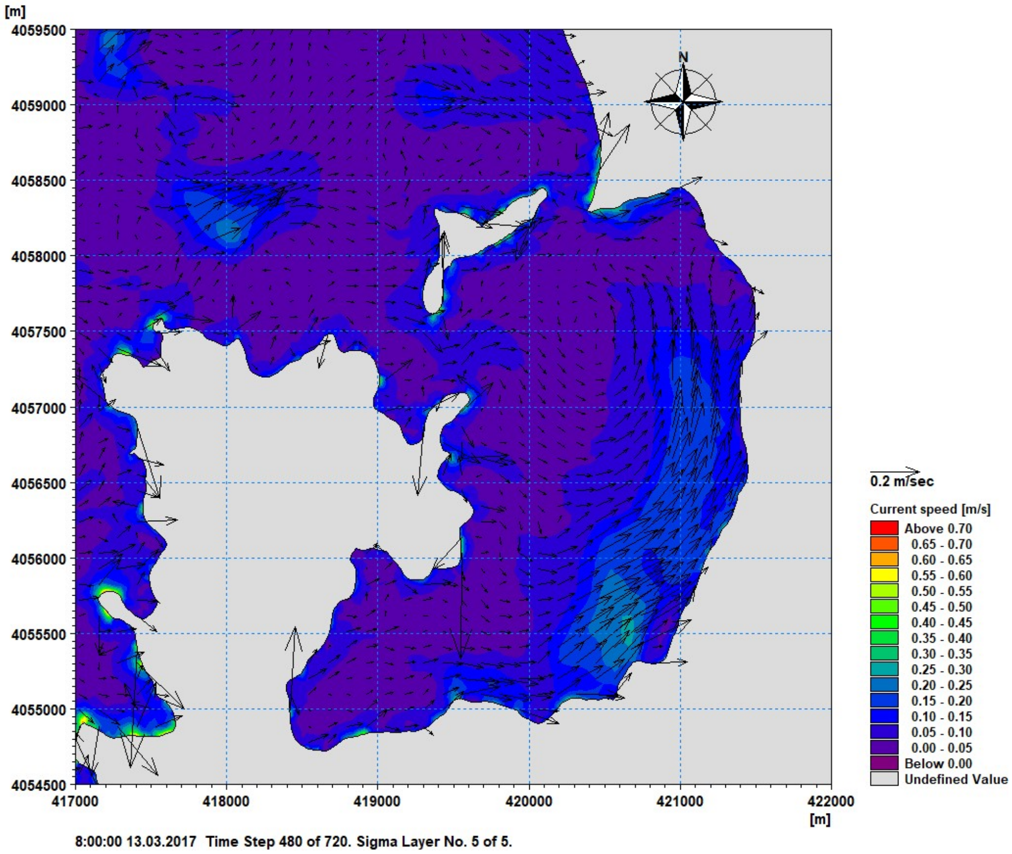


Figure H.2. Circulation pattern at Fethiye Bay at 8th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: WSW)

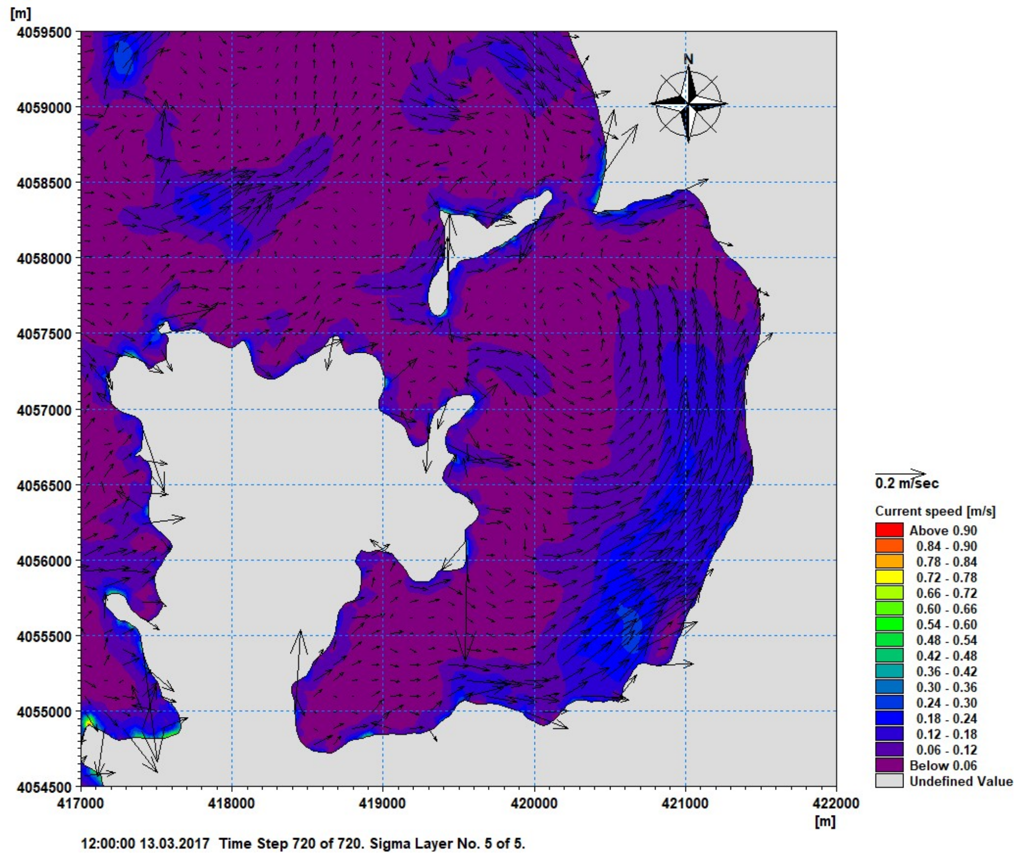


Figure H.3. Circulation pattern at Fethiye Bay at 12th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: WSW)

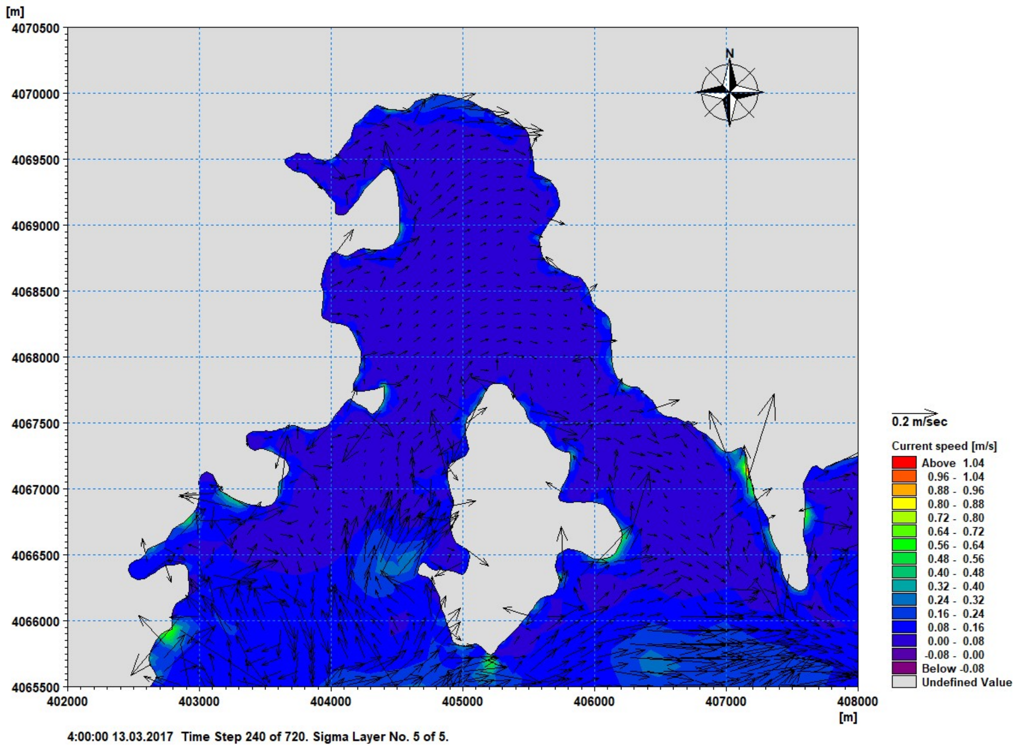
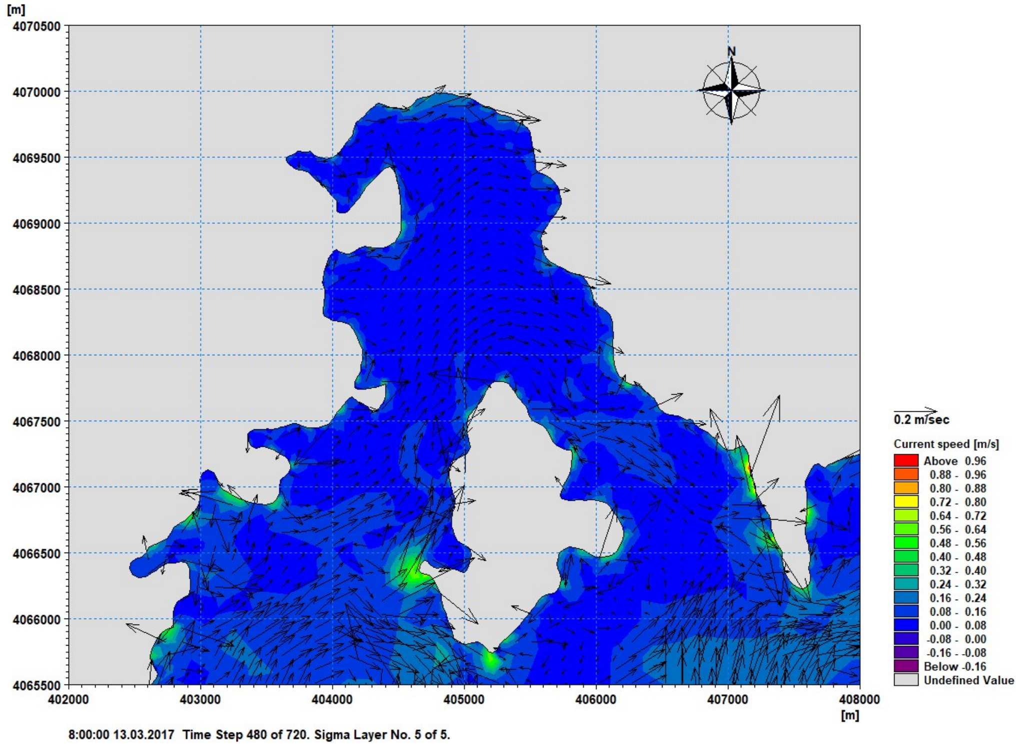


Figure H.4. Circulation pattern at Göcek Bay at 4th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: WSW)



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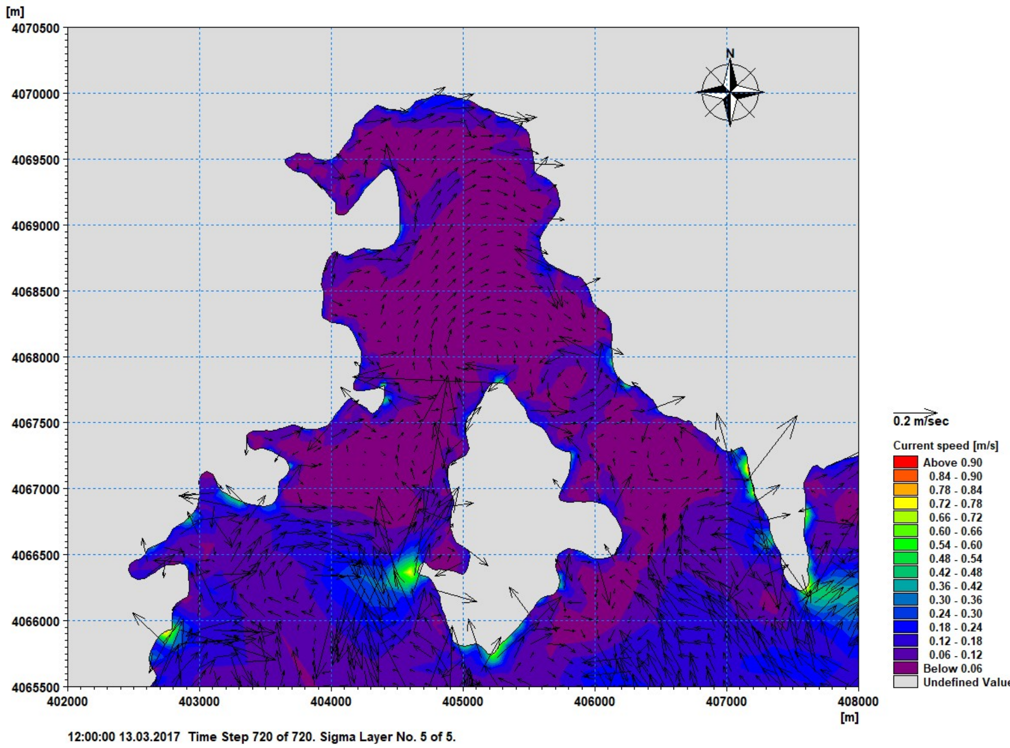

Figure H.6. Circulation pattern at Göcek Bay at 12th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: WSW)

APPENDIX I CIRCULATION PATTERNS AT FETHIYE AND GOCEK BAYS UNDER WIND FORCE (Wind Speed: 5 m/sec-Wind Direction: NNW)

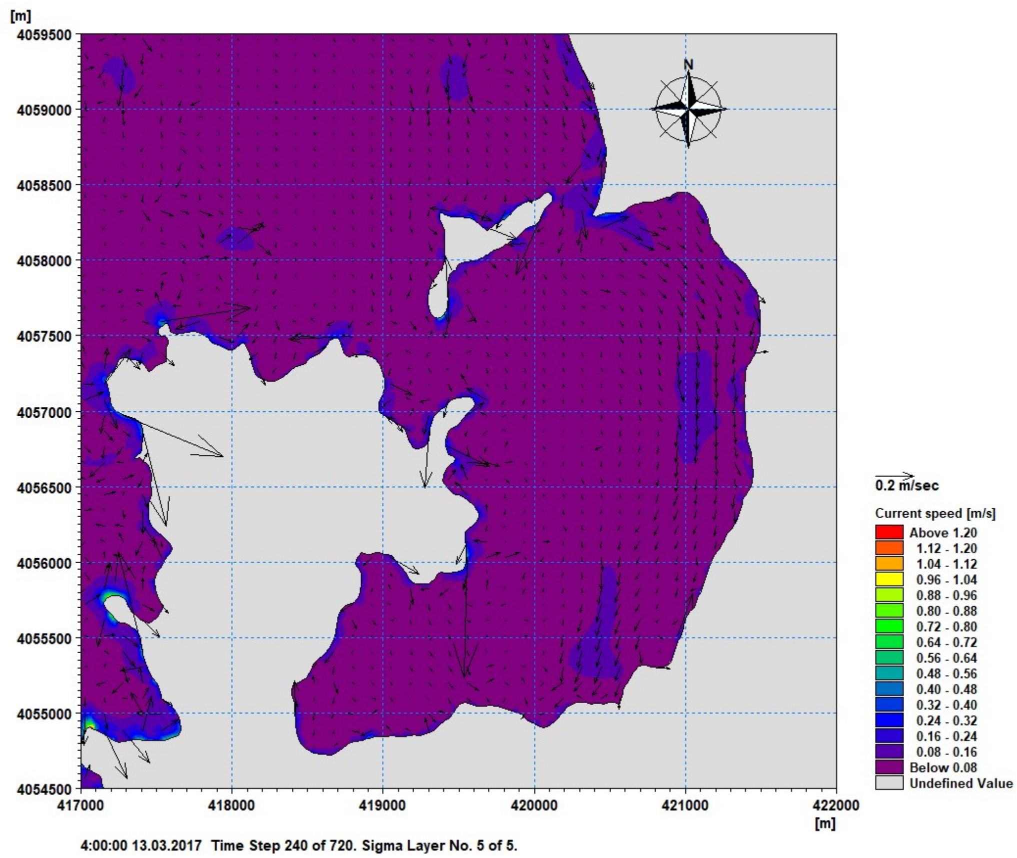

Figure I.1. Circulation pattern at Fethiye Bay at 4th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: NNW)

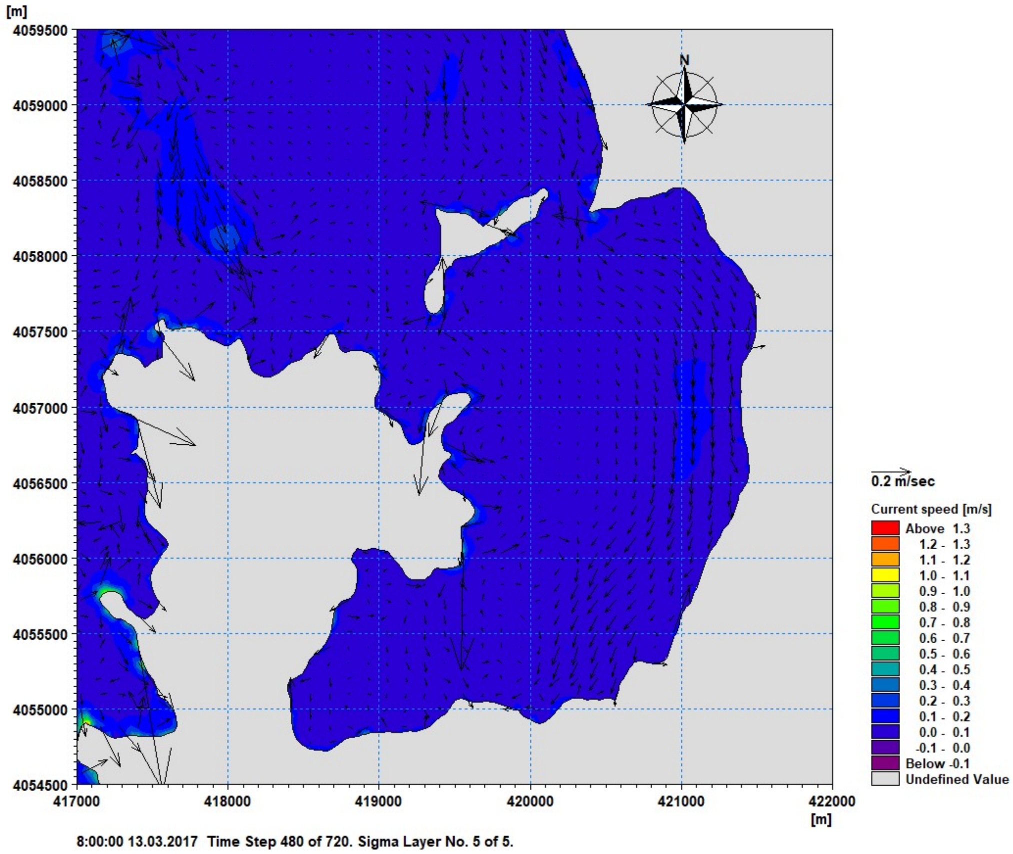

Figure I.2. Circulation pattern at Fethiye Bay at 8th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: NNW)

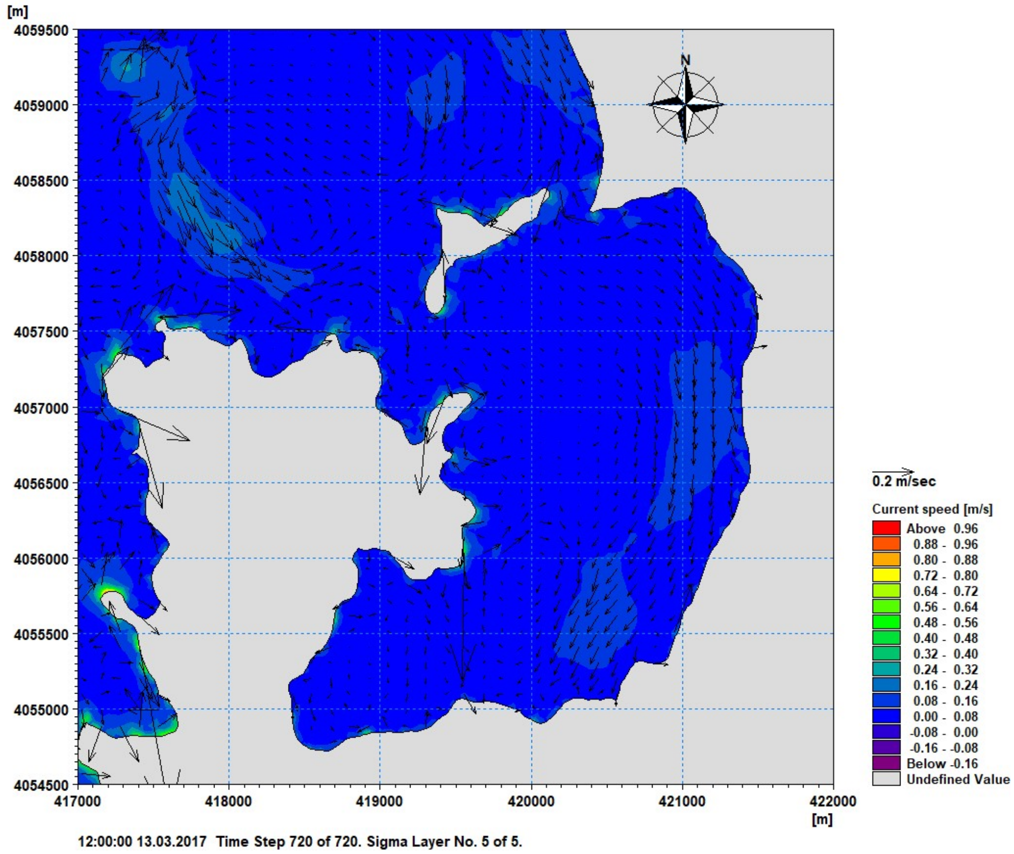

Figure I.3. Circulation pattern at Fethiye Bay at 12th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: NNW)

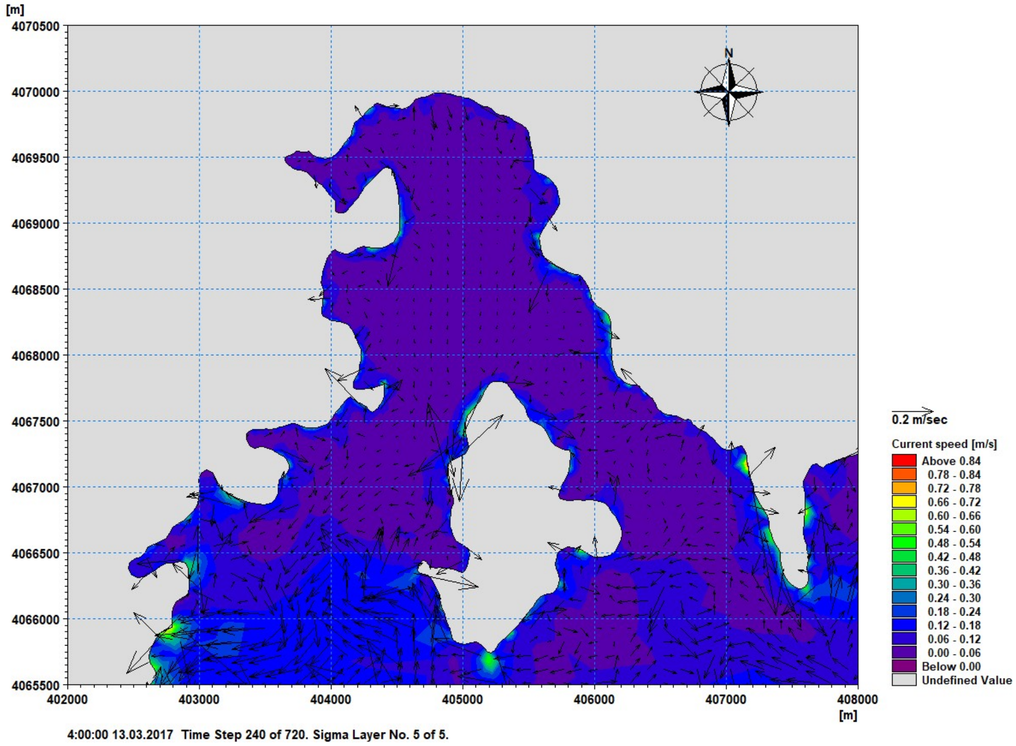

Figure I.4. Circulation pattern at Göcek Bay at 4th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: NNW)

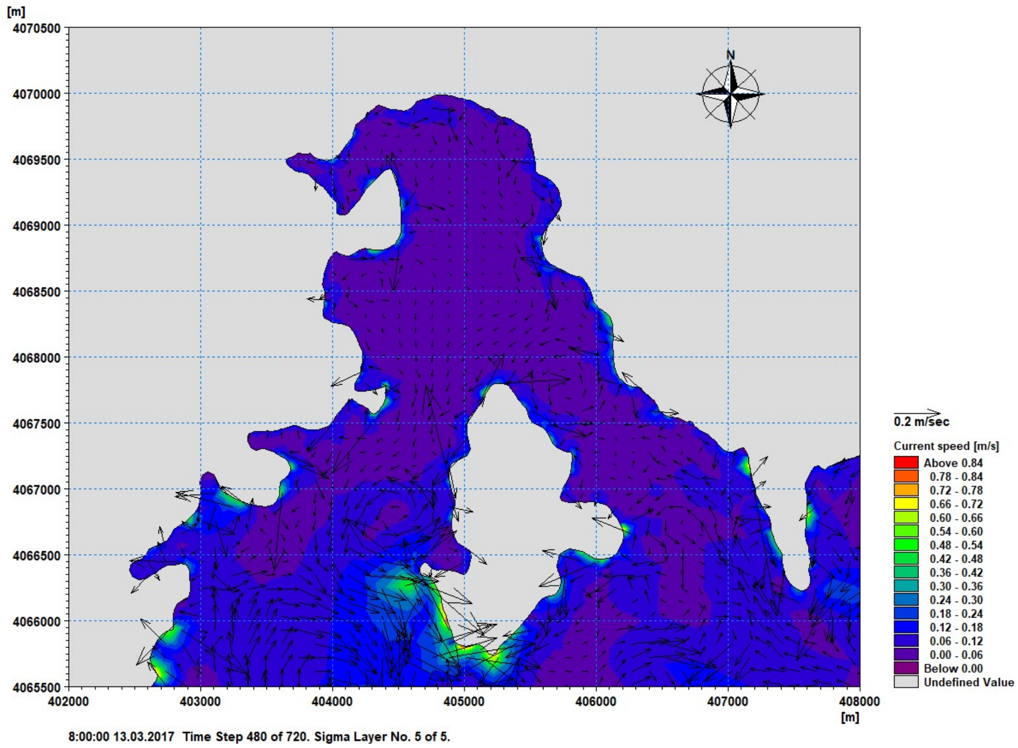

Figure I.5. Circulation pattern at Göcek Bay at 8th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: NNW)

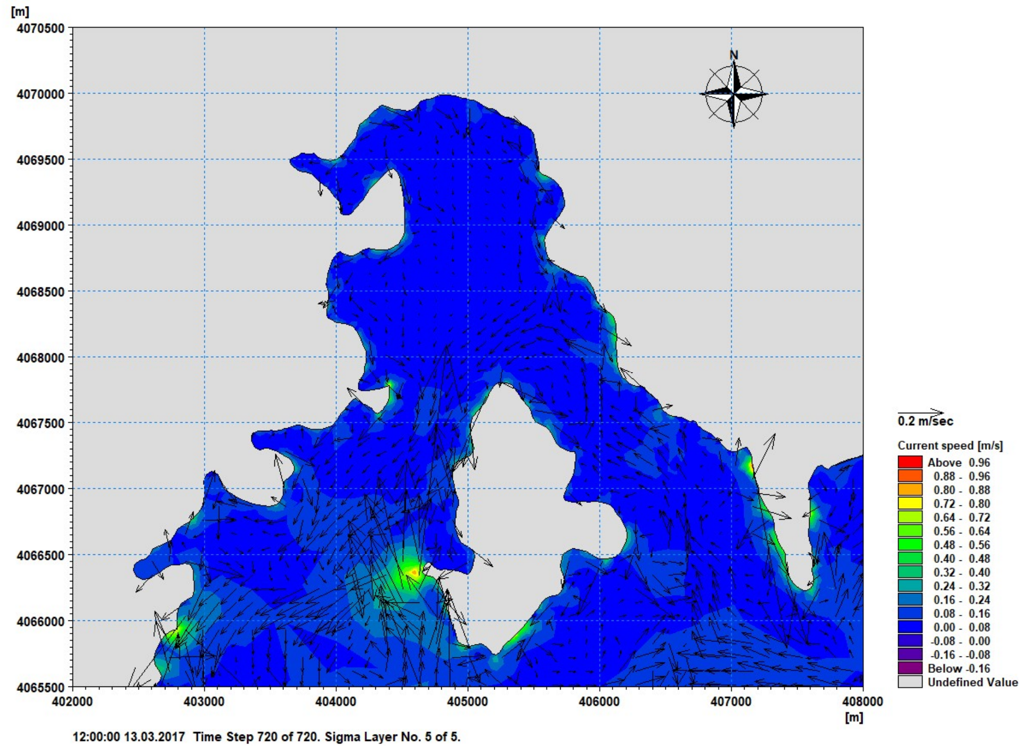

Figure I.6. Circulation pattern at Göcek Bay at 12th hour under 12 hours of wind forcing (Wind Speed: 5 m/sec, Wind Direction: NNW)

APPENDIX J CIRCULATION PATTERNS AT FETHIYE AND GOCEK BAYS UNDER WIND FORCE (Wind Speed: 10 m/sec-Wind Direction: NNW)

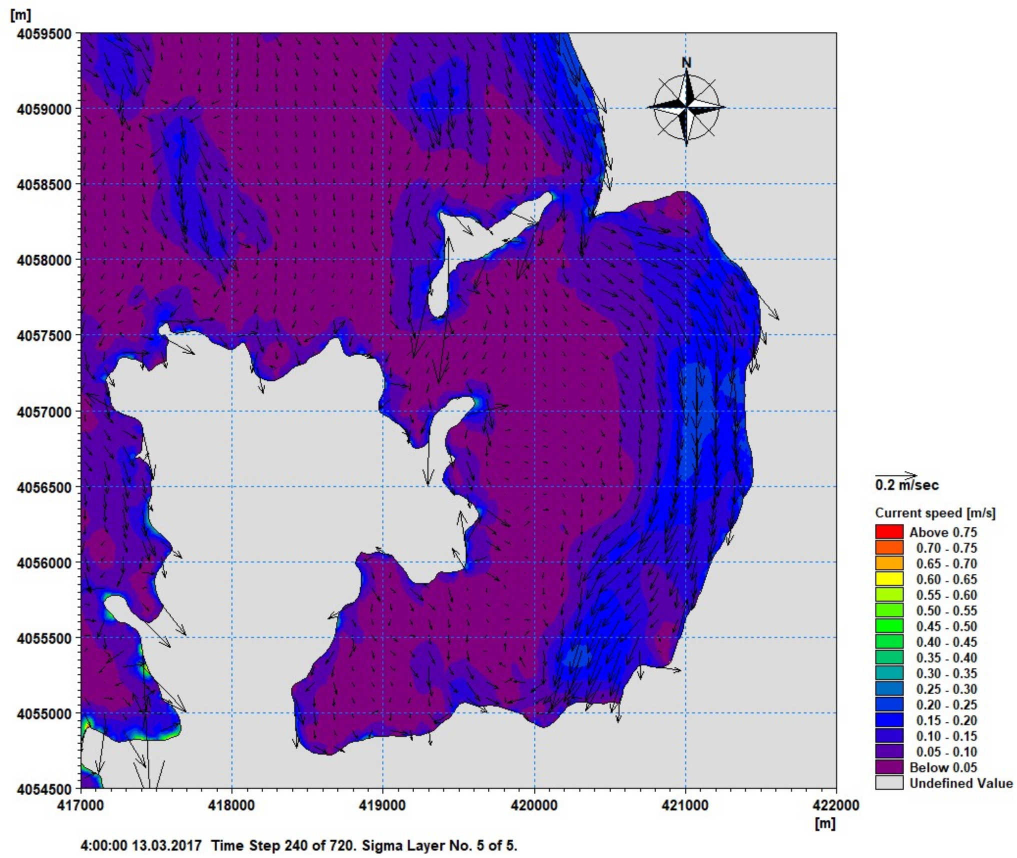

Figure J.1. Circulation pattern at Fethiye Bay at 4th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: NNW)

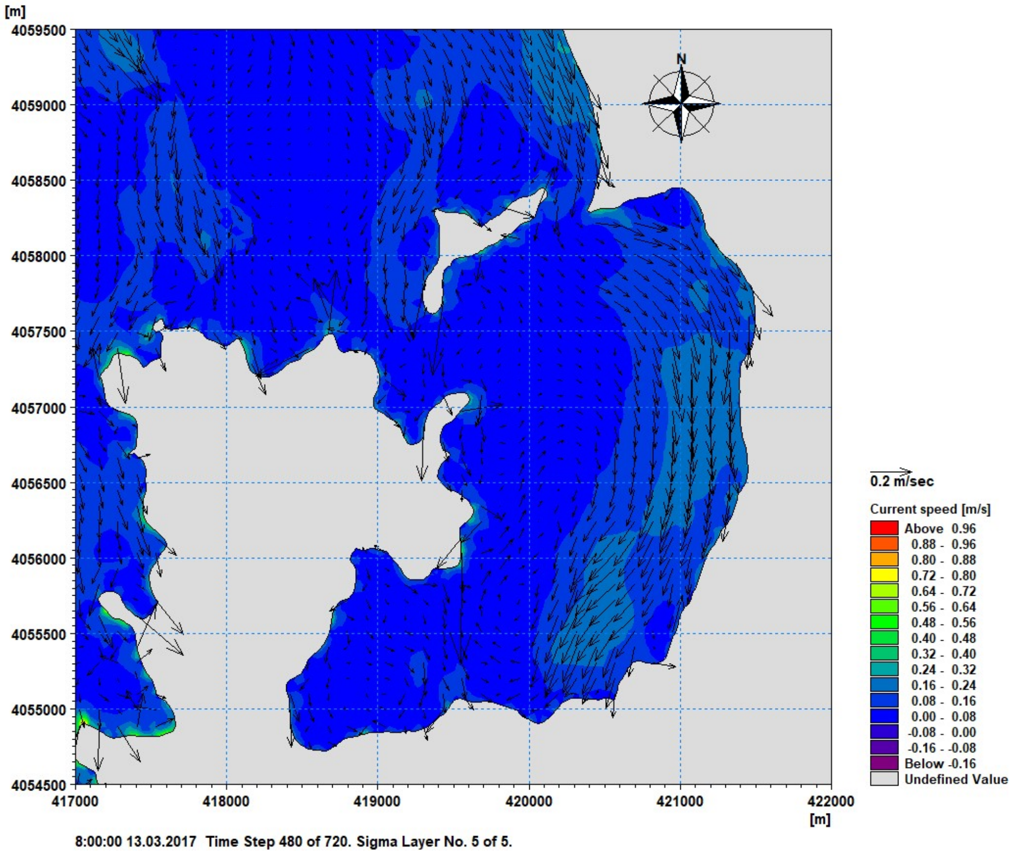

Figure J.2. Circulation pattern at Fethiye Bay at 8th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: NNW)

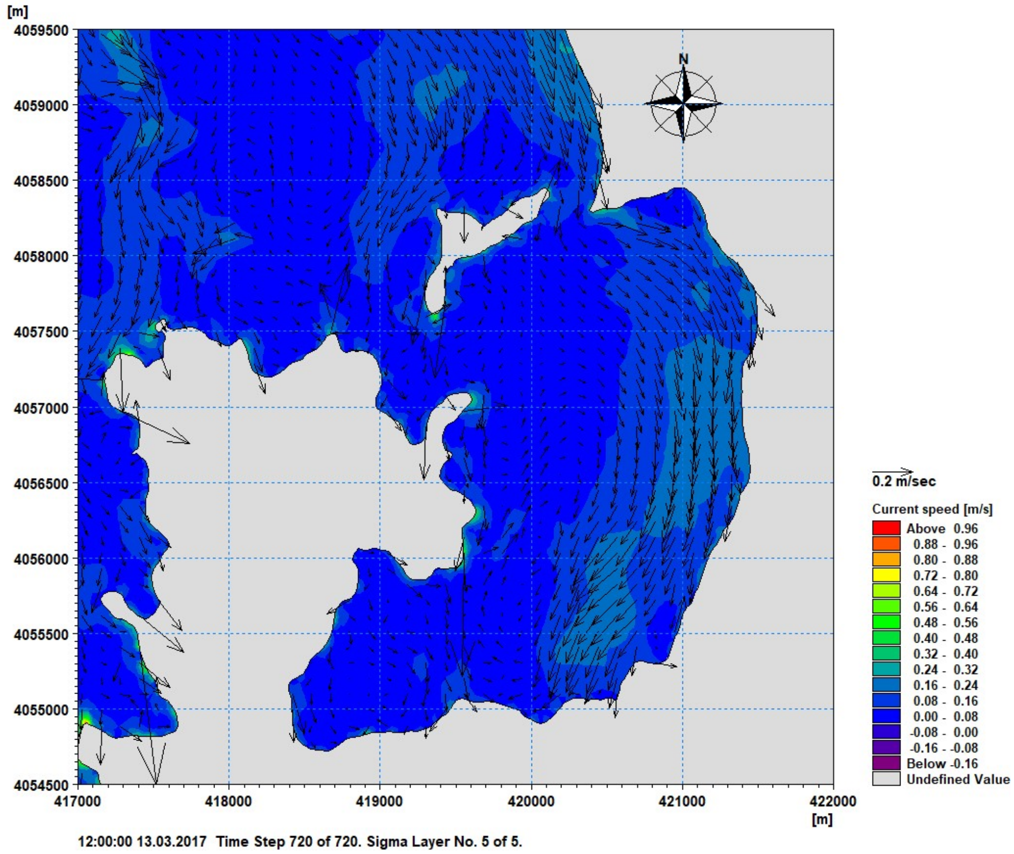

Figure J.3. Circulation pattern at Fethiye Bay at 12th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: NNW)

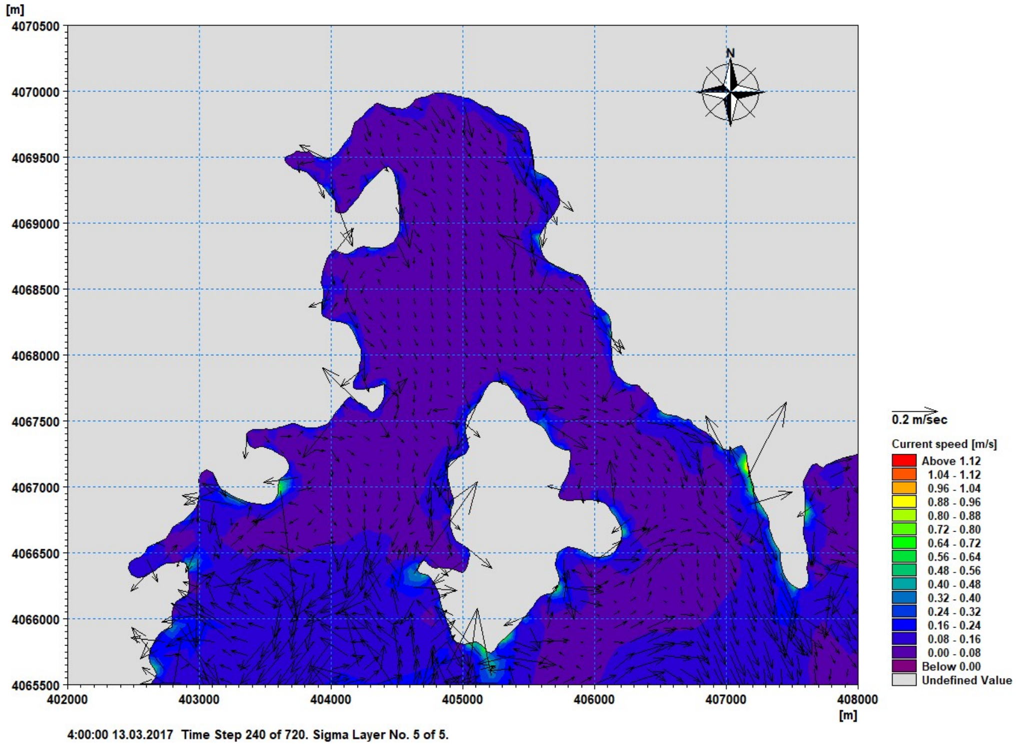

Figure J.4. Circulation pattern at Göcek Bay at 4th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: NNW)

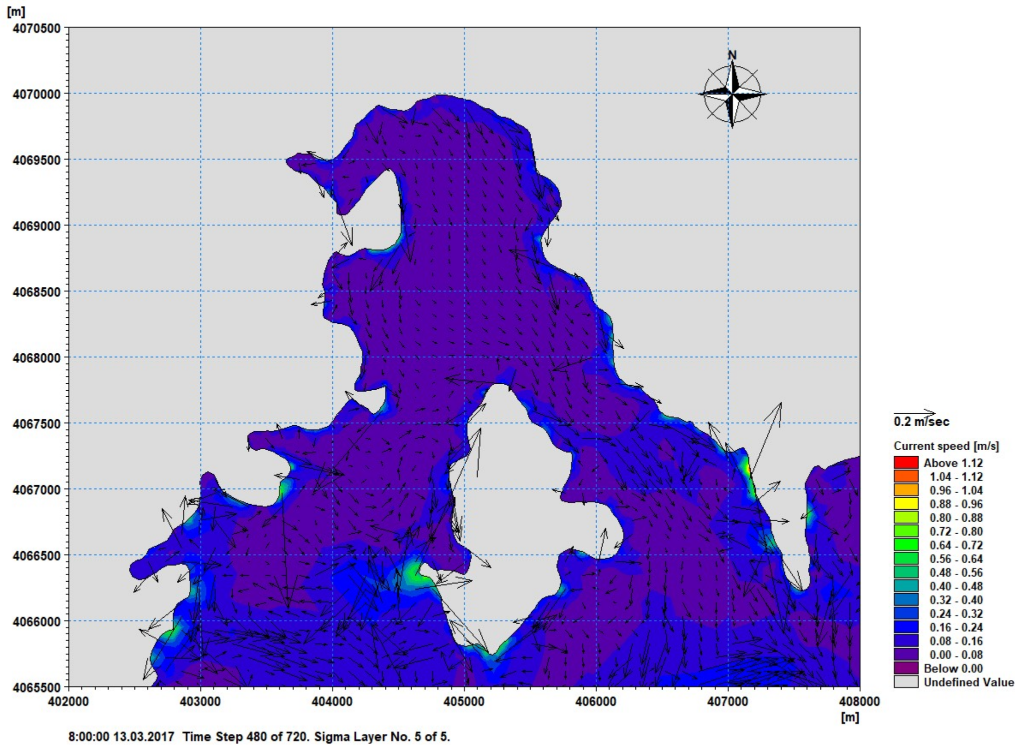

Figure J.5. Circulation pattern at Göcek Bay at 8th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: NNW)

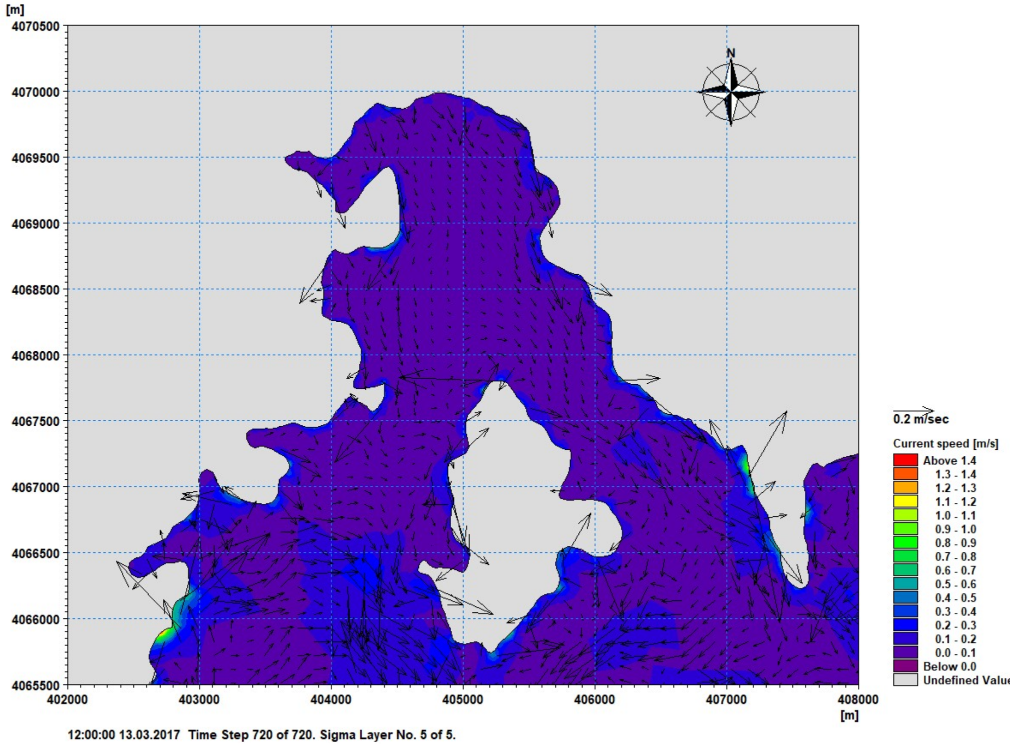

Figure J.6. Circulation pattern at Göcek Bay at 12th hour under 12 hours of wind forcing (Wind Speed: 10 m/sec, Wind Direction: NNW)

APPENDIX K CROSS-SECTIONS AT NUMERICAL GAUGE POINTS

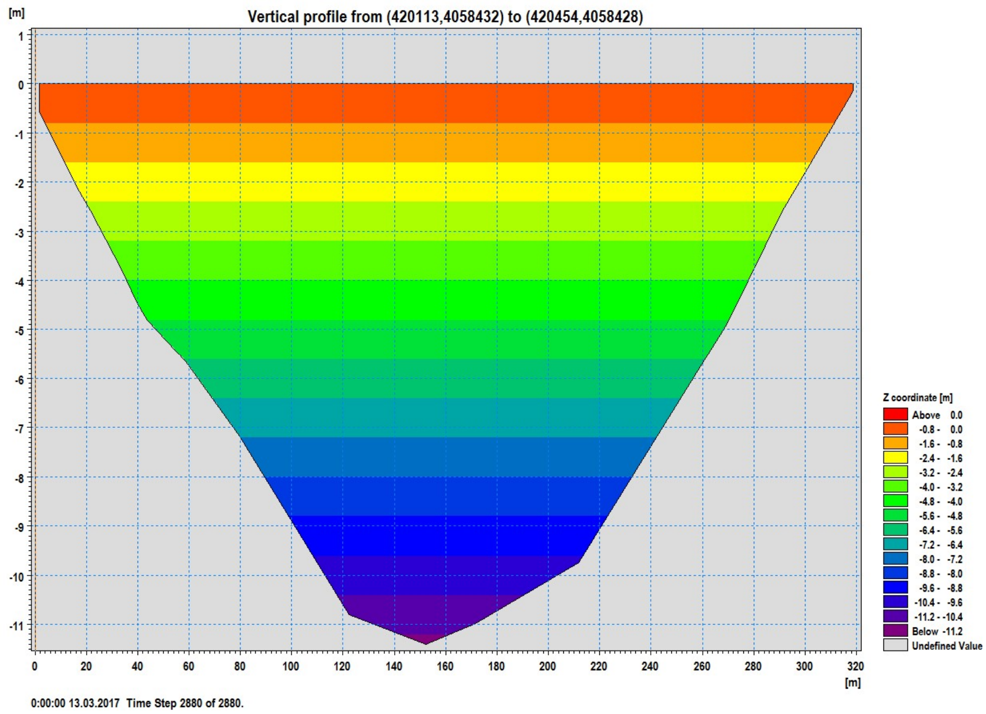

Figure K.1. Cross-section for strait 1

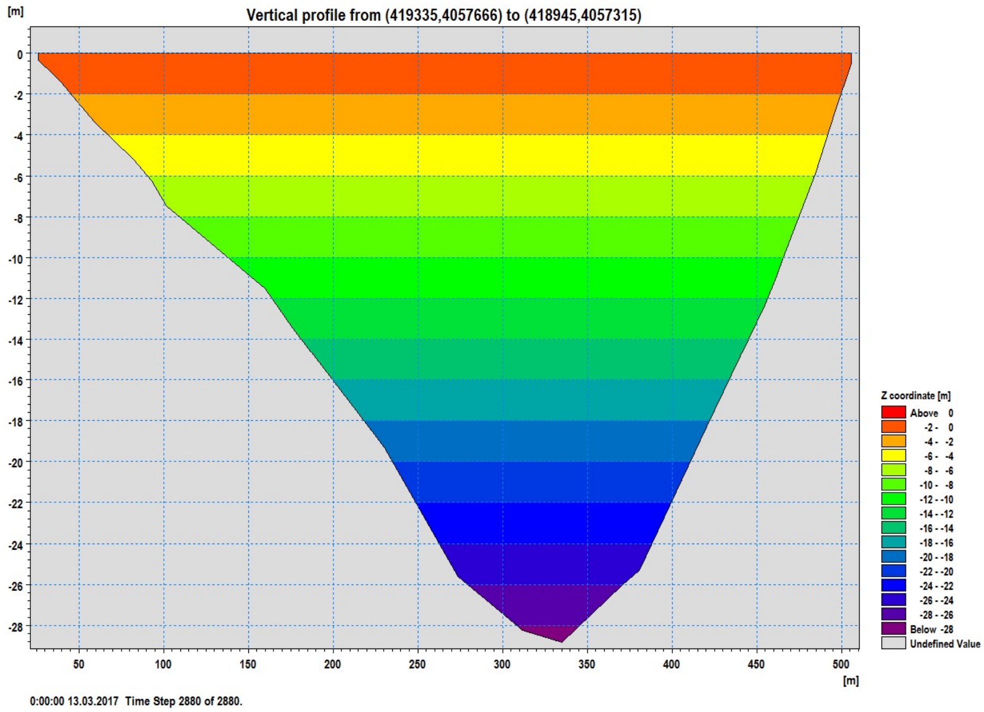

Figure K.2. Cross-section for strait 2

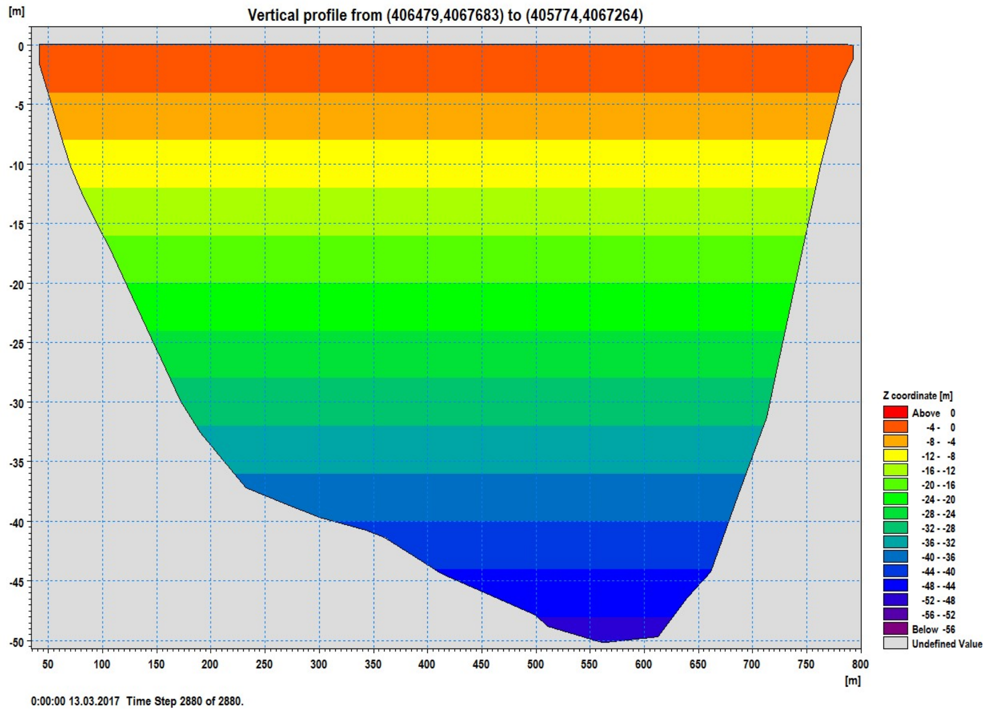

Figure K.3. Cross-section for strait 3

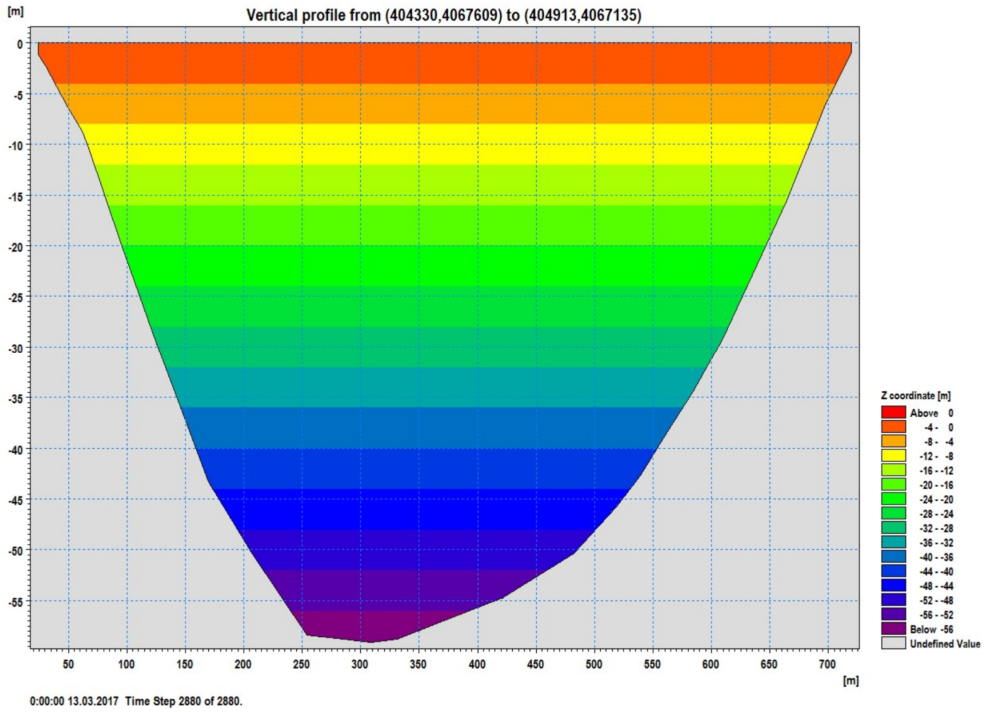

Figure K.4. Cross-section for strait 4

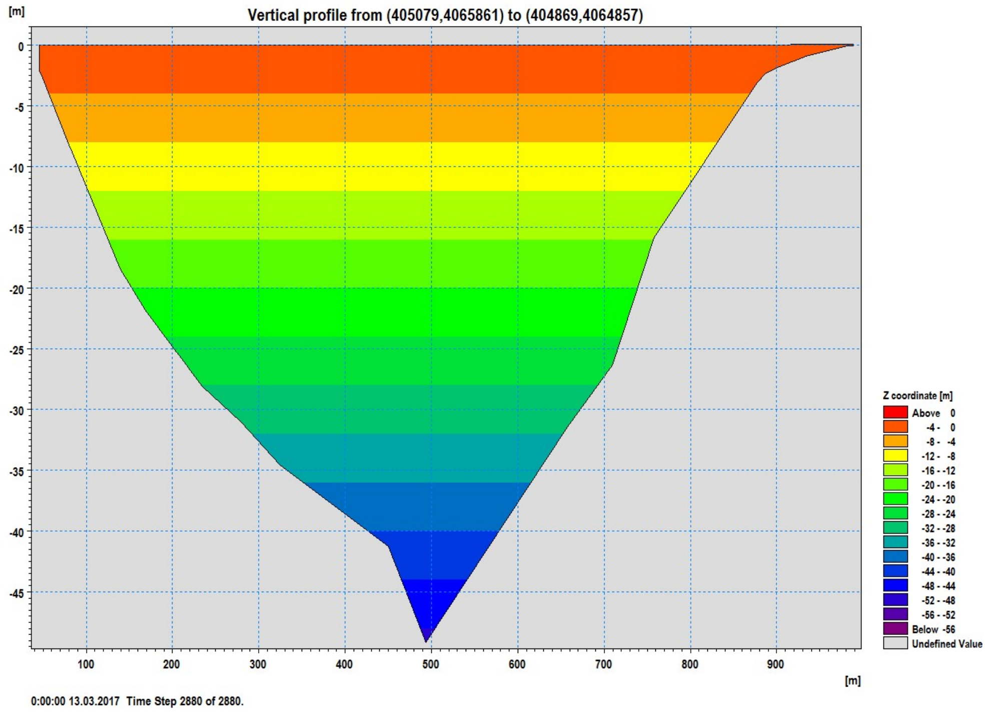

Figure K.5. Cross-section for strait 5

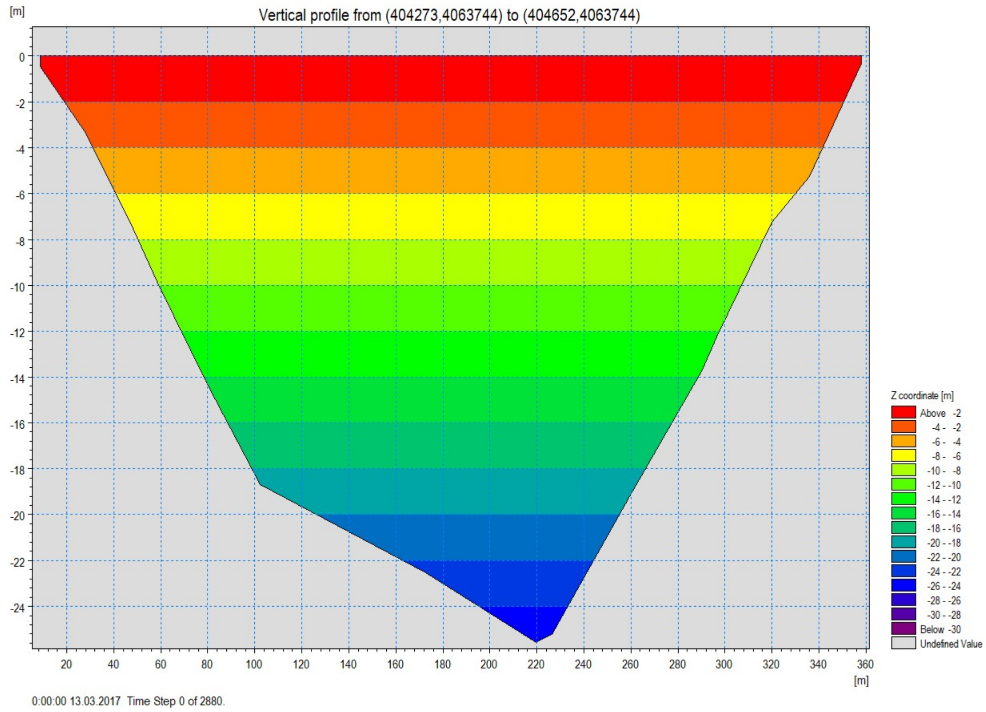

Figure K.6. Cross-section for strait 6

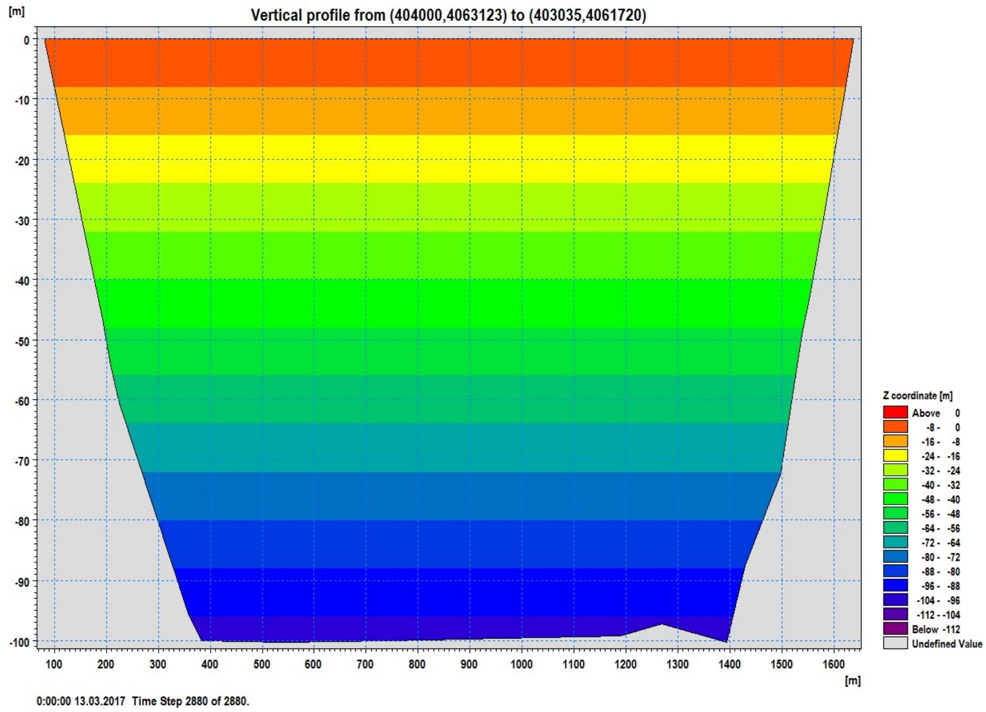

Figure K.7. Cross-section for strait 7

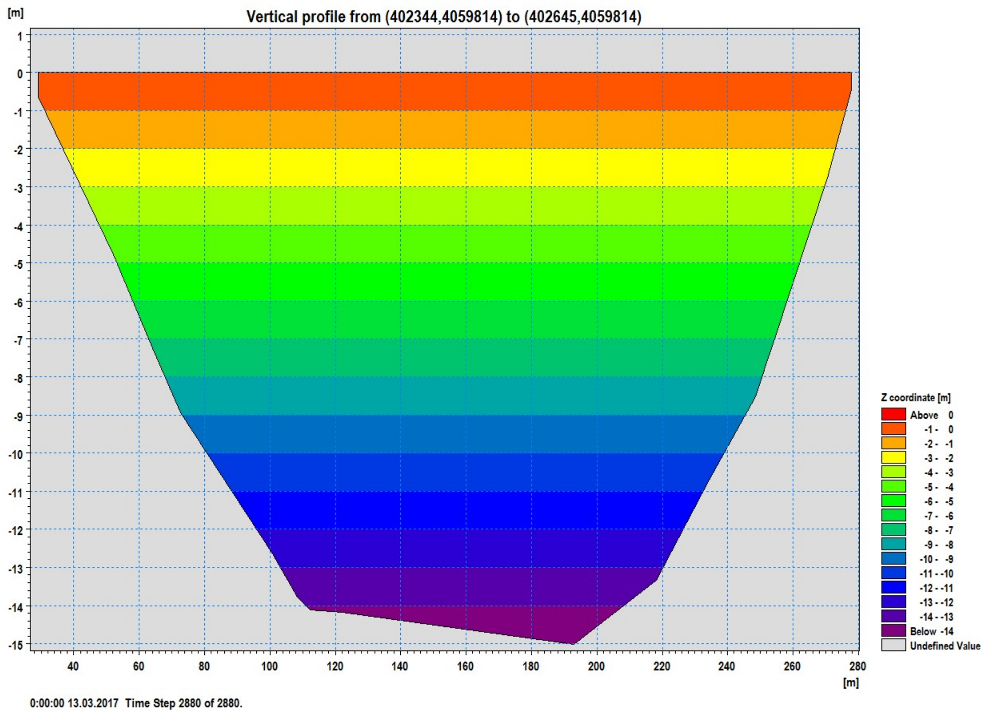

Figure K.8. Cross-section for strait 8

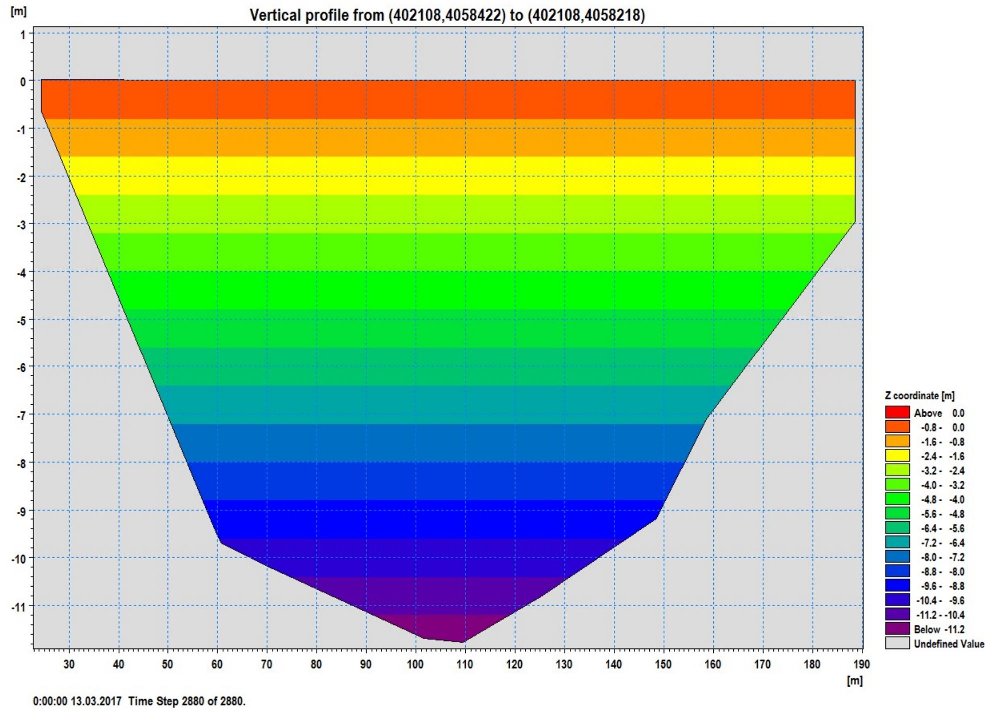

Figure K.9. Cross-section for strait 9