

**DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED
SCIENCES**

**DETERMINATION OF THE IMPACTS OF
MARINE FARMS ON MARINE ECOSYSTEMS
BY USING REMOTE SENSING: ILDIRI BAY**

**by
Fethi BENGİL**

**July, 2011
İZMİR**

**DETERMINATION OF THE IMPACTS OF
MARINE FARMS ON MARINE ECOSYSTEMS
BY USING REMOTE SENSING: ILDIRI BAY**

**A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Master of Science in the
Institute of Marine Sciences and Technology, Marine Living Resources
Program**

**by
Fethi BENGİL**

**July, 2011
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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled “**DETERMINATION OF THE IMPACTS OF MARINE FARMS ON MARINE ECOSYSTEMS BY USING REMOTE SENSING: ILDIRI BAY**” completed by **FETHİ BENGİL** under supervision of **ASSIST. PROF. DR. KEMAL CAN BİZSEL** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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DETERMINATION OF THE IMPACTS OF MARINE FARMS ON MARINE ECOSYSTEMS BY USING REMOTE SENSING: ILDIRI BAY

ABSTRACT

The Bay of Ildırı is one of the areas where the most intensive aquaculture activities have taken place along the Aegean coast of Turkey. In order to evaluate the possible impacts of aquaculture to the marine ecosystem by using remote sensing and geographic information systems, fieldworks performed in the bay between February 2010 and 2011. The impact is evaluated in terms of total suspended matter, Secchi depth and sea surface temperature. Images from MERIS sensor of the ENVISAT were used to determine distribution of Secchi depth and total suspended matter. Empirical algorithm performed after atmospheric corrections applying the analysis concentrated on the derivation of data from satellite imagery by artificial neural network technique. Geographical information system was used for data arrangement analysis and presentation purposes. Results show that as limitation of this study, there is no apparently impact of aquaculture activities to their environment in Ildırı Bay. Images of MERIS are not very sensitive because of its medium spatial resolution. Although it relatively lower resolution seems a problem to evaluate local impacts, the study will provide probably important input for further studies or will support as a complementary in field studies to increase understanding.

Keywords: MERIS, artificial neural networks, GIS, aquaculture, marine ecosystem.

BALIK ÇİFTLİKLERİNİN DENİZEL EKOSİSTEME ETKİLERİNİN UZAKTAN ALGILAMA İLE TESPİTİ: ILDIRI KÖRFEZİ

ÖZ

Çalışma alanı olarak seçilen Ildırı Körfezi akuakültür aktivitelerinin yoğunluğu ile bilinmektedir. Balık çiftliklerinin deniz ekosistemine olası etkilerini uzaktan algılama ve coğrafi bilgi sistemleri kullanımı ile değerlendirmek amacıyla, Şubat 2010 ve Şubat 2011 tarihleri arasında arazi çalışmaları gerçekleştirilmiştir. Etki, askıda katı madde, Secchi derinliği ve yüzey suyu sıcaklığı ile değerlendirilmiştir. ENVISAT üzerinde bulunan sensörlerden biri olan MERIS'ten elde edilen görüntüler askıda katı madde ve Secchi derinliği dağılımının belirlenmesinde kullanılmıştır. Bu çalışmada oluşturulan ampirik algoritma atmosferik düzeltme adımı sonrasında oluşturulmuştur. Analizler yapay sinir ağı ile uydu görüntülerinden üretilen veriler üzerine yoğunlaşmıştır. Coğrafi bilgi sistemleri sonuçları düzenlemek ve sunmak için kullanılmıştır. Elde edilen sonuçlar, bu çalışma sınırları içerisinde akuakültür aktivitelerinin çevresine açık bir etkisi yoktur. Mekansal çözünürlüğünün orta seviyede olması MERIS sensörüne ait görüntülerin Ildırı Körfezi'nde gerçekleştirilen akuakültür aktiviteleri için hasas olmadığı görülmüştür. Göreceli düşük çözünürlüğün yerel etkileri değerlendirmek konusunda yeterli olmamasına rağmen, bu çalışmanın ileride yapılacak çalışmalar için bir yol gösterici olacağını ya da arazi çalışmaları için bir tamamlayıcı olacağı düşünülmektedir.

Anahtar sözcükler: MERIS, yapay sinir ağları, CBS, akuakültür, deniz ekosistemi.

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CHAPTER ONE

INTRODUCTION

1.1 General Introduction

The coastal zone is the area where land meets the sea or ocean. The coasts have always been a popular place to live and human population is tends to increase near the ocean. Today, more than half of the global human population lives in the coastal zone, resulting in an enormous number of economical or recreational activities. In many countries, people live near the coast not by choice but by necessity and their daily lives are strongly connected to the rhythms of the ocean, which supplies food, products that can be sold or exported, a means for shipping, and a mode of travel (International Ocean Color Coordinating Group [IOCCG], 2008). The activities depending on the exploitation of marine resources make human predators and consumers of the marine ecosystems.

Marine ecosystems are based on interactions between organisms and their external conditions and they cover a high percentage of the Earth's surface. Balance of this system can collapse with the effect of anthropogenic factors. Growing human population and increasing food demand lead people to find alternative food supply beside natural processes occurs in earth. Although using technology for fisheries provides pretty more food supply for human population, time shows overfishing in wild fisheries is one of the problem in degradation of marine ecosystems. As highlighted by Pure Salmon group (2006), by replacing wild fisheries with farmed fish, aquaculture has the potential to reduce the pressure on marine systems and limit the overall human impact on the marine environment. Unfortunately, prevailing practices used in the rapidly growing fish farming industry are currently having the opposite effect. Scientific studies have identified some adverse impacts, such as pollution, contaminations or diseases resulting from aquaculture activities. On the other hand, the conflicts of the aquaculture with other sectors/activities have increased, parallel to the increasing number of aquaculture facilities. This fact has raised the arguments on aquaculture activities and discussions on new management approaches including regulatory arrangements and monitoring of these activities. As

noted by Kapetsky & Manjarrez (2007), Geographic Information Systems, remote sensing and mapping may have an effective tool in the management and monitoring of aquaculture activities.

IOCCG (2009) mentions the advantages of using remote sensing in aquaculture and continues that “approaches include providing information on where to base fish and shellfish farms by taking account of factors such as water quality, transport of nutrients and sea surface temperature (e.g. Pérez, Telfer & Rose, 2003). The detection of harmful algal blooms (HABs) is essential for both fishing and aquaculture operations: remotely-sensed maps of chlorophyll-a concentration and SST can help quick detection (e.g. Stumpf et al., 2003) and understanding the formation of HABs (Tanga, Kawamurab, Sang Ohc & Bakerd, 2006)”. Geographic Information Systems, with its high spatial analysis capability, can also be used in such complex aquaculture management issues since Geographic Information Systems applications are used to manipulate and analyze spatial and attribute data from all sources (Kapetsky & Manjarres, 2007).

Turkey, as a developing country with a considerable coastal area, has increased investments on aquaculture in the last decades in order to meet the fish demand in the country. According to the Ministry of Agriculture and Rural Affairs, the production in marine farms has increased from 35 tons in 1986 to 86,629 tons in 2008. The number of marine farms was also reached up to 314 before 2007. The arguments on negative impacts of aquaculture rose in the country in those years and conflicts with other sectors, especially tourism, became an important management problem. Finally, legal arrangements were made by 2007, resulting in a decrease in the marine farm facilities in Turkey.

Today, there are 241 marine farm facilities are active in production in Turkey. These changes in the sector have brought up the need for objective evaluation methods for the impacts of aquaculture on the marine environment and determination of the conflicts with other uses, as well as site selection. Remote sensing technique with its capability in data derivation and Geographic Information Systems with its

enhanced use for spatial analysis come forward to meet the needs. The subject of the thesis has emerged from this fact.

The thesis aims to make use of remote sensing and Geographic Information Systems in order to evaluate the possible impacts of aquaculture to the marine ecosystem. The aquaculture in the thesis refers and limited to marine aquaculture. Thus, Ildırı Bay was chosen as the study area because of intense aquaculture activity in the region. The impact is evaluated in terms of total suspended matter, Secchi depth and sea surface temperature. These limitations were due to the availability of the data collected in the field work. The analysis concentrated on the derivation of data from satellite imagery by Artificial Neural Network. Another purpose was to obtain time series remotely sensed data for the parameters concerned in the scope of the thesis to be able to evaluate the temporal changes, which can be further developed for monitoring such dynamic marine ecosystems.

Proceeding sections include a theoretical background based on literature survey, method applied, results of the analysis and discussions on the outputs of the study.

1.2 Theoretical Background

1.2.1 Aquaculture

Aquaculture is defined by The Food and Agriculture Organization of the United Nations (FAO) as “farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated”. A simpler definition of aquaculture is the “cultivation of plants or breeding of animals in water” (Stickney, 2000).

The main aim of aquaculture activity is to produce food for human population of the world. Parallel to the population increase, aquaculture supply has increased

enormously to meet the demand. The contribution of aquaculture to total aquatic resources production increased from 3.9 percent to 36.0 percent throughout last three decades (The Food and Agriculture Organization [FAO], 2008).

There are 1717 aquaculture corporations in Turkey by 2010 and 18 percent of these aquaculture firms works on sea water species (Akkın, 2010). Despite this low percentage, 53 percent of total product of last 8 years is from aquaculture of sea water species (Turkish Statistical Institute [TUIK], 2010) (Figure 1). Percentage of marine aquaculture production by species and regional distribution for 2008 and 2009 are given in Table 1.1.

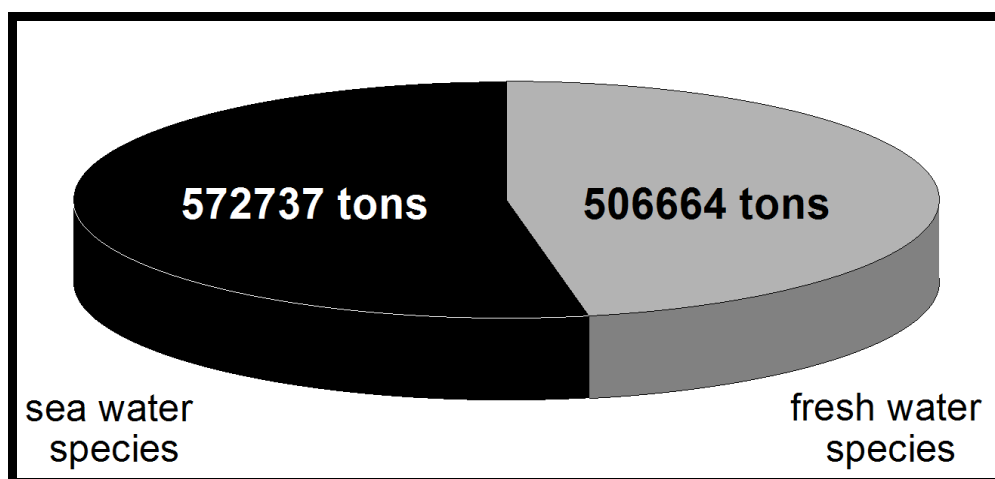


Figure 1.1 Total aquaculture products (ton) by resources between 2000-2009 in Turkey (Data from TUIK 2010)

Table 1.1 Aquaculture products in 2008 - 2009 and their distribution in Turkish seas in 2008 (Data from TUIK, 2010)

Products	Percentage (%)		Turkish Coasts of	Percentage (%)
	2008	2009		2008
Sea Bass	57.5	56.4	Aegean Sea	93.1
Sea Bream	37	34.4	Black Sea	3.8
Trout	3.2	6.3	Levantine Sea	3.1
Others	2.1	2.7	Sea of Marmara	0.1
Mussel	0.2	0.1		

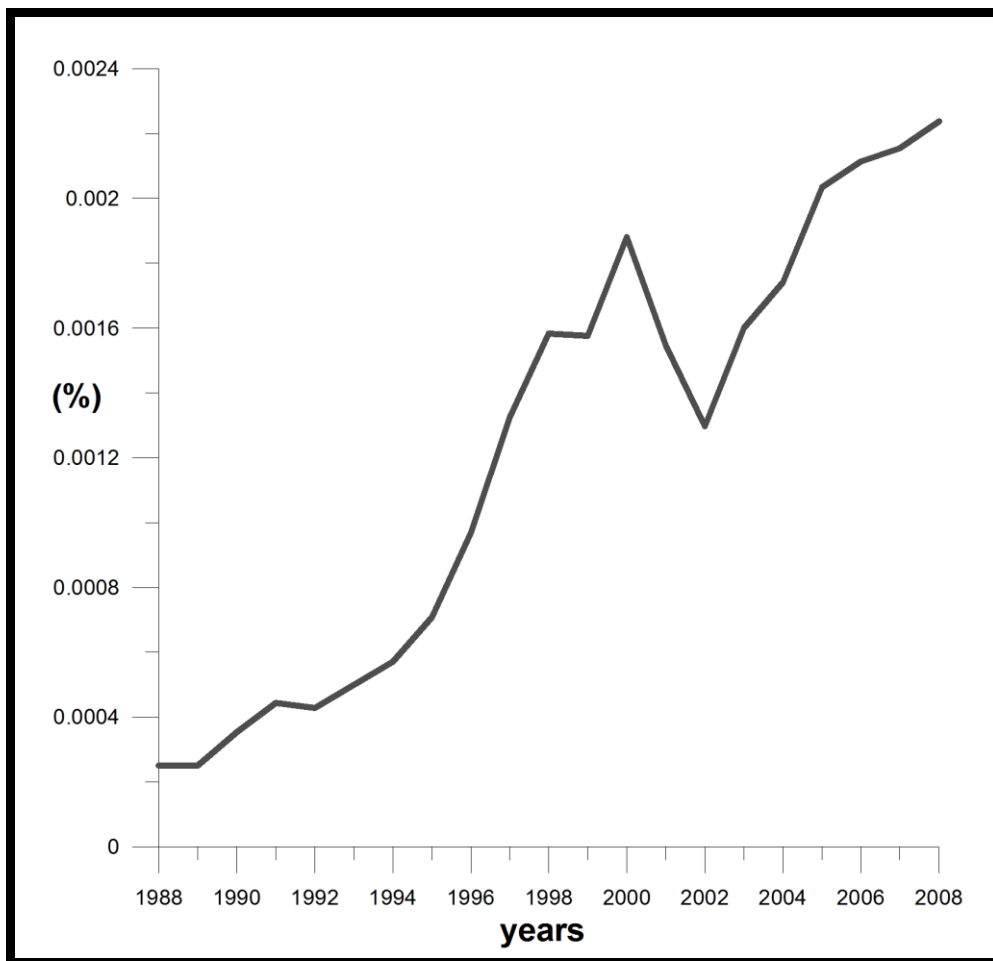


Figure 1.2 Contribution of Turkey to annual aquaculture products of the world from 1988 to 2008 [Data from FAO (2010), TÜİK (2010)]

1.2.1.2 Impacts of Aquaculture on Marine Ecosystem

Since aquaculture has grown rapidly because of increasing demand, the influence of aquaculture activity on marine ecosystem has become a popular discussion and research issue. Impacts of aquaculture on marine ecosystem can either be biological, chemical or physical such as interaction of cultured and wild individuals, escaping of invasive cultured species to the wild, increasing of suspended matters and decreasing of light transmission.

Impacts of aquaculture can be classified in two main categories according to the affected marine component: sea water column and seabed. Wastes generated by aquaculture activity like ammonia, nitrates and phosphates or suspended solids,

fragmented feeds, glands by cultured fish and their faeces are soluble or suspended in water column. On the other hand, antibiotics and drugs are also used for protecting fish health or treating diseases (Austin & Austin, 1987), and antifoulants are used on fish farm pens (Chiu, Ho & Wong, 1991). These substances can be accumulated on sediments and affect benthic environment (Björklund, 1990; Capone, 1996). Accumulations on sediment have strong impact on the structure of benthic communities (Mazzola, Mirto, La Rosa, Fabiano & Danovaro, 2000; Brown, Gowen, & McLusky, 1987; Pocklington, Scott & Schaffer, 1994).

There are a lot of studies for determining impacts of fish farms on marine ecosystems. Some relevant studies in the Mediterranean Sea are listed in Appendix 1.

1.2.2 Colour of Seawater

Water colour is determined by “scattering and absorption of visible light by pure water itself, as well as by the inorganic and organic, particulate and dissolved, material present in the water” (IOCCG, 2000). Netting (2003) explains that “the colour of the ocean is determined by the interactions of light with the water”; and he continues that when light hits the surface of an object, different colours can be absorbed, transmitted, scattered or reflected in differing intensities. The observed sea colour is generated by the reflected colours (Figure 1.3).

“The substances in seawater which most affect the colour reflected are phytoplankton, inorganic particles, dissolved organic chemicals, and the water itself. Phytoplankton contains chlorophyll, which absorbs red and blue light and reflects green light. Particles can reflect and absorb light, which reduces the clarity (light transmission) of the water. Dissolved organic matter strongly absorbs blue light, and its presence can interfere with measurements of chlorophyll” (Netting, 2003). The IOCCG (2000) categorized these substances into three according to their optical properties in practice:

- **Phytoplankton:** This component is taken to include phytoplankton and other microscopic organisms. But for convenience, it is called the “phytoplankton” component, in recognition of their major influence on optical properties.
- **Suspended material (inorganic):** Even though microscopic organisms are also “suspended” material, this term here represents only suspended material of inorganic nature that is not included in the phytoplankton component.
- **Yellow substances:** These are a group of organic, dissolved substances, consisting of humic and fulvic acids, also including “detrital” particulate material, which generally has absorption characteristics similar to yellow substances.

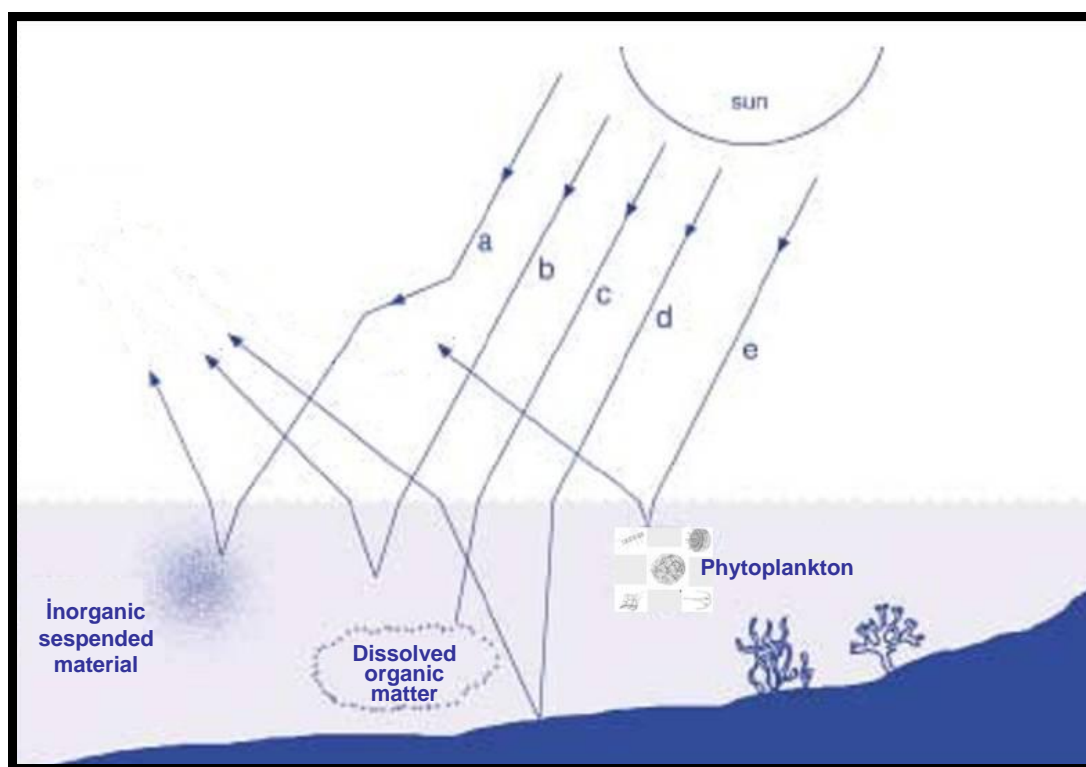


Figure 1.3 Factors that influence upwelling light leaving the sea surface. (a) upward scattering by inorganic suspended material; (b) upward scattering from water molecules; (c) absorption by the yellow-substances component; (d) reflection off the bottom; and (e) upward scattering from the phytoplankton component. (IOCCG, 2000)

The composition of these substances characterizes the sea colour. There is a common approach to classify this composition. “A bipartite classification scheme, according to which oceanic waters are partitioned into Case 1 or Case 2 waters (Morel & Prieur, 1977; Sathyendranath & Morel, 1983; Gordon & Morel, 1983). By

definition, Case 1 waters are those waters in which phytoplankton (with their accompanying and co-varying retinue of material of biological origin) are the principal agents responsible for variations in optical properties of the water. On the other hand, Case 2 waters are influenced not just by phytoplankton and related particles, but also by other substances, that vary independently of phytoplankton, notably inorganic particles in suspension and yellow substances” (IOCCG, 2000).

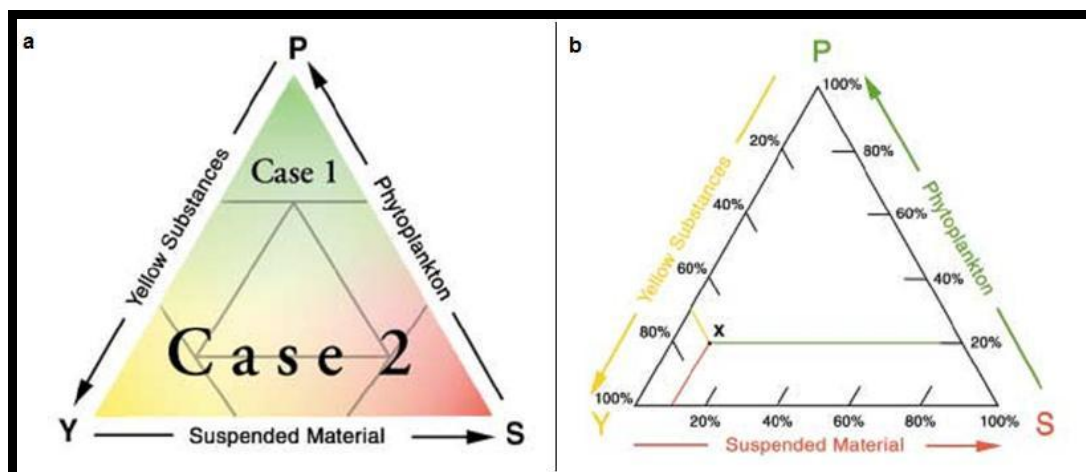


Figure 1.4 Classification of waters as its components (a) Diagrammatic representation of Case 1 and Case 2 waters, adapted from Prieur & Sathyendranath (1981) (see also Morel & Antoine, 1997; Dowell, 1998). (b) An illustration of the triangular diagram (also known as the trilinear graph) in use to classify waters. The classification is based on the relative contributions to an optical property from three components: phytoplankton, yellow substances and suspended material (IOCCG, 2000).

1.2.3 Remote Sensing

The term ‘remote sensing’ is defined by Canada Centre for Remote Sensing (2008) as “Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is performed by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information”. Conventionally, remote sensing deals with the use of light e.g. electromagnetic radiation as the medium of interaction. Remote Sensing refers to the identification of earth features by detecting the characteristics electromagnetic radiation that is reflected by the earth surface. Every object reflects a portion of electromagnetic radiation incident on it depending upon

its physical properties. Additionally, objects also emit electromagnetic radiation depending upon their temperature and emissivity. Reflectance pattern of each object is different at various wave lengths. Such a set of characteristics is known as spectral signature of the object, resulting in identification and discrimination of objects. At the simplest level, remote sensing is the visual perception of objects (Salgaonkar et al., n.d.).

The remote sensing is an energy, sensor, human, hardware and software dependent procedure. Stages in remote sensing can be summarized as:

- Requirement of an energy source
- Energy interaction with the atmosphere
- Interaction with the target
- Recording of energy by sensor
- Data transmission & processing
- Image processing & analysis

The increase in preference of remote sensing in earth sciences in the last decades comes from the advantages brought by the technique. The major advantages of remote sensing over ground based methods according to Salgaonkar et al. (n.d.) are

- Synoptic view: It facilitates the study of various features of earth surface in their spatial relation to each other and helps to delineate the required features and phenomenon.
- Accessibility: It makes it possible to gather information about inaccessible areas where it is not possible to gather information through ground surveys.
- Time: These techniques save time & efforts as information about large area can be gathered quickly.
- Multidisciplinary applications: Remote sensing data are useful to different disciplines such as geology, fisheries, forestry, land use etc.

1.2.3.1 Remote Sensing of Ocean Colour

Remote sensing of ocean colour is the determination of the ocean water-leaving radiance spectra after removing the atmospheric and surface effects. 90 percent of sensor-measured signal over ocean comes from the atmosphere and surface at satellite altitude (Figure 1.5). It is crucial to have accurate atmospheric correction and sensor calibration before deriving water leaving radiance (Wang, 2009). Satellite sensors for ocean colour have the capability to orient the detector to avoid specular reflection from the sun, but there are no ways to prevent some of the flux scattered by the atmosphere from reaching the sensor (IOCCG, 2000).

“Examining the water-leaving signal in some more detail, we see that several factors influence this signal. Direct sun light and scattered sky light that penetrates the sea surface may be absorbed or scattered by the water molecules, or by the various suspended and dissolved materials present in the water. In shallow clear waters, a significant part of the light from the sun may reach to the bottom, and be reflected from it” (IOCCG, 2000).

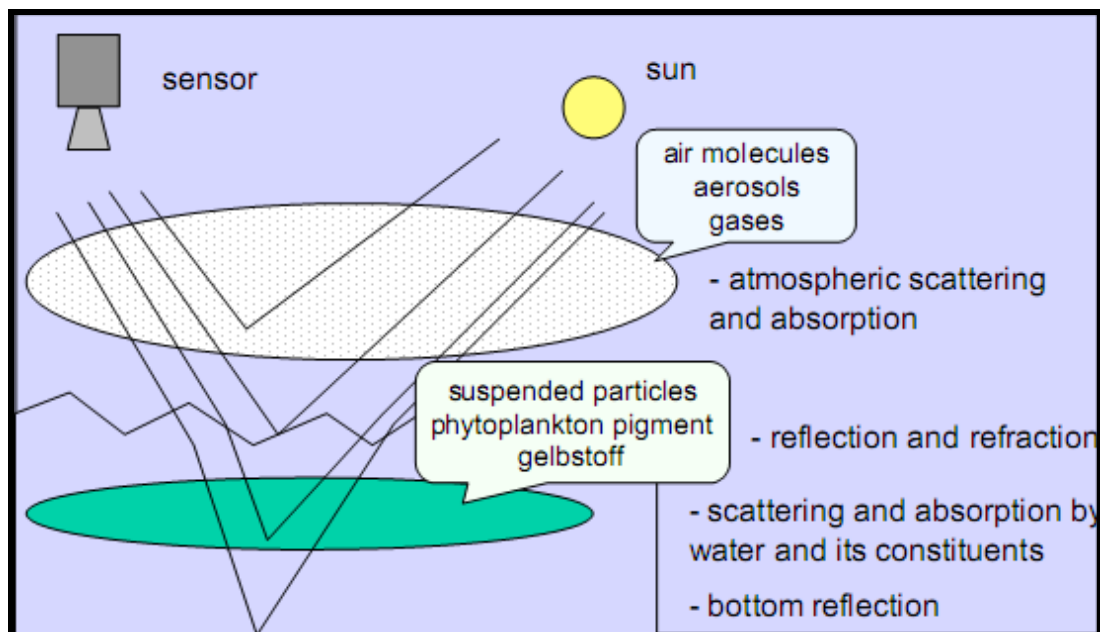


Figure 1.5 Basic principles of remote sensing of ocean colour (Doerffer, 2008)

1.2.3.2 Remote Sensing Algorithms

There are two major approaches to the retrieval of water components from radiances at the top of the atmosphere:

- Empirical approaches algorithms
- Model-based approaches algorithms

1.2.3.2.1 Empirical Approaches Algorithms. This kind of algorithms establishes a relationship between optical measurements and the concentration of constituents based on experimental data sets. Formulas that describe relationship are derived from regressions between the radiance ratios and the desired property and are based on experimental data sets (IOCCG, 2000). Advantages and limitations of empirical approaches are shown in Table 1.2.

Table 1.2 Advantages and limitations of empirical approaches algorithms

Advantages	Limitations
Simple	The resulting errors may quickly exceed acceptable limits.
Easy to derive even from a limited number of measurements	Particularly sensitive to changes in the composition of water constituents and the atmosphere.
short computing time due to their mathematical simplicity	The lack of mathematical formulation makes it difficult to analyze the source of the errors.
Easy to implement and test	
Stable results	

1.2.3.2.2 Model-based Approaches Algorithms. Model-based algorithms use bio-optical models to describe the relationship between water constituents and spectra of water-leaving radiance and reflectance, as well as radiative transfer models to simulate the light propagation through the water and the atmosphere.

Four different model-based techniques are listed below:

- Algebraic methods. An ocean-colour model is first implemented using empirical data. In fact it is called semi-analytical. The result is a set of algebraic equation that can be solved sequentially. As the number of unknown parameters increase, it becomes very difficult to implement.
- Non-linear optimization techniques. In this method, a forward model is inverted directly by minimizing the differences between the calculated values and the measured radiances. It requires substantial computation time.
- Principal component approach (PCA). In this method, water constituents are directly computed from TOA radiances. A segmentation of the range space of derived parameters should be needed to keep accuracy in this scheme.
- Neural network approach (NN): involves the inversion of the relationship between reflectance in different spectral bands, and the concentrations of multiple types of water constituents. For this purpose, the neural network is used a multiple non-linear regression technique, and is thus related to the simpler case of linear regression (IOCCG, 2000)

Advantages and limitations of model-based approaches algorithms are shown in Table 1.3.

Table 1.3 Advantages and limitations of empirical approaches model-based approaches algorithms

Advantages	Limitations
Bio-optical models that allow better understand the underlying processes.	More complex mathematically and computationally than empirical models.
Implementation in a more global scale because they are based on a more general theoretical basis.	Increasing the number of unknown variables may make the mathematical solution of the inverse problem unstable, due to its nonlinear nature.

1.2.3.3 Atmospheric Correction

The purpose of the atmospheric correction for the remote retrieval of ocean properties is to remove the atmospheric and surface effects from the signal measured by the satellite-sensor, thereby deriving the radiances coming from the ocean waters IOCCG (2010). As highlighted by Pedrero (2009) this radiance is made of photons that have crossed the atmosphere down to the ocean and then have twice crossed the air-sea interface before reaching the sensor after a second atmospheric travel. The spectrum of the water-leaving radiances carries information about the water constituents in which they were scattered.

Effect of atmosphere can be categorized into 4 main groups:

- Gaseous absorption (ozone, water vapour, oxygen)
- Scattering by air molecules (Rayleigh)
- Scattering and absorption by aerosols (haze, dust, pollution)
- Polarization (MODIS response varies with polarization of signal)

Rayleigh, includes 80-85 percent of total signal, is small molecules compared to nm wavelength, scattering efficiency decreases with wavelength as λ^{-4} . Rayleigh can be accurately approximated for a given atmospheric pressure and geometry. Aerosols, includes 0-10 percent of total signal, is particles comparable in size to the wavelength of light, scattering is a complex function of particle. It is significantly varies and cannot be easily approximated (Franz, 2007).

There are two main assumptions on atmospheric corrections:

- Ocean is black at the NIR wavelengths.
- Aerosols are non- or weakly absorbing

Coastal waters have violations of the both assumption (Wang, 2009). Open waters have limited aerosols in atmosphere and substances in seawater because of lack of interaction to land, so atmospheric corrections are applied more simple and accurately than coastal waters.

Various atmospheric corrections have been developed for following ocean colour satellite sensor: MERIS (Fischer & Bennartz, 1997; Antoine & Morel, 1998; Antoine & Morel, 1999; Bennartz & Fischer, 2001; Nobileau & Antoine, 2005; Antoine & Nobileau 2006; Schroeder, Behnert, Schaale, Fischer & Doerffer, 2007; Doerffer & Schiller, 2008), SeaWiFS and MODIS (Gordon & Wang, 1994a; Siegel, Wang, Maritorena & Robinson, 2000; McClain, Feldman & Hooker, 2004; Wang, 2005; Bailey & Werdell, 2006; Zibordi, Mélin & Berthon, 2006) , OCTS and GLI (Fukushima et al., 1998; Tanaka et al. 2004) and POLDER (Deschamps, Fougnie, Frouin, Lecomte & Verwaerde, 1999) (IOCCG, 2010).

1.2.4 Remote Sensing and Geographical Information Systems (GIS) in Aquaculture

1.2.4.1 Remote Sensing in Aquaculture

Remote sensing is an important tool for monitoring marine environments that respond to changes in the hydrologic regime. Remotely sensed data provides the necessary spatial data on suspended sediments, dissolved organic matter, phytoplankton, algal blooms and oil slicks etc which will be useful in management of fish stocks, monitor the water quality and natural water pollution such as oil or algal blooms, which are harmful to aquatic life. Remote sensing imageries have been of immense use in providing information on temporal and spatial changes in area under aquaculture, mangrove areas, coral reef mapping and other land use patterns (Salgaonkar et al, n.d.).

As highlighted by IOCCG (2009), there is tremendous potential for remotely-sensed ocean colour to be applied to fish and shellfish farming, and the examples below hint at this promise. Specifically, these applications include:

- Identification of high-chlorophyll zones for farm site selection

- Identification of unfavourable locations for farm sites because of unfavourable temperature, turbidity, or potential development of harmful algal blooms
- Characterization of boundary conditions for ecological modeling (e.g. production capacity)
- Ground-truthing of model results, particularly spatial model output
- Quantification of seston depletion by suspension-feeder grazing; and parameterization of primary production in fish farm models.

Remotely-sensed data have been used in near-shore aquaculture site selection for more than 20 years (Kapetsky, McGregor, & Nanne, 1987; Kapetsky & Aguilar-Manjarrez, 2007). Historically, satellite images have been used in two different ways (IOCCG, 2009):

- as survey tools prior to field work (Edwards, 2000)
- as input data for GIS analysis for the preparation of suitability maps for regional planning or for aquaculture facilities design (Giap et al., 2003; Buitrago, Rada, Hernández, & Buitrago, 2005).

Site selection for near-shore aquaculture sites has been routinely based on the use of multispectral images from high spatial-resolution sensors (e.g. Landsat, Spot) which more recently have been complemented with the application of new sensors such as Aster or IRS LISS/PAN (Dwivedi & Kandrika, 2005). The use of remotely-sensed imagery for aquaculture site selection in the open sea (e.g. fish cages, mollusc rafts or long-line systems) is much more recent. In contrast to land-based aquaculture planning where a few high spatial-resolution images are used, site selection in open seas requires extensive use of medium-resolution images (e.g. AVHRR, SeaWiFS, MODIS and QuickSAT) for the analysis of the seasonal and inter annual variability of the highly-dynamic characteristics of the marine environment, and also for the determination of environmental patterns and trends of potential aquaculture sites, or for the preparation of aquaculture suitability maps (IOCCG, 2009).

1.2.4.2 Geographical Information System in Aquaculture

Geographical Information System is a system specially designed to work with data referenced by spatial or geographic coordinates (Perez et al., 2003) and can be considered as a database management system which allows users to store, retrieve and manipulate data, integrated with a series of routines that allow sophisticated spatial analysis and display (Burrough, 1986).

Works on GIS in the marine environment have been mainly promotional and aimed at demonstrating a variety of applications. For example, conceptual, technical and institutional issues as well as a variety of applications are presented by Wright and Bartlett (2000) in an edited volume. Wright (2002) deals with the coastal and open ocean environments focusing on broad applications of GIS including mapping and visualization, electronic navigational charting, and the delivery of maps and data via the internet. Breman (2002) has assembled a collection of chapters to demonstrate the progress in the use of GIS in a variety of marine sciences.

Aquaculture spatial issues addressed most frequently include (Aguilar-Manjarrez, Bensch, Carocci, Graaf & Taconet, 2006):

- Development (siting and zoning, strategic planning),
- Practice and management (inventory and monitoring of aquaculture and the environment, environmental impacts), and
- Integration of aquaculture into other uses of lands and waters (management of aquaculture together with fisheries, multisectoral planning including aquaculture).

Geographical Information Systems are widely used as tools to digitize remotely sensed or cartographic data complemented with various ground-truth data, which are geo-coded using a Global Positioning System (GPS). Geographical Information System can be used to analyze the spatial characteristics of the data over various digital layers. If sequential data are available, quantification of spatial changes becomes possible through overlay analysis. GIS can be described as databases where

the information is spatially referenced, what has made GIS so popular is the fact that the spatial referencing of information is related to maps. It is the manipulation and analysis of the spatial database and the display of maps with relative speed and ease is the trade mark of Geographical Information System. The literature on Geographical Information System is vast, but there are two bench mark publications (Maguire, Goodchild & Rhind, 1991; Longley, Goodchild, Maguire & Rhind., 1999), which summarize most of the research and development issues in this field. GIS has proved useful in assessing impacts on aquatic resources and environments for development projects involving land and water use, in aquaculture site selection in relation to ecological and socio-economic variables, in space and resource allocation to conflicting types of use, in aquaculture development planning and environmental impact monitoring (Rajitha, Mukherjee & Chandran, 2007).

Remotely sensed data can be integrated to GIS environment for additional spatial analysis in order to obtain information for aquaculture management. Derived imageries can either be used in raster-based GIS analysis or in vectorizing classes obtained by remote sensing. Increasing the analysis capability by integrating these two tools enhances decision-making in aquaculture.

1.2.5 MERIS: A Sensor for Ocean Colour

Environmental Satellite (ENVISAT) and its payload instruments were developed by European Space Agency (ESA) and launched on 2002, March 1st. Meris is one of the instruments of the ENVISAT (Figure 2.1). The instrument is suitable to be used in water quality monitoring. MERIS was designed to acquire fifteen spectral bands between 390 nm and 1040 nm (Figure 2.2). The wavelengths, bandwidths and their uses of the MERIS spectral bands are given in Table 1.6.

MERIS measurement data are used to derive information in three main spheres:

- Ocean mission is detection of phytoplankton, yellow substance and suspended matter

- Atmospheric mission is detection of aerosol optical thickness, aerosol type, and water vapour column contents
- Land mission is understanding of vegetation seasonal dynamics and responses to environmental stress (European Space Agency [ESA], 2006)

The MERIS instrument has a cross-track Field of Vision (FOV) of 68° . Therefore, it produces an image swath width of approximately 1150 km. The swath is comprised of 5 imaging spectrometer modules. However, it may operate at Full Resolution (FR) of approximately 0.3 km pixels at nadir, or at Reduced Resolution (RR) of approximately 1.2 km pixels at nadir:

- Full Resolution (FR): In full resolution mode, it pixel has an Instantaneous Field of Vision (IFOV) of 0.019° , with a nadir spatial sampling of 0.26 km across track by 0.29 km along track. The data are processed on request from the acquired level 0 segments, on a floating scene basis. MERIS Full Resolution Swath (FRS) data are processed offline.
- Reduced Resolution (RR): In reduced resolution mode, it has a maximum length of 43.5 minutes (all of full sunlight orbit), producing approximately 17400 km of coverage. Each pixel is approximately 1.04 km across track by 1.16 km along track at nadir. The processing is done systematically (Pedrero, 2009).

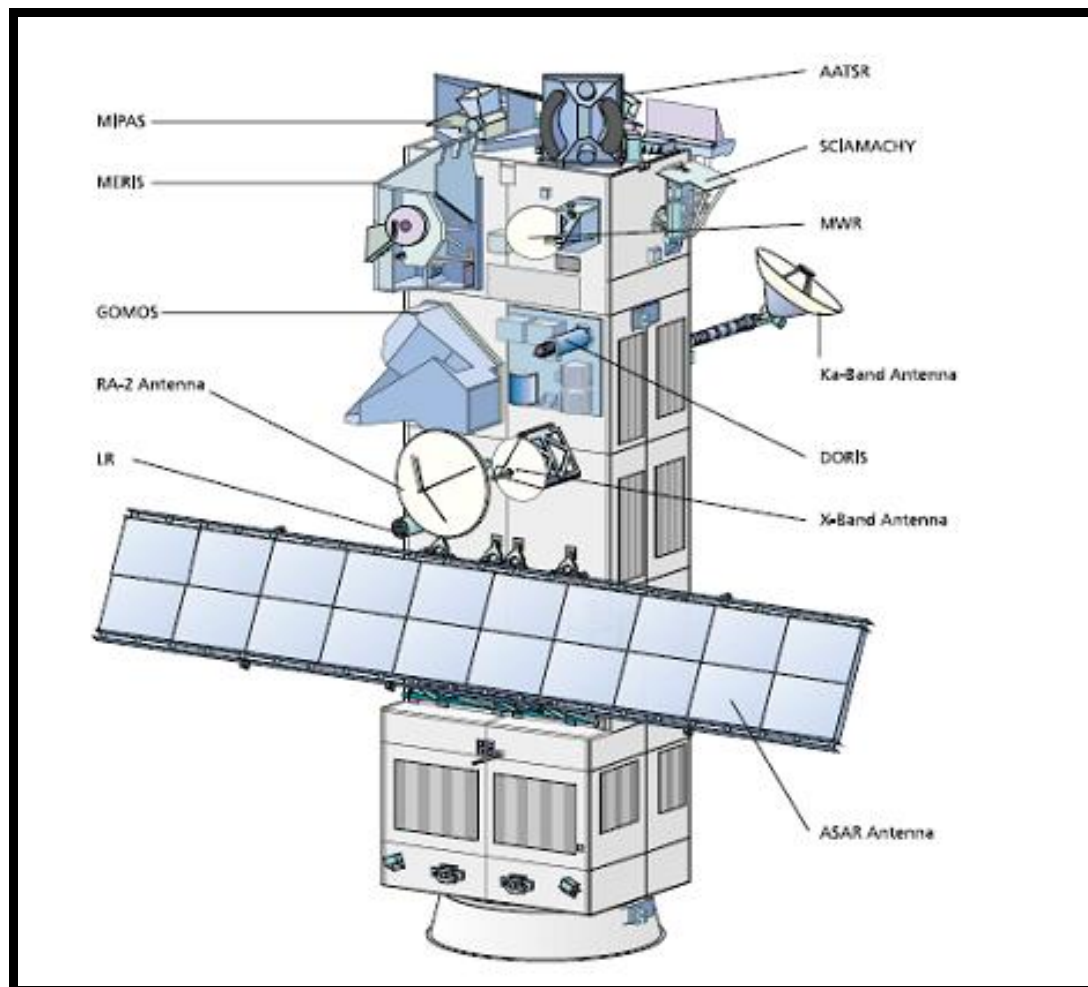


Figure 1.6 ENVISAT Satellite Configuration and location of instruments (ESA, 2001)

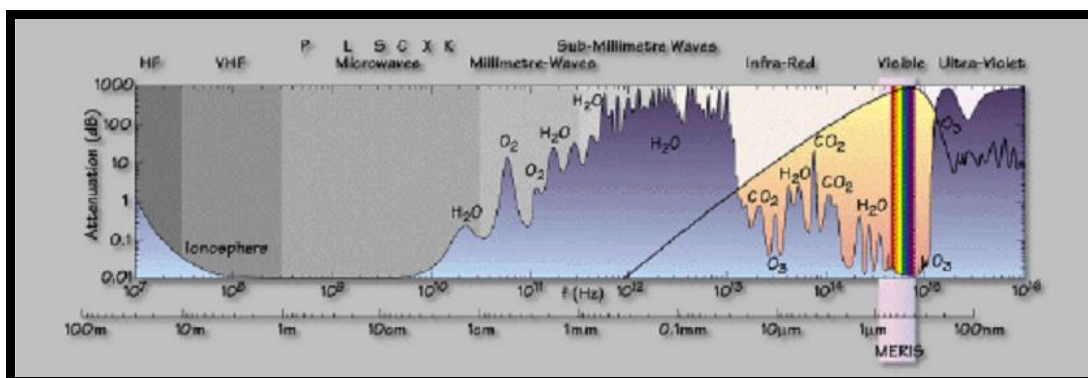


Figure 1.7 The electromagnetic spectrum indicating the data set measured by MERIS (ESA, 2006)

Table 1.4 MERIS bands wavelength, bandwidth and their uses (ESA, 2001)

Band Nr.	Band centre (nm)	Bandwidth (nm)	Potential applications
1	412.5	10	Yellow substance, turbidity
2	442.5	10	Chlorophyll absorption maximum
3	490	10	Chlorophyll, other pigments
4	510	10	Turbidity, suspended sediment, red tides
5	560	10	Chlorophyll reference, suspended sediment
6	620	10	Suspended sediment
7	665	10	Chlorophyll absorption
8	681.25	7.5	Chlorophyll fluorescence
9	705	10	Atmospheric correction
10	753.75	7.5	Oxygen absorption reference
11	760	2.5	Oxygen absorption R-branch
12	775	15	Aerosols, vegetation
13	865	20	Atmospheric correction over ocean
14	890	10	Water vapour absorption reference
15	900	10	Water vapour absorption, vegetation

1.2.5.1 Meris Coastal Water Processors

Some processor has been developed for MERIS ocean mission in coastal waters (Doerffer & Schiller 2008, Schroeder et al 2007; Santer & Zgolski 2008). These processors include two algorithms. First one is atmospheric correction algorithms to determine water leaving radiance from top of atmosphere radiance. Second one is water algorithm to compute products about water quality.

1.2.5.1.1 Case 2 Regional Processor. As mentioned by Doerffer and Schiller (2008), the atmosphere model can be classified in two main parts (Figure 2.3):

- Part 1 contains the variable aerosol / cirrus concentrations with a constant Rayleigh scattering and ozone absorption profile. It has 50 layers, each 1 km thick
- Part 2 consists of 2 virtual layers on top of this standard atmosphere with only a variable ozone and Rayleigh scattering atmosphere.

The water algorithm derives the inherent optical properties:

- absorption coefficient of phytoplankton pigment
- absorption coefficient of gelbstoff and total suspended matter after bleaching the phytoplankton pigment fraction
- the scattering coefficient and absorption of total suspended matter (TSM).

The algorithm is based on a neural network (NN), which relates the bi-directional water leaving radiance reflectance with these IOPs (Doerffer & Schiller 2007).

1.2.5.1.2 FUB/WEW Water Processor. Like previous processor, atmospheric correction scheme is in two parts:

- A Rayleigh-Ozone correction
- Atmospheric correction network (Schroeder et al., 2007).

Water algorithms are unlike in the other processors; the retrieval process of the water constituents does not use the water leaving radiance reflectance estimated in the atmospheric correction. An independent Neural Network for each constituent is trained with 100,000 simulated vectors of the forward model. It estimates the concentrations directly from the collected radiances at the top of the atmosphere (Pedrero, 2009).

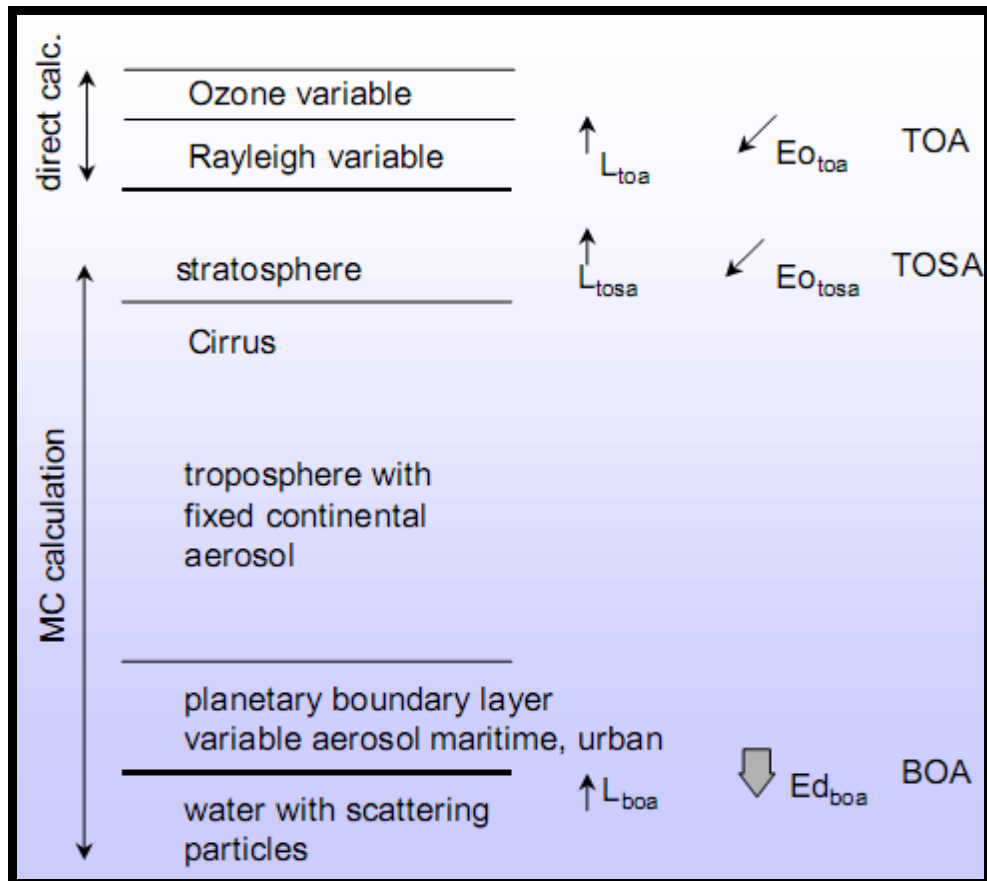


Figure 1.8 Model atmosphere, TOA is top of atmosphere, TOSA top of standard atmosphere and BOA is bottom (Doerffer & Schiller 2008)

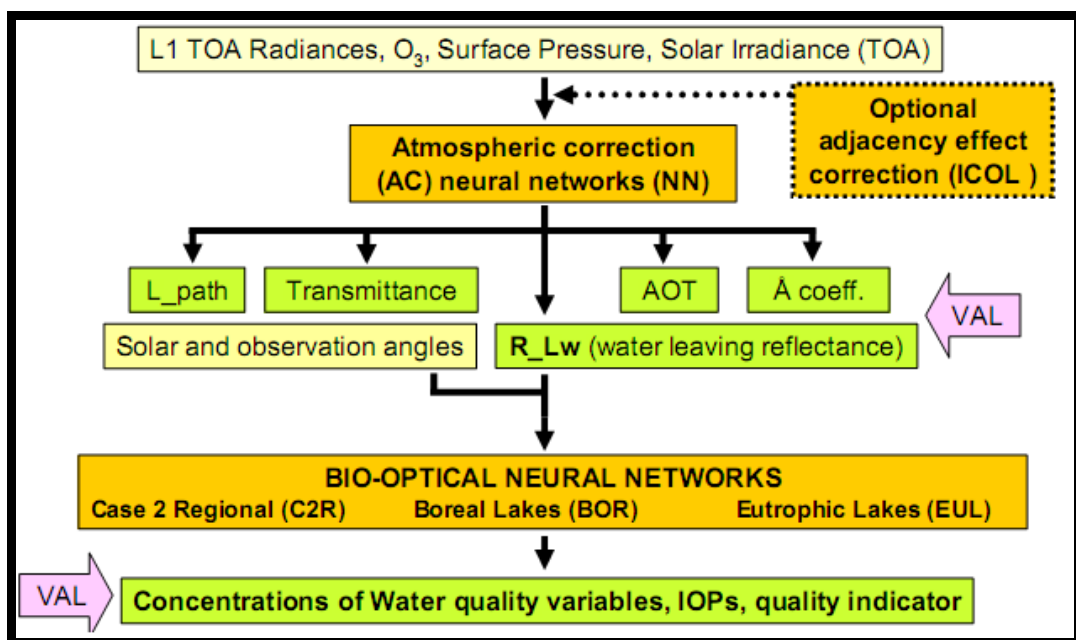


Figure 1.9 Case 2 regional (C2R) algorithm overview (Koponen, n.d.)

1.2.5.1.3 *Improved Contrast Between Ocean and Land (ICOL) Processor*. The processor reduces the Adjacency Effect (AE) in MERIS images. Firstly, it estimates atmospheric parameters and then, computes new top of atmosphere radiances that do not include adjacency effect due to aerosol and Rayleigh scattering (Santer & Zgolski, 2008).

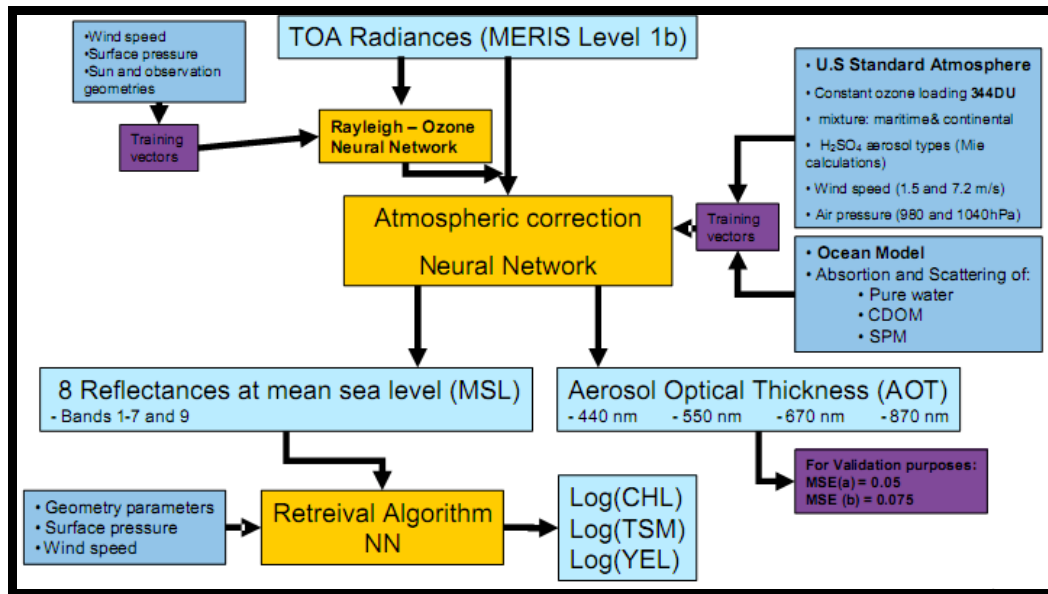


Figure 1.10 FUB/Wew algorithm overview (Koponen, n.d.)

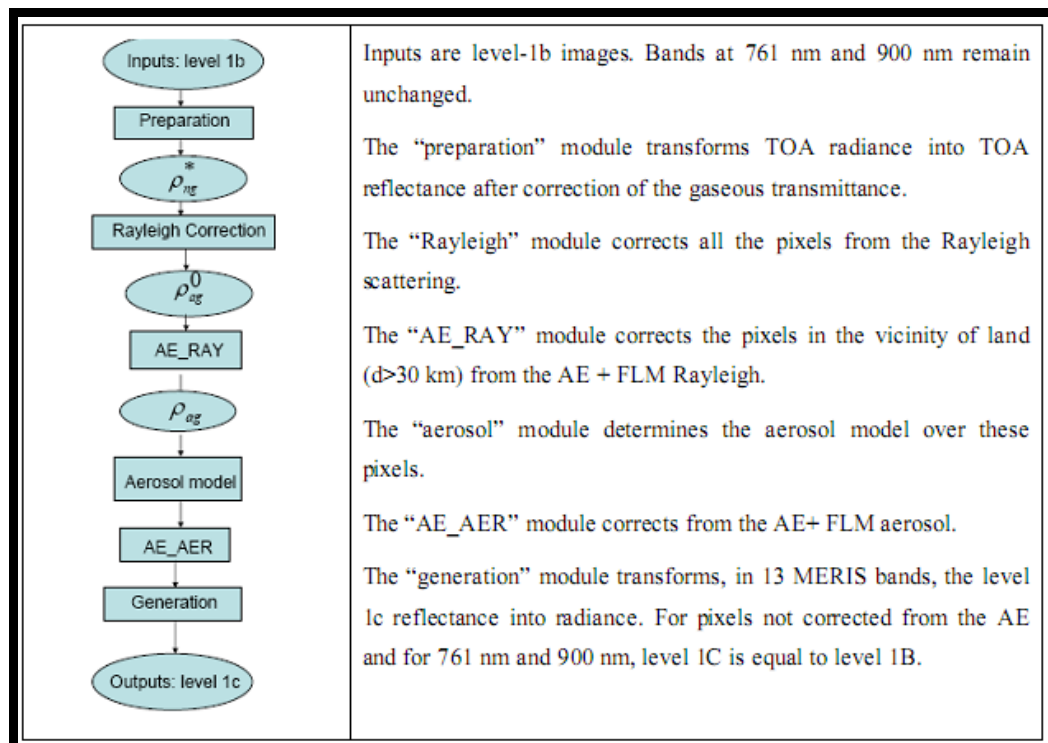


Figure 1.11 Flowchart of ICOL algorithm from Santer & Zgolski (2008).

CHAPTER TWO

MATERIAL AND METHOD

2.1 Study Area

The Bay of Ildırı is located at the middle-Eastern coasts of the Aegean Sea in Turkey. It's surrounded by Çeşme and Karaburun Peninsulas. Opening of the bay, includes some islands that separate opening into two parts, connects it with Chios Strait (Figure 2.1).

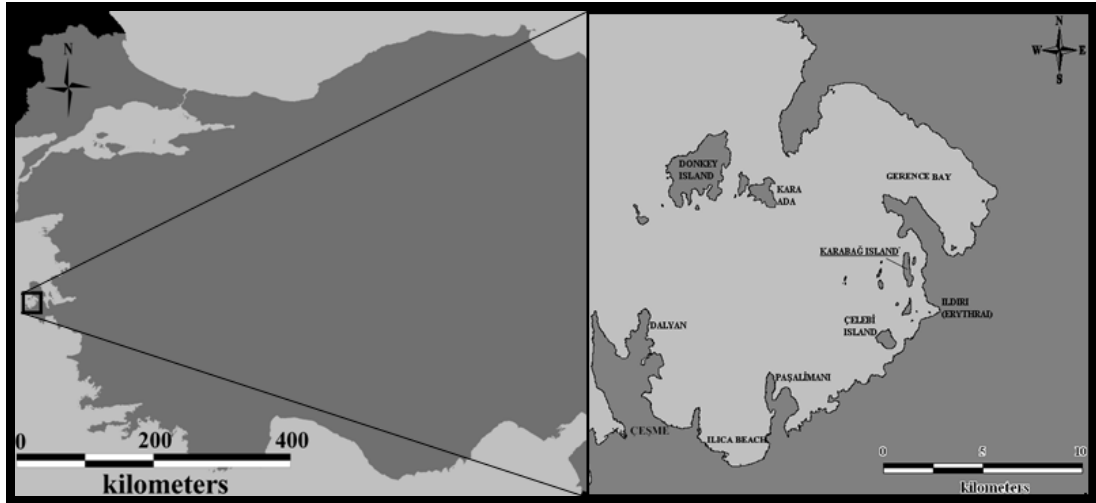


Figure 2.1 Location of the study area and locations in the study area

The bay is characterized with high density of aquaculture activity. As highlighted by Demirel (2010), data from The Provincial Agriculture Directorate (TIM) shows 15,690 tons of aquaculture fish (seabream and seabass) capacity per year are produced by 20 facilities in Ildırı Bay. Tuna fish facility is also known in the bay. Distribution of aquaculture activity areas in the bay are shown in Figure 2.2. Other important activity in the bay is tourism. Çeşme, one of the most popular tourism destinations, is located at southern side of Ildırı Bay. Tourism profile of Çeşme is dominantly on sea/sun/sand and this situation implies that tourism activity in the area is the another important effect for marine ecosystem (Akyurt, 2008; Demirel, 2010).

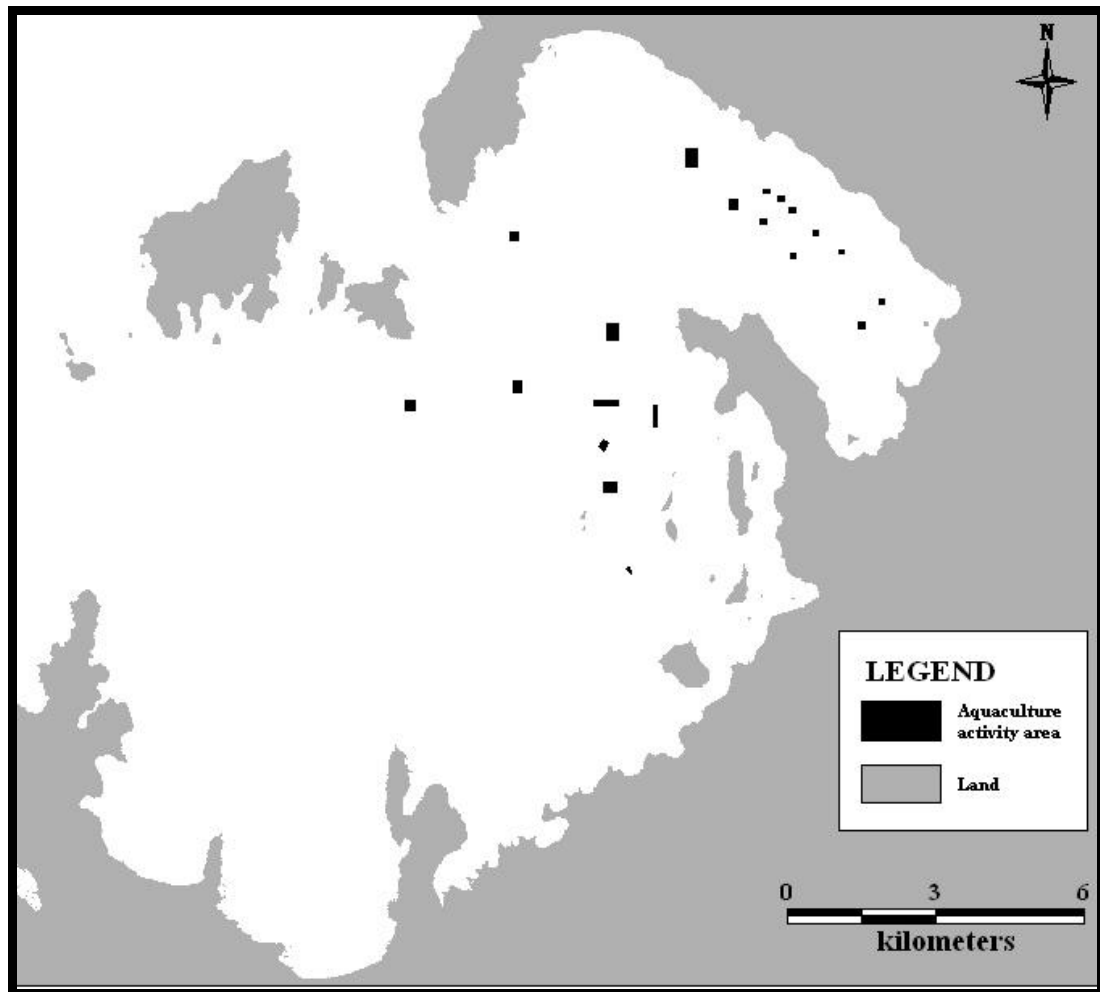


Figure 2.2 Previous aquaculture activity area (Data from Demir 2010)

According to the data of Station of Turkish State Meteorological Service in Çeşme in 47 years (1963 - 2010), detailed climate data are available for Çeşme, which located at South-west of the bay. Annual mean temperature is 17.2 (30.2-6.0) °C and total annual rainfall is 48 (344-0) kg/m² (Turkish State Meteorological Service [DMI], 2010). These show that approximately 8 months of the year are arid periods between April to November, as shown in Ombrothermic diagram of Çeşme station (Figure 2.3). Max speed, average speed and monthly dominant direction of wind of the area among 1963 – 2010 are shown in Table 2.1.

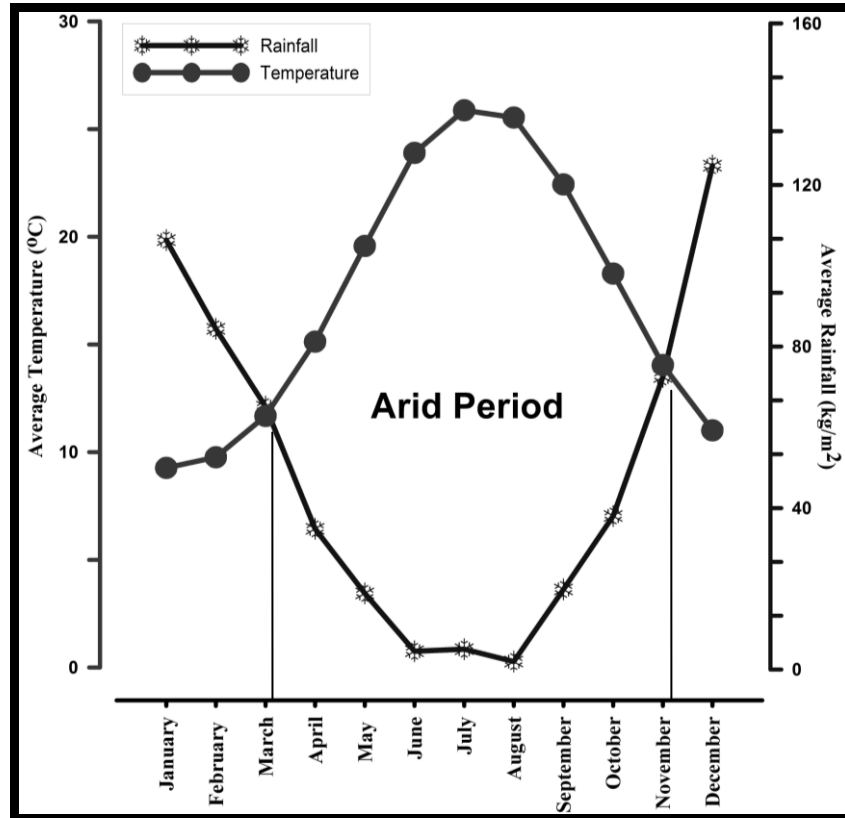


Figure 2.3 Ombrothermic diagram of Çeşme station and its surrounding area with average data from 1963 to 2010 (Data from DMI, 2010)

Table 2.1 Max speed, average speed and monthly dominant direction of wind on Çeşme station and its surrounding area with average of 43 years (1963 – 2010; data from DMI, 2010)

Month	Max speed (m/sec)	Average speed (m/sec)	Dominant Direction
January	21.8	3.3	SSE
February	21.5	3.5	S
March	20.1	3.2	SSE
April	18.2	2.9	SSE
May	14.8	2.5	SSE
June	13.8	2.6	S
July	14.2	2.8	NNE
August	13.6	2.5	NNE
September	14.8	2.4	NE
October	17.3	2.6	NNE
November	20.3	2.8	SSE
December	20.8	3.3	S

2.2 Field Measurements

The dataset used in this study extends from February, 2010 to February, 2011. In situ data of physical, bio-chemical and biological parameters were collected in Ildırı Bay from the six expeditions with “R/V Dokuz Eylül 1” and one with R/V K. Piri Reis. This study was carried out under a project called 107Y225 which was financially supported by TUBITAK (The Scientific and Technological Research Council of Turkey). Sample months and stations are given in Table 2.2. Spatial distribution of stations is shown in Figure 2.4.

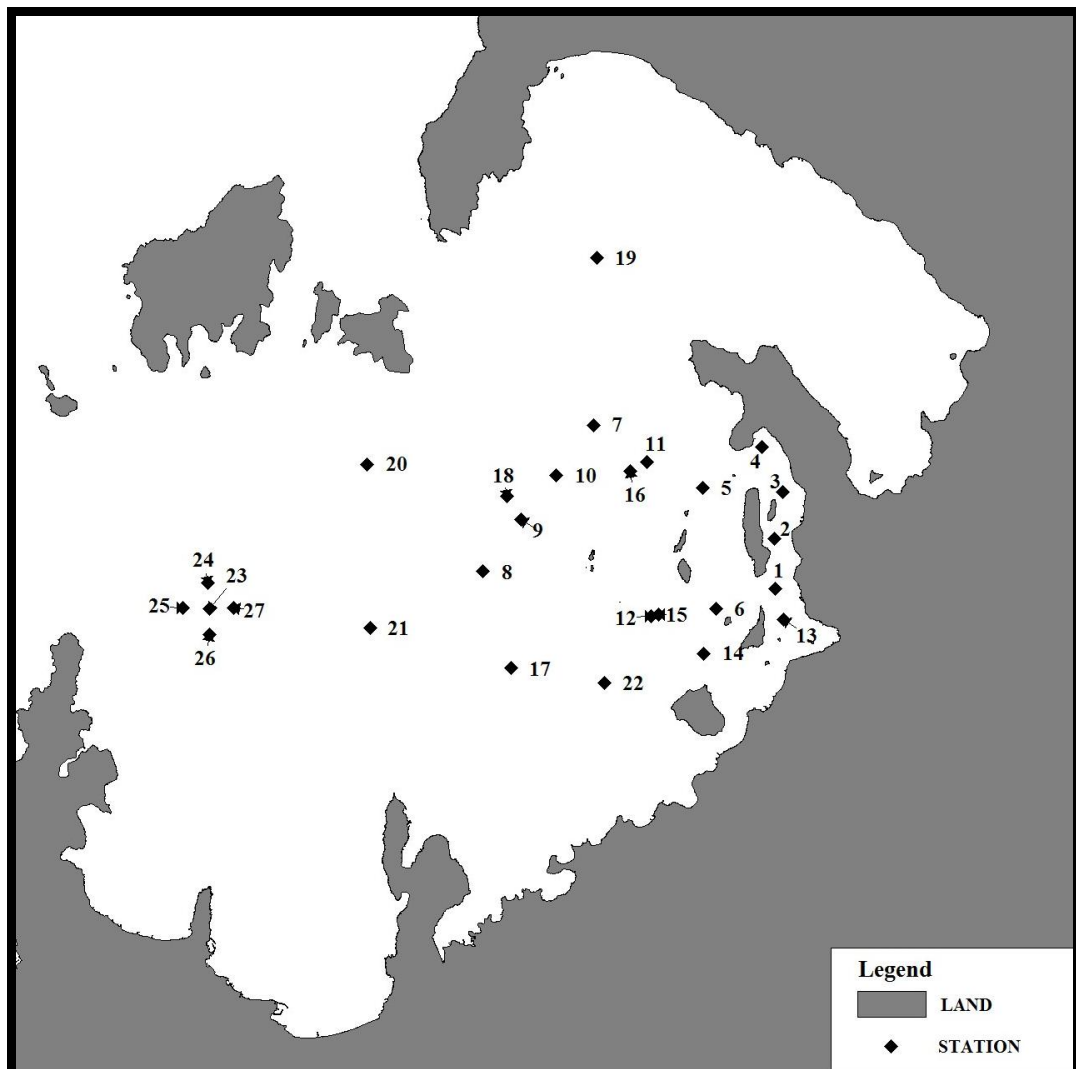


Figure 2.4 Distribution of sampling stations

Table 2.2 Months of field sample and sampling stations of the study

Station	Feb '10	Mar '10	Apr '10	Jun '10	Jul '10	Sept '10	Feb '11
1	x	x	x	x	x	x	x
2	x	x	x	x	x	x	x
3	x	x	x	x	x	x	x
4	x	x	x	x	x	x	x
5	x	x	x	x	x	x	x
6		x	x	x	x	x	x
7	x	x	x	x	x	x	x
8	x	x	x	x	x	x	x
9				x	x	x	
10				x	x	x	
11				x	x	x	
12							
13							x
14							x
15							x
16							x
17							x
18							x
19							x
20							x
21							x
22							x
23							x
24							x
25							x
26							x
27							x

Water samples at each station were taken from the sub-surface layer of the sea (0–0.5 m). Analyses of total suspended matter (TSM) (mg/l) were carried out by filtering of samples on to Whatman GF/F Glass Microfibre Filters (47 mm diameter, 0.45 micron pore size). Filters were dried in fixed temperature (105 °C) to constant weight before and after filtration. The increase in weight of filter indicates total suspended matter concentration in the sea water sampling (Sipelgas, Ossipova, Raudsepp & Lindfors, 2009; Lindell, Pierson, Premazzi & Zilioli, 1999). The Secchi disc which is a circular flat 32 cm in diameter with two quarters painted black and other two ones painted white in diameter. It was dipped through the water column until just disappearing. This depth is called the Secchi depth (SD). Data of sea water temperature (SST) obtained by using “Sea-Bird SBE – 9 CTD profiling” system (in R/V K. Piri Reis) and “Sea Bird SBE 19 Plus” portable CTD profiling system (in R/V Dokuz Eylül 1) during study time. The systems dipped through the water column and set for obtaining data per second. First 1 meter averaged data used for validation of SST algorithm which used to represent SST distribution of the study area.

2.3 Satellite Imagery

2.3.1 MERIS

The MERIS FRS (Full Resolution Level 1) data were received from European Space Agency (https://oa-es.eo.esa.int/ra/mer_frs_l1/index.php) by PI 6611 project between September 2009 and February 2011, excluding November and December 2010 because of technical problem of ESA data system. Sampling days for the empirical neural network (NN) algorithm were chosen between September 2009 and February 2011 in 16 months from a period of 18 months. A total number of sampling days are 37 which include calibrating days (7 days) and cloud free days (30 days). Whole image which are collected were prepared for processing with created empirical neural network algorithm. MERIS images selected in order to field measurements in step of calibration. Dates of the images and fields study are given in Table 2.3. Subsets of location of Ildırı Bay with 30 km buffer at minimum are

extracted from images. Subset images were processed by using ICOL processor module under Beam Visat 4.8 software. Case 2 Regional Processor (C2R) under Beam Visat 4.8 software was used for atmospheric correction step. The C2R is a two step procedure; first it uses a neural network for atmospheric correction. Inputs to this NN are the top of standard atmosphere radiance reflectance together with the sun and viewing angles. Outputs are the water leaving radiance reflectance for the same angles. C2R provides these data as output and it can be used for calibration with field data. Field station coordinates were superposed on atmospherically corrected pixels on images. 3X3 pixels were exported for every station's pixel and averaged for calibrating data with field data.

Whole data of the study area were also extracted with created mask area by using Rectangle Drawing Tool in Beam Visat. Extracted data were collected in MS Excell as input of empirical NN algorithm of the study area.

Table 2.3 MERIS image and field study date which used for data calibration.

Meris date	19 Feb '10	23 Mar '10	20 Apr '10	14 June '10	09 July '10	07 Sept '10	11 Feb '11
Field date	18-19 Feb '10	22 Mar '10	19-20 Apr '10	13 - 14 June '10	08 - 09 July '10	06 - 07 Sept '10	11-12 Feb '11

2.3.2 MODIS

The remote sensing SST data which used in this study were recorded by MODIS-Aqua sensors and have been downloaded from the website of Ocean Biology Processing Group (OBPG) (<http://oceancolor.gsfc.nasa.gov/>).

As explained by OBPG 2006 (http://oceancolor.gsfc.nasa.gov/DOCS/modis_sst/), “the long wave SST algorithm makes use of MODIS bands 31 and 32 at 11 and 12 um. The brightness temperatures are derived from the observed radiances by inversion (in linear space) of the radiance versus blackbody temperature relationship. For ms112, these relationships were precomputed for the spectral response of each MODIS channel, and the tables were then stored in HDF files to be loaded at run-

time. In modsst, the radiance versus blackbody temperature relationship was computed at run-time. The nonlinear SST algorithm was tuned for two different regimes based on brightness temperature difference. The algorithm for computing long-wave SST (sst) from observed brightness temperatures is shown below:

$$dBT \leq 0.5$$

$$sst = a00 + a01*BT11 + a02*dBT*bsst + a03*dBT*(1.0/mu-1.0)$$

$$dBT \geq 0.9$$

$$sst = a10 + a11*BT11 + a12*dBT*bsst + a13*dBT*(1.0/mu-1.0)$$

$$0.5 < dBT < 0.9$$

$$sstlo = a00 + a01*BT11 + a02*dBT*bsst + a03*dBT*(1.0/mu-1.0)$$

$$ssthi = a10 + a11*BT11 + a12*dBT*bsst + a13*dBT*(1.0/mu-1.0)$$

$$sst = sstlo + (dBT-0.5)/(0.9-0.5)*(ssthi-sstlo)$$

where:

$$dBT = BT11 - BT12$$

BT11 = brightness temperature at 11 um, in deg-C

BT12 = brightness temperature at 12 um, in deg-C

bsst = baseline SST, which is either sst4 (if valid) or sstref (from oisst)

mu = cosine of sensor zenith angle.”

MODIS images for sea surface temperature sampling days were chosen appropriate to MERIS sampling days that are from September 2009 to February 2011 in 37 sampling days which have cloud free satellite image of the study area, but it could not be available for some days to make in same day with MERIS sampling days because of differences in acquisition date of the sensors. These differences caused changes in atmospheric condition in images of these sensors. In that situation, they are chosen the closest available day.

2.4 Data Analysis

2.4.1 An Empirical Neural Network Algorithm

An empirical neural network algorithm was applied in this study to estimate surface water quality parameters such as TSM and SD. Coastal waters which are optically complex situation because of the presence of suspended sediments and dissolved organic matter (Bukata, Jerome, Kondratyev & Pozdnyakov, 1991; Keiner & Yan, 1998), are the task of modelling the transfer function seems a natural application for a neural network (Zhang, Pulliainen, Koponen & Hallikainen, 2002)

Neural networks were originally developed to model the functioning of the human brain. The networks have many applications, such as the fields of classification, pattern recognition, and signal processing (Keiner & Yan, 1998). It works by simulating a large number of interconnected simple processing units that resemble abstract versions of neurons (Clementine, 2007).

Multi layer perceptions (MLP) of neural network are a so-called feed-forward network and are typically used in function approximation application. All information moves in one direction during operation, from the input layer to the output layer. The first layer distributes the input parameters (usually radiance measurements at different wavelengths in case of optical remote sensing) to the second layer (defined as hidden layer). The second layer consists of a varying number of neurons, where each input parameter is multiplied by its connection's

weight parameter and all the inputs to the neuron are summed and passed through the nonlinear sigmoid function. The third layer receives the output of the second layer in which it is processed through neurons again (Keiner, 1999; Zhang et. al., 2002).

“The network learns by examining individual records, generating a prediction for each record, and making adjustments to the weights whenever it makes an incorrect prediction. This process is repeated many times, and the network continues to improve its predictions until one or more of the stopping criteria have been met” (Clementine, 2007)

As defined by Tanaka et al. (2004), the development of a neural network algorithm consists of three steps: (1) compilation of a data set of corresponding pairs of multiple concentrations and multiple reflectances according to the empirical model; (2) definition of the structure of an NN and its training, such as determination of the coefficients of the NN and testing its performance; (3) application of the NN to in situ data and remote sensing data and validation of the results.

In this study, first eight bands of water leaving reflectance which are occurred after atmospheric correction step of C2R processor are chosen as NN input values; NN output values are TSM and SD in two different NNs.

Clementine 11.1 software was used for building neural network model. The software includes six different methods for neural network module namely quick, dynamic, multiple, prune, radial basis function network (RBFN) and exhaustive prune. Multiple method, used for building neural networks in this study, creates several networks of different topologies. These networks are then trained in a pseudo-parallel fashion. At the end of training, the model with the lowest RMSE (Root Mean Square Error) is presented as the final model. Software also includes partition field option to separate a dataset into two partitions as training and testing (Clementine, 2007). While a sub-dataset is used for training neural network model, other sub-dataset is used to validate the model.

Two different neural networks were trained for each of TSM and SD. Number of variables, number of data which are available for neural network analysis, resolution of satellite images and size of study area make it available. A total of datasets of TSM and SD were divided into 2 sub-datasets (partitions) by using Clementine partition module.

The output of the network was compared to the in situ measurements of the parameters. The RMSE (Root Mean Square Error) and the R^2 of the comparison were calculated to evaluate performance of results in the network

2.4.2 Validation of the Empirical Algorithm in Shallow Waters.

Additionally two control points were performed to test algorithm in shallow water. These two control points are parallel to two station of the study called 1 and 2, as shown in Figure 2.5. This will give possible to compare performance of the algorithm in near locations but different features such as depth. Data used from control stations collected in samplings of February, 2010 – 2011, March 2010, April 2010, June 2010 and July 2010.

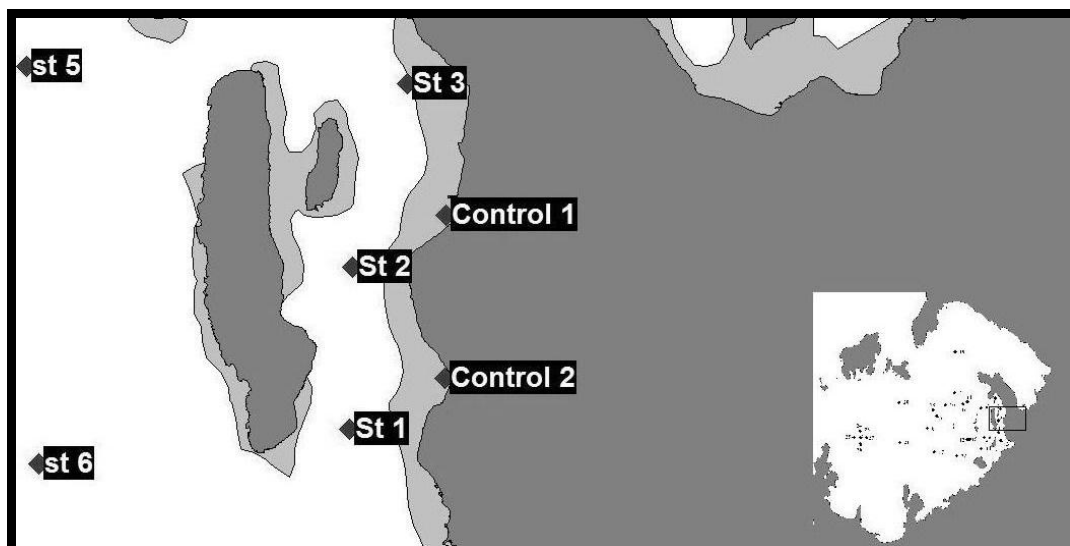


Figure 2.5 Locations of control stations in the study area

2.4.3. Validation of SST Data from MODIS with Data from Field

For evaluation of sea surface temperature (SST) parameter, satellite imageries and field measurements in the same day of the image or one day before or later were used.

MODIS Aqua SST data downloaded from the website of OBPG were imported into Beam Visat 4.8 software. First of all, data were projected by Reprojection module (projection of Lat / Long (WGS 84)). Field station coordinates were superposed on pixels which include SST data from MODIS images. 3X3 pixels were exported for every station's pixel and averaged for testing with field data.

Projected products were also used for creating subsets of the study area. Subset data were extracted with created mask area by using Rectangle Drawing Tool. Extracted data were collected in MS Excel for getting ready to import GIS environment.

2.5 Building the GIS Environment

The base map layer of study area is same with Demirel (2010). Additionally, data of stream layer, aquaculture region layer of study area were utilized in the study

Bathymetric layers are created by using digitized map section (2223) of Office of Navigation, Hydrography and Oceanography (SHOD). The image was registered manually to MapInfo environment. Depth marks were defined on the geographically registered image as a new layer and entered their numerical values into the new layer's datasheet in MapInfo 8.5 software. The depth data layer was interpolated using with Natural Neighbourhood method to convert point layer to regional raster layer (Figure 2.6.). First five meter contour layer were used with base map layer for removing pixels for seasonally distribution maps and these two layers are also used together with land pixels, base map, stream and aquaculture region layers for presenting daily distribution of the algorithm outputs.

Extracted remotely sensed data into MS Excel were converted to browser data in MapInfo software and created geographical points layer with projection of Lat / Long (WGS 84) to carry in GIS environments. This layer superposed with base map layer with depth of 0-5m layer. The data layer's points that are overlapped with land region and 5 meter depth contour are removed from that layer.

Filtrated data layer were interpolated by using Vertical mapper (Version 3.0) module in MapInfo software. Interpolation was done by Inverse Distance Weighting (IDW) method.

IDW is generally used more for region applications which are small scaled. The method suits for such kind of data, in which the value has a local influence that diminishes with distance. It weights the points closer to the processing points, greater than those farther away. A specified number of points or all points within a specified radius is used to determine the output value for each location. The power parameter in the IDW interpolator controls the significance of the surrounding points upon the interpolated value (Kant, Verma, Rao & Singh, 2002).

2.6 Meteorological Data

Temperature, precipitation and wind velocity and direction data were used as meteorological data. The data received in Çeşme weather ground station of DMI were obtained.

To compare climatic features of the study area, data of precipitation and temperature between 2008 and 2010 are detailed. Ombrothermic diagram of 2008, 2009 and 2010 was created to compare climatic features of last three years include study period and last 63 years.

Wind data were ordered as Wind Chart module of Grapher 7 (Golden Software) to produce wind charts that include data of sampling, previous and next day of sampling day.

Precipitation data were also shown as scatter plots include whole days of a month. Months were grouped as seasons. Sampling days were also marked on graphs.

2.7 Total Suspended Matter versus Secchi Depth

Daily estimations of both parameters were used for further analysis. Estimated TSM concentrations and Secchi depths were extracted. Secchi depth can be restricted by water depth in shallow waters. When considering bottom effect on SD, extraction area was determined by bathymetry layer. Depth limit were chosen 30 m which is half times more than maximum SD of the study. Extracted points of SD and TSM concentration were matched in MS Excel.

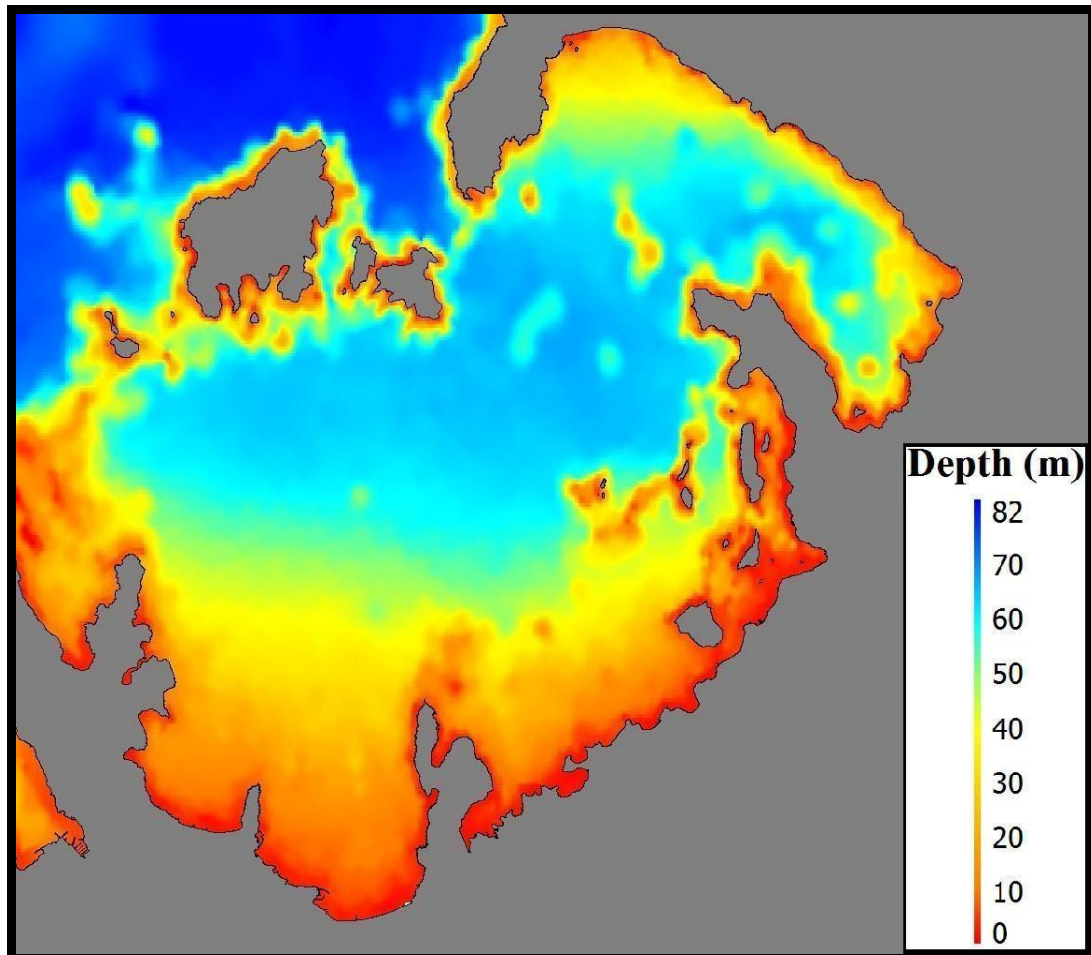


Figure 2.6 Bathymetry grid layer of the study area (Data from SHOD)

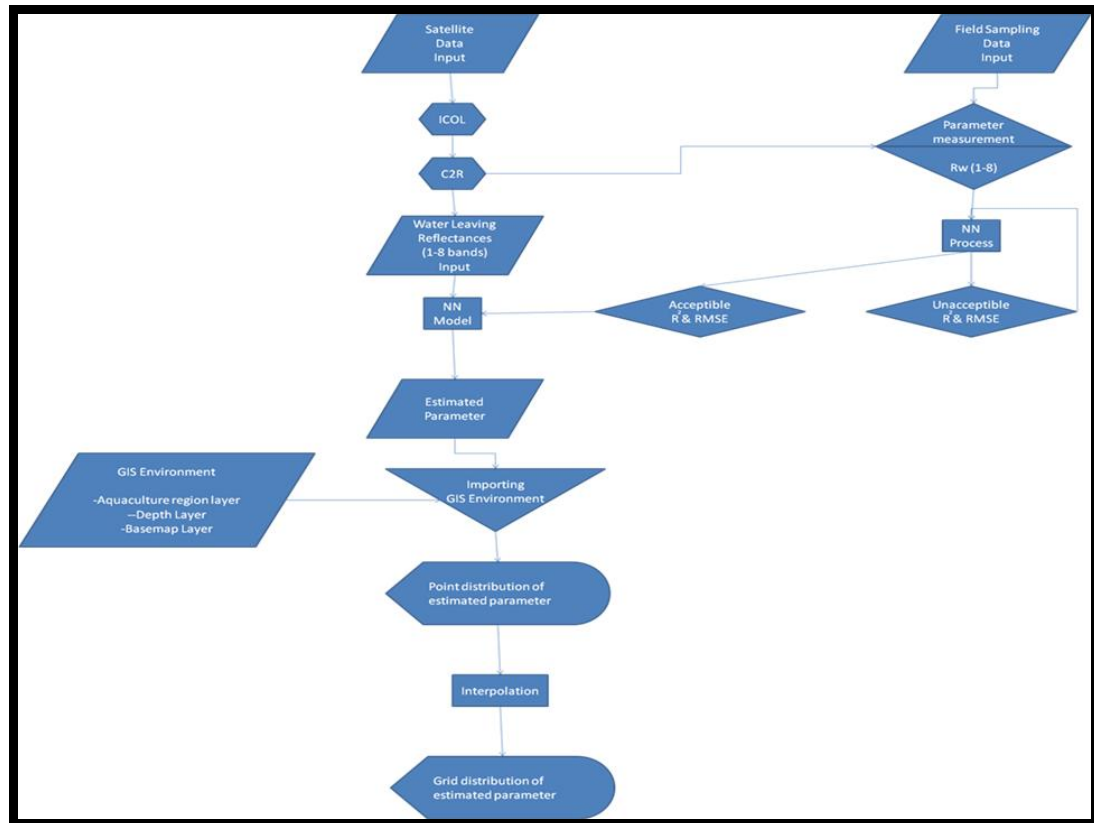


Figure 2.7 Flow chart of the study

CHAPTER THREE

RESULTS

3.1 Field Data

Total suspended matter (TSM), Secchi depth (SD) and sea surface temperature were measured in this study. A total of 73 data were available for this study. Table 3.1 describes properties of samplings of the study. Histograms of TSM, SD and SST are shown in Figure 3.1, 3.2 and 3.3, respectively.

Table 3.1 Description of measured data in field

Measured data	N	Mean	Min	Max	Range	Standard Deviation
TSM	73	1.44	0.12	7	6.89	1.41
Secchi depth	73	11.64	6	20	14	3.68
Sea Surface Temperature	72	20.07	14.86	25.19	10.33	4.07

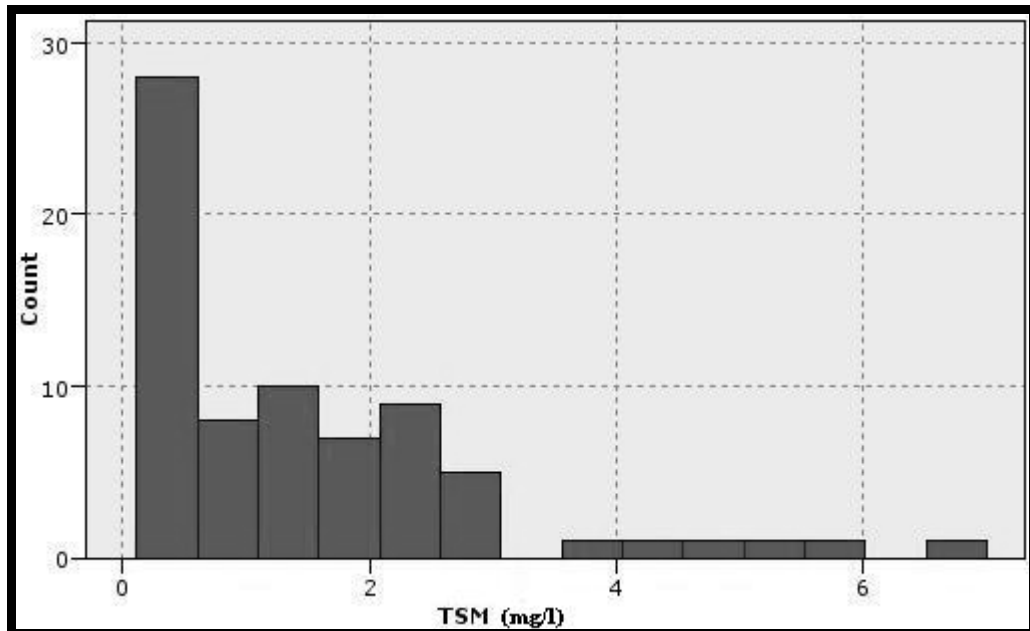


Figure 3.1 Histogram of measured TSM

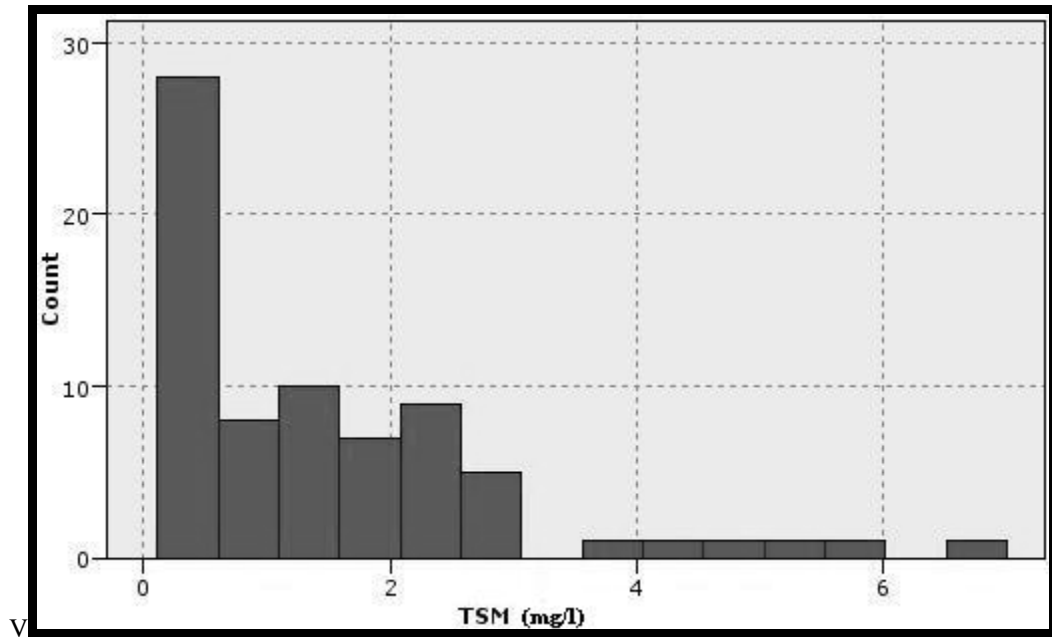


Figure 3.2 Histogram of measured SD

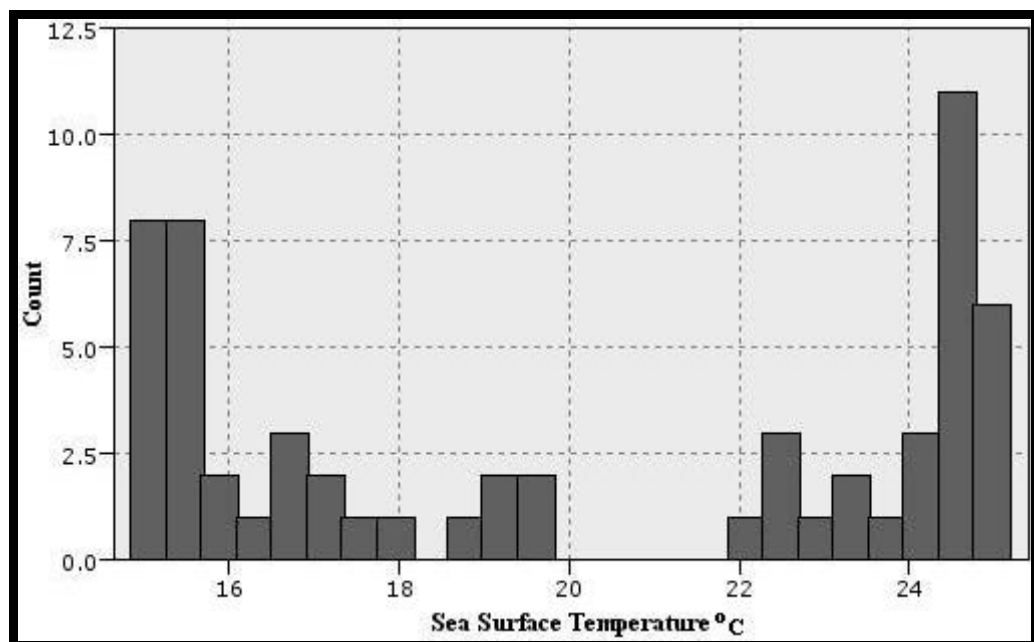


Figure 3.3 Histogram of measured SST

3.2 Comparison of Empirical Algorithm Results with Data from Field Study

Partitions of datasets of SD and TSM and their distribution as sampling time are shown in Table 3.3. While percentage of training and testing data set are 55% and 45% in dataset of Secchi depth, they are 52% and 48% in dataset of total suspended matter, respectively.

The resulting accuracies and topologies of the networks of both of variables are presented in Table 3.2. Even though they have different neural networks, topologies of the networks and their accuracies are similar.

Statistical comparison of neural network training, testing and total dataset for both parameters are shown (Table 3.4). Results show significant relationship between estimated values and measured values. Although training datasets have better performance than testing ones, taking into account only testing datasets, they have also high R^2 values and low RMSPE. It indicates that model will have acceptable outputs with datasets which even doesn't include value or value of training dataset. Some statistics comparisons of the datasets are shown in Table 3.4.

Table 3.2 The resulting accuracies and topologies of the networks

Parameter	Input	Hidden Layer 1	Hidden Layer 2	Output	Estimated Accuracy (%)
TSM	8	12	10	1	97.48
SD	8	19	17	1	99.58

Table 3.3 Partitions of datasets of SD and TSM and their distribution as sampling time

Month	Secchi Depth		Total Suspended Matter	
	Training	Testing	Training	Testing
Feb-10	2	4	5	1
Mar-10	1	3	1	3
Apr-10	4	4	5	3
Jun-10	4	7	5	6
Jul-10	9	1	3	7
Sep-10	8	3	4	7
Feb-11	12	11	15	8
Overall	40	33	38	35

Table 3.4 Statistical comparison of neural network training, testing and total dataset

Statistics	Secchi Depth			Total Suspended Matter		
	Training	Testing	Total	Training	Testing	Total
Minimum Error	-0.37	-0.591	-0.59	-1.004	-1.489	-1.49
Maximum Error	0.414	0.359	0.414	0.539	1.109	1.109
Mean Error	0.014	-0.019	-0.001	-0.021	0.015	-0.004
Linear Correlation (r)	0.999	0.999	0.999	0.991	0.937	0.975
R²	0.999	0.999	0.999	0.981	0.878	0.951
RMSE	0.125	0.134	0.129	0.233	0.383	0.314
N	40	33	73	38	35	73

Estimated dataset have similar characteristics with measured dataset, such as mean and range. They have almost same mean values with measured datasets in both, but estimated datasets have narrower range in both of these two parameters. Descriptive statistics of estimated dataset are given in Table 3.5.

Table 3.5 Description of estimated data in the network models

Estimated data	Count	Mean	Min	Max	Range	Standard Deviation
TSM	73	1.45	0.13	6.46	6.33	1.325
SD	73	11.64	6.17	19.91	13.73	3.675

Figure 3.4 and Figure 3.5 shows the graphs of Secchi depth and total suspended matter estimated from MERIS versus field measurements, respectively. Data are classified in two groups which have different symbols as training and testing sub-dataset. These classes provide to present the relation for both of sub-datasets and all data.

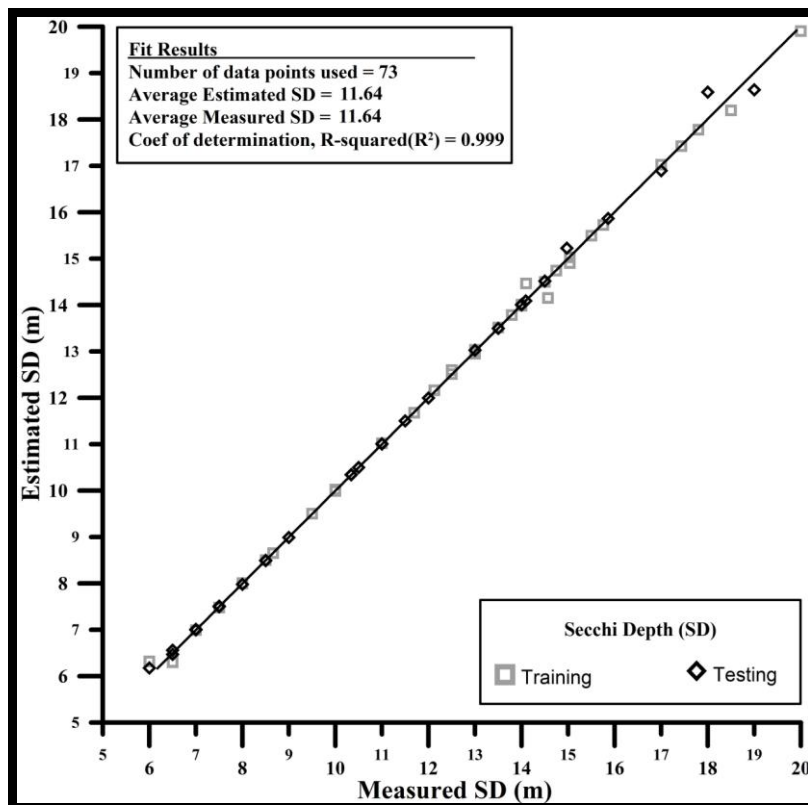


Figure 3.4 SD estimated from MERIS versus field measurements

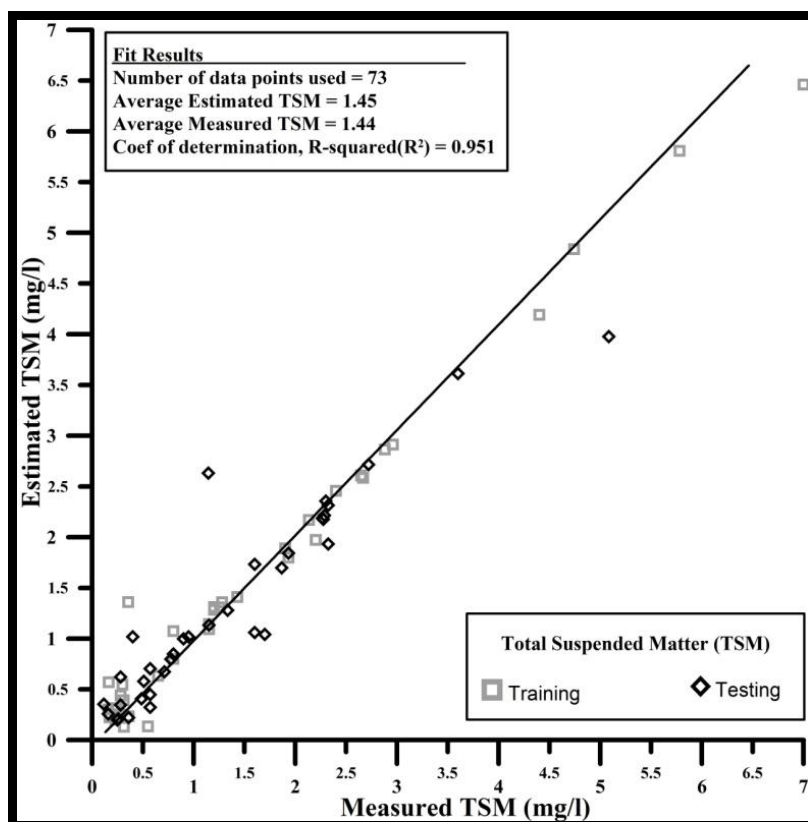


Figure 3.5 TSM estimated from MERIS versus field measurements

Result of the algorithm in shallow waters shows that control points have not good relation between estimated and measured values. ($R^2=0.30$), while parallel stations to control stations have strong relation between field measurements and estimated values ($R^2=0.99$) and have similar range. They have also too big differences between ranges of measured and estimated dataset. It shows there are some reasons for those shallow regions may have deviations and get not fair enough to output of algorithm.

The reasons may be bottom effect, adjacency to land and fast interaction with land source particles. Therefore, it will be not available to take account into data derived in shallow region for further analysis. It exhibits importance of using 0-5 depth region mask in produced maps.

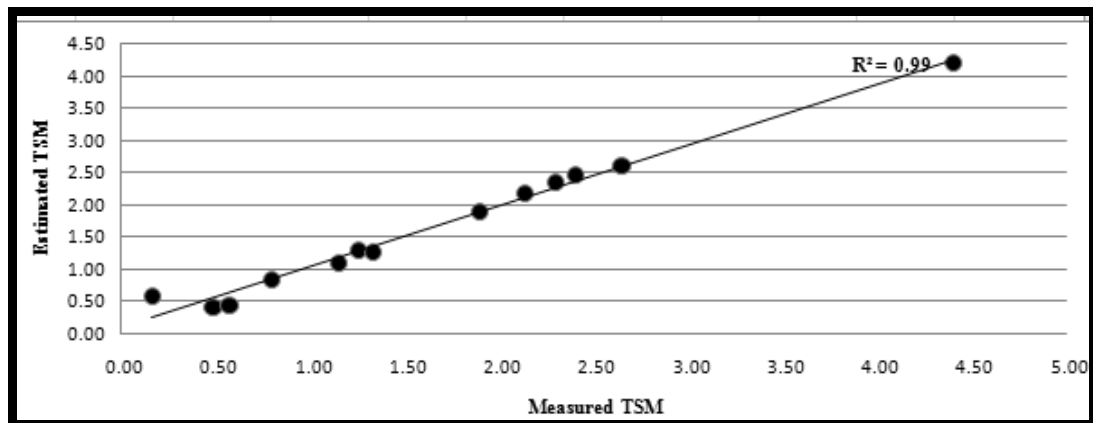


Figure 3.6 Relation between measured and estimated values in Station 1-2

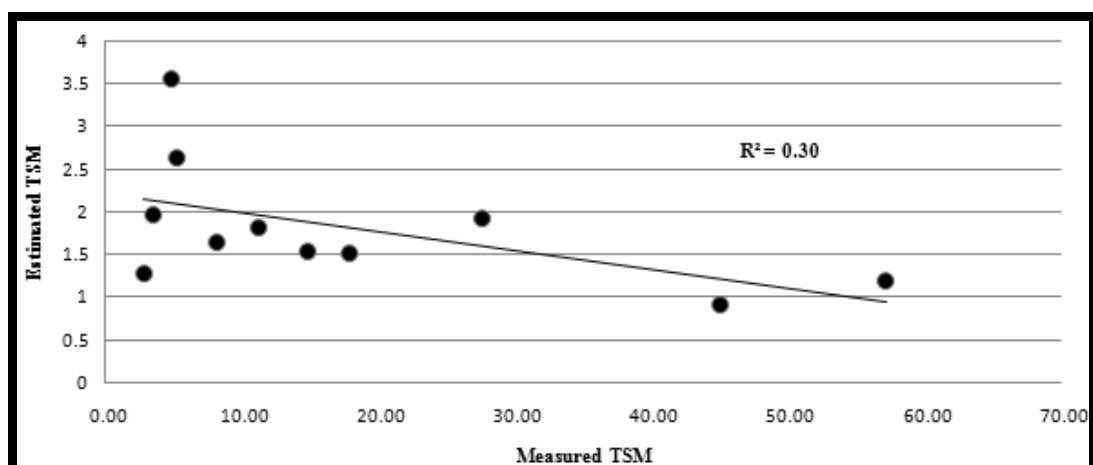


Figure 3.7 Relation between measured and estimated values in Control 1-2

3.3 Validation of Remotely Sensed Data of Sea Surface Temperature with Data from Field

SST parameter values derived from MODIS images have been generally overestimated the field measurements. Relation between field measurements and data from MODIS are strong ($R= 0.97$). Even though overall data have high correlation, values which is higher than 26 ($^{\circ}\text{C}$) have higher overestimation and not correlation with field measurements in each sampling time and overall data (Table 3.6). Results validate only values which is lower than 26 ($^{\circ}\text{C}$). On base of this validation, extracted data from MODIS SST algorithm were filtered values higher than 25.99 ($^{\circ}\text{C}$).

Table 3.6 Comparison of SST between MODIS derived data and field measurements

	$\geq 26(^{\circ}\text{C})$		$< 26(^{\circ}\text{C})$		Overall data	
	Correlation	N	Correlation	N	Correlation	N
Overall sampling	0.05	11	0.99	61	0.97	72
Mar-10	-	0	0.72	8		8
Apr-10	-	0	0.93	8		8
Jun-10	-	1	0.77	10		11
Jul-10	-0.23	5	0.93	6		11
Sep-10	0.14	5	0.72	6		11
Feb-11	-	0	0.59	23		23

3.4 Meteorological Data

As presented in Figure 3.8, while the area has very arid period in 2008 (11 months), it is near average in 2009 and 2010 (8 and 9 months, respectively). Precipitation is lower than average in 2008, while temperature is higher. Both of precipitation and temperature are higher than average in 2009 and 2010 (Table 3.7). It shows the years which include sampling period has similar pattern in regime of temperature and precipitation in the study area. Precipitation can be also reason for carrying of land source particles into sea by channels such as rivers, streams.

Intensive precipitation may cause increasing of particles in suspension around outfall of streams which are active during year or temporary along coast line. Knowing precipitation amounts previous days of sampling time may help to understand some local increases in suspended matters. Appendix 2 contains precipitation amounts during study period with marked sampling days.

Wind is one of the important forces for movement of sea water. These movements caused dispersion of suspended matters in surface layer of seawater. When taking into account this state of wind, it can be help to evaluate pattern of suspended matters in a certain area. To present dominant winds during sampling dates, wind charts are occurred with data from Çesme weather ground of DMI. Results show winds from Northern are dominant directions during study time period in the study area, even though the data of last 47 years shows Southern winds are dominant. Maximum and average speed of winds per months shows lower than mean of long time data during the study period. Winter months have stronger winds than other seasons in both, all time data and last years' data. Dominant direction and speed of wind of sampling day are shown as wind chart graphics in Appendix 2.

Table 3.7 Comparison of precipitation and temperature of last three years with average of 47 years (Data from DMI 2010)

Year	Precipitation (kg/m ²)			Temperature(°C)		
	Average	Max	Min	Average	Max	Min
2008	33.9	120.2	0	17.9	26.6	8.4
2009	64.4	227.2	0	18.1	27	10.4
2010	53.3	204.3	0		28.3	11.1
(1963-2010)	48	344	0	17.2	30.2	6.1

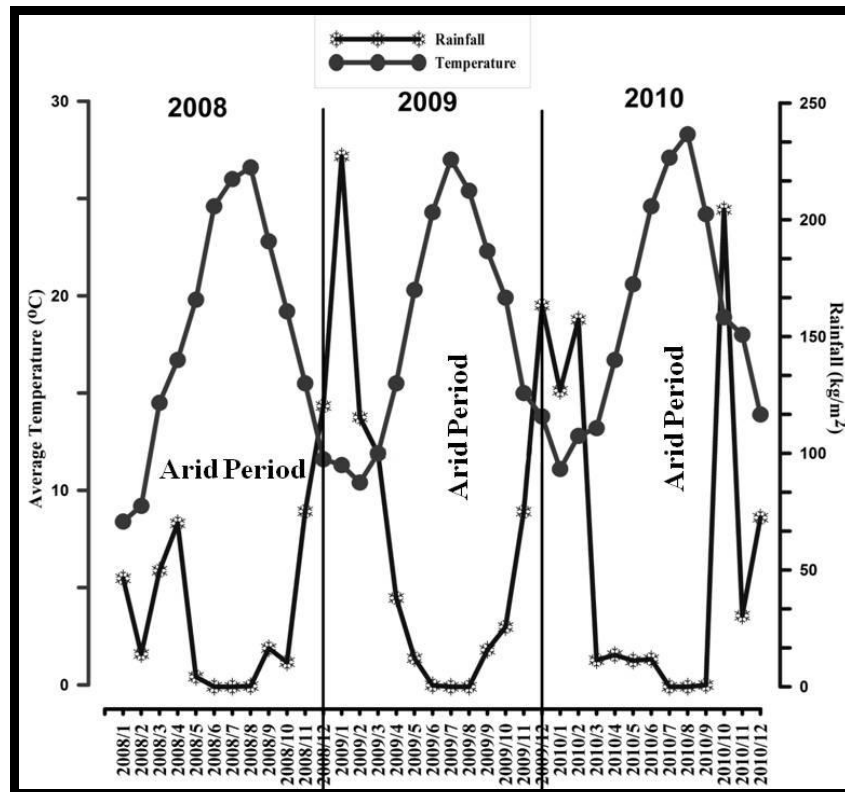


Figure 3.8 Ombrothermic diagram of Çeşme and its surrounding area in a period from 2008 to 2010 (Data from DMI 2010)

Table 3.8 Comparison of wind speed and direction of last two years with average of 47 years (Data from DMI 2010)

Year	Max speed (m/sec)			Average speed (m/sec)			Dominant Direction		
	2009	2010	1963-2010	2009	2010	1963-2010	2009	2010	1963-2010
January	24.8	20.0	21.8	2.7	3.4	3.3	NNE	ESE	SSE
February	16.9	22.6	21.5	3.3	3.3	3.5	S	W	S
March	15.7	19.3	20.1	2.3	2.4	3.2	ESE	N	SSE
April	12.0	11.9	18.2	1.9	2.4	2.9	SSW	NW	SSE
May	16.8	14.8	14.8	2.0	1.7	2.5	NNE	S	SSE
June	13.4	15.9	13.8	2.3	2.2	2.6	NE	NNW	S
July	13.3	12.0	14.2	2.4	2.8	2.8	NE	NW	NNE
August	13.0	14.4	13.6	2.4	2.2	2.5	NNE	N	NNE
September	14.0	13.4	14.8	2.3	2.2	2.4	N	SE	NE
October	16.9	14.7	17.3	2.2	2.6	2.6	S	ESE	NNE
November	18.0	17.8	20.3	2.1	2.7	2.8	SSW	SSE	SSE
December	19.2	19.1	20.8	3.1	3.2	3.3	N	ESE	S

3.5 Results of Total Suspended Matter and Secchi Depth distribution in the Study Area

The study were carried out from September 2009 to February 2011 in 37 sampling days which have satellite image of the study area. The empirical algorithm was rendered for these sampling days and maps of distribution of TSM concentration and SD depth were created. Daily distribution maps of TSM and SD are presented in Appendix 2. Seasonally distribution maps are also created by averaged value of sampling days in a season. TSM and SD seasonally distribution maps are presented in Figure 3.10 and 3.11, respectively.

To summarize daily data derived from the algorithm, an area of 162 km² (Figure 3.9) is defined and average values of the study area are calculated.

Overall average TSM concentrations of sampling days are 1.97 mg/l. The highest concentrations of TSM are in May (04-10-20/05/2010; 3.86, 3.85, 3.60 mg/l, respectively), while the lowest concentrations show in September 11th 2009 during study period. In monthly scale, the highest concentration of TSM is in May 2010 (3.51 mg/l) and the lowest is in December 2009 (0.94 mg/l). When sampling days are classified by seasons, the highest value for concentration of TSM is 2.51 mg/l in spring 2010; the lowest value is 1.32 mg/l in winter 2011.

Average values of the study area were also calculated for Secchi depth. Overall average of SD is 12.9 in study period. September 2nd 2009 has the deepest penetration (16.63 m) of Secchi disk in average during study time, while the lowest penetration (9.97 m) is in April 20th. In monthly scale, the maximum value in average of Secchi disk is 15.48 meter in December 2009 and the minimum value is 11.08 meter in April 2010. When sampling days are classified by seasons, the maximum visibility of Secchi disc is 14.29 m; the lowest value is autumn 2009; minimum visibility of Secchi disc is 12.02 m in spring 2010.

Regions which have permission for aquaculture activities in the study area are known as spatial. Same procedures were applied for those regions. Thus, TSM

concentration and Secchi depth are also calculated in those regions. Overall average for the regions is 1.88 mg/l for TSM and 13.37 m for SD. The minimum average shows in September 11th 2009 (0.58 mg/l) for TSM and in January 31th 2011(9.46 m) for SD, while the maximum average is 3.69 in May 20th 2010 for TSM and 17.7 m in October 2nd 2009 for SD.

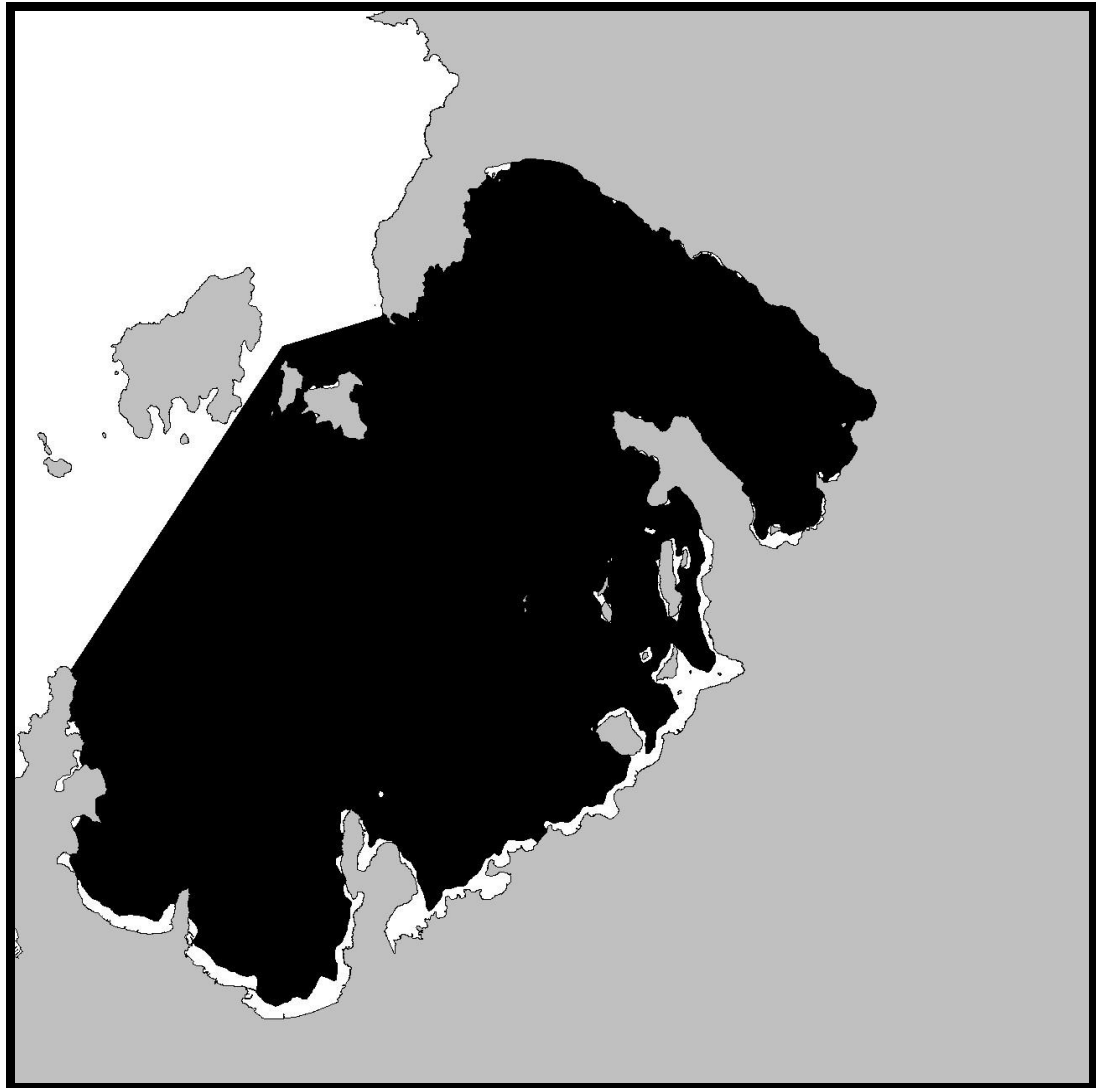


Figure 3.9 Analyzing data area (Black area). 0-5 meter depth zone is discarded

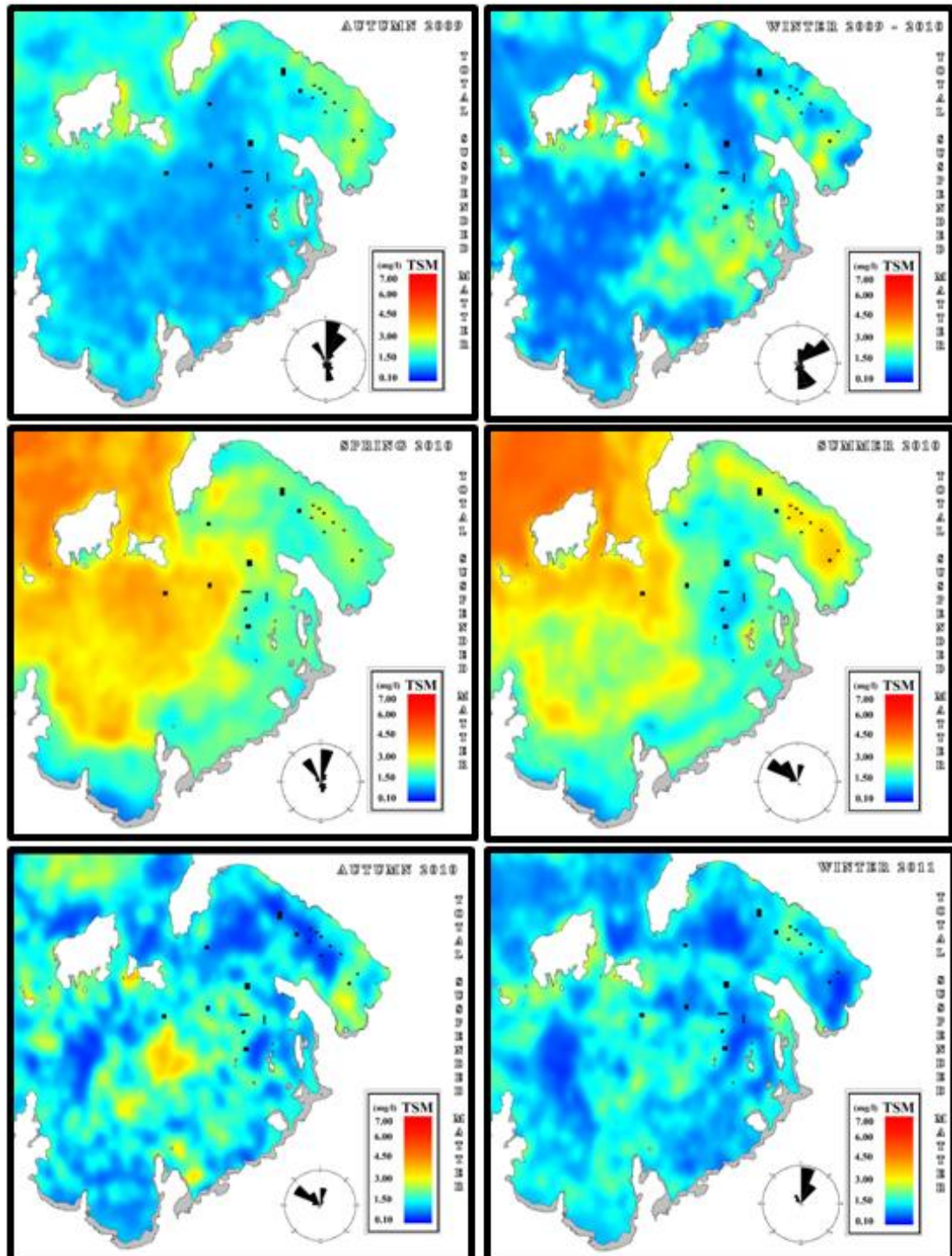


Figure3.10 Seasonal distribution of Total Suspended Matter

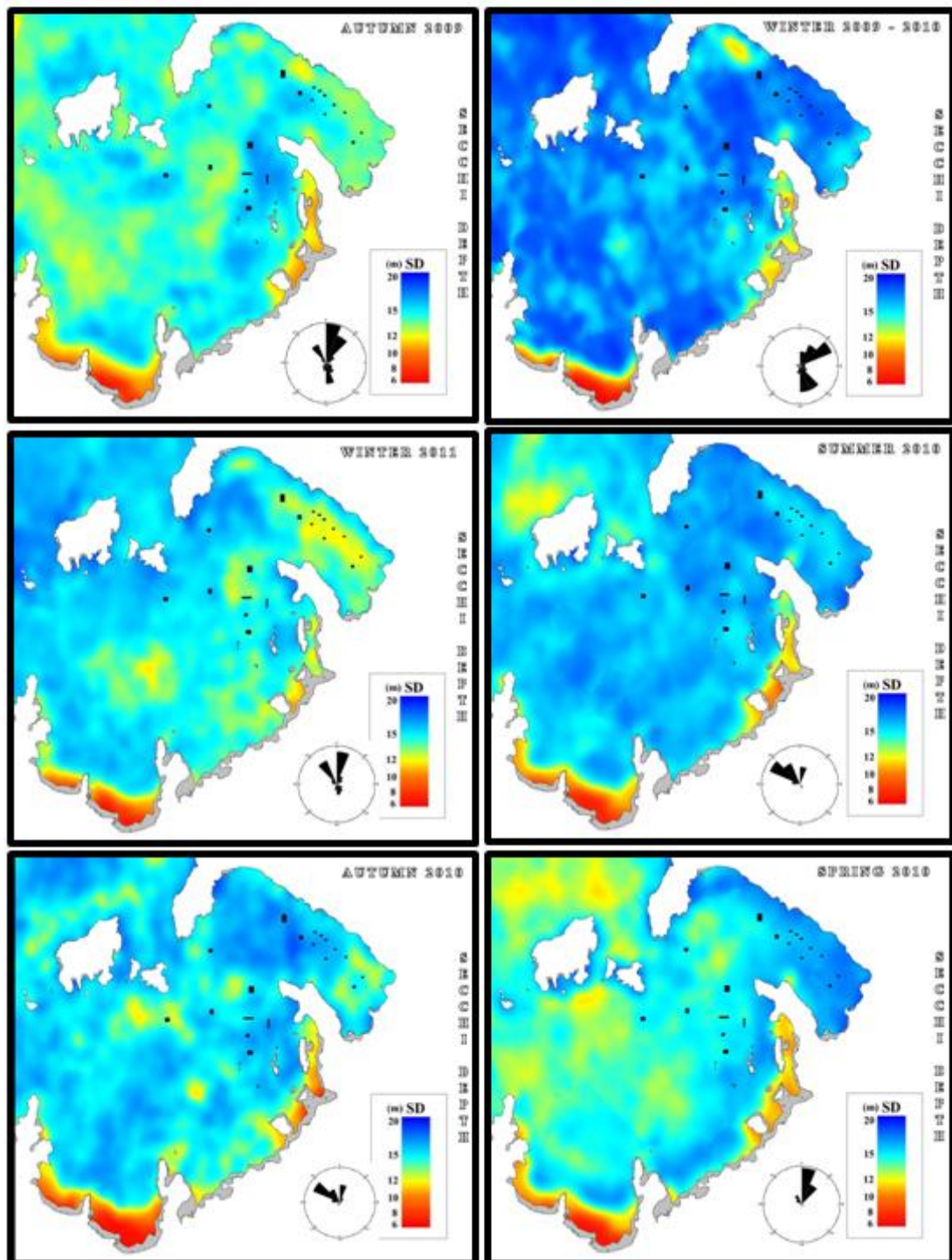


Figure 3.11 Seasonal distribution of Secchi Depth

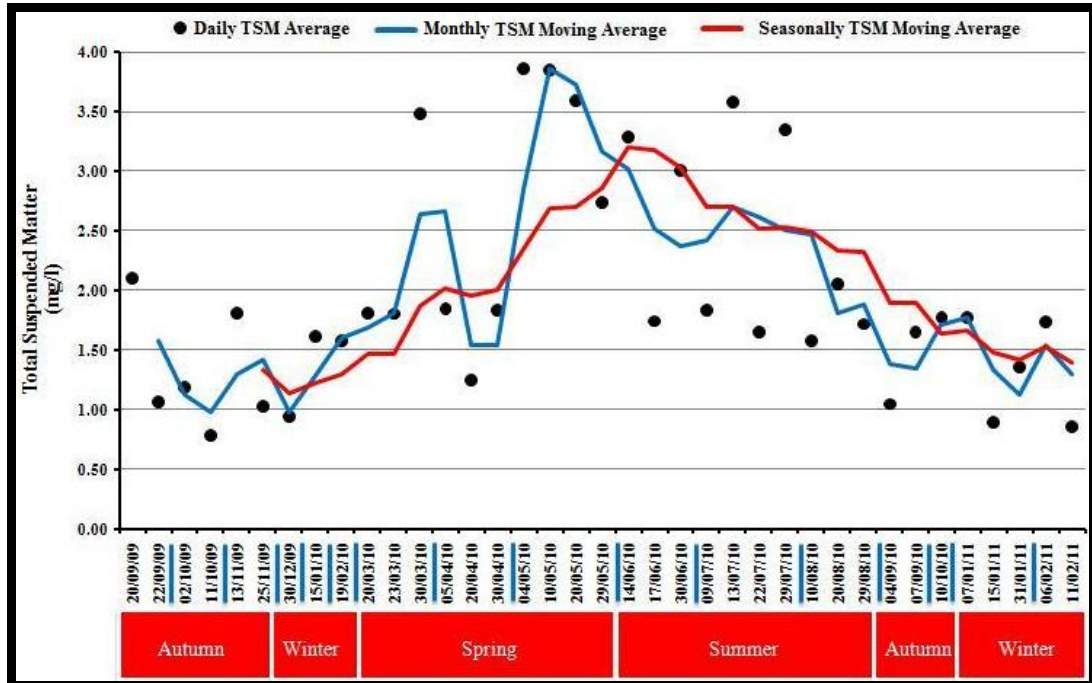


Figure 3.12 Average values of TSM in sampling days and their monthly and seasonally moving averages in the study area

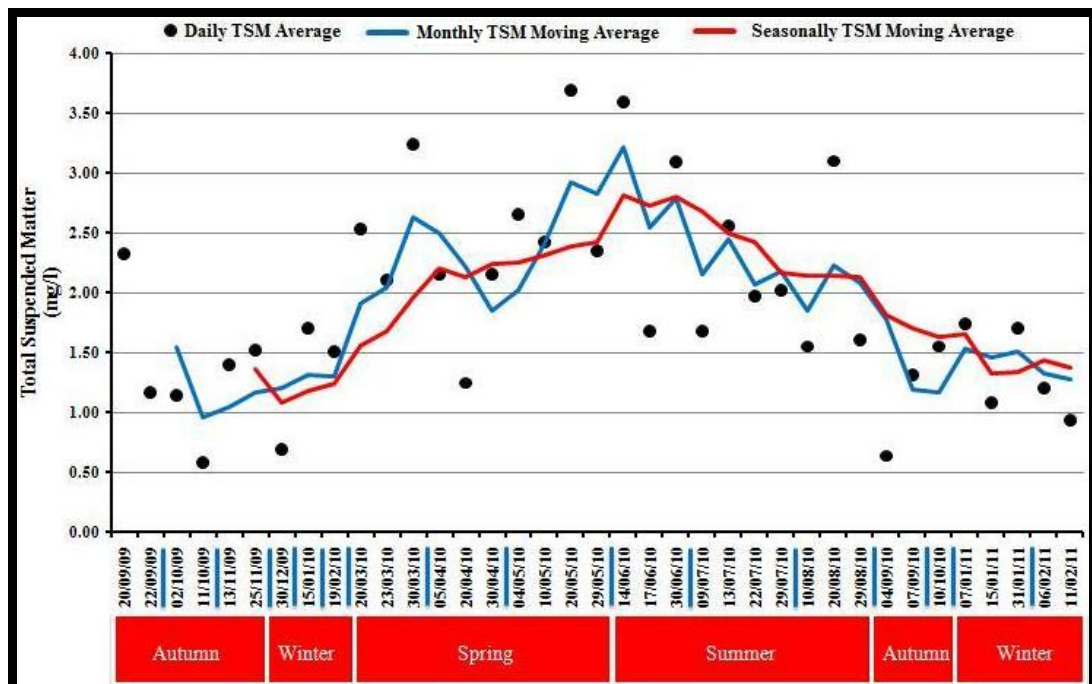


Figure 3.13 Average values of TSM in sampling days and their monthly and seasonally moving averages in aquaculture region of the study area

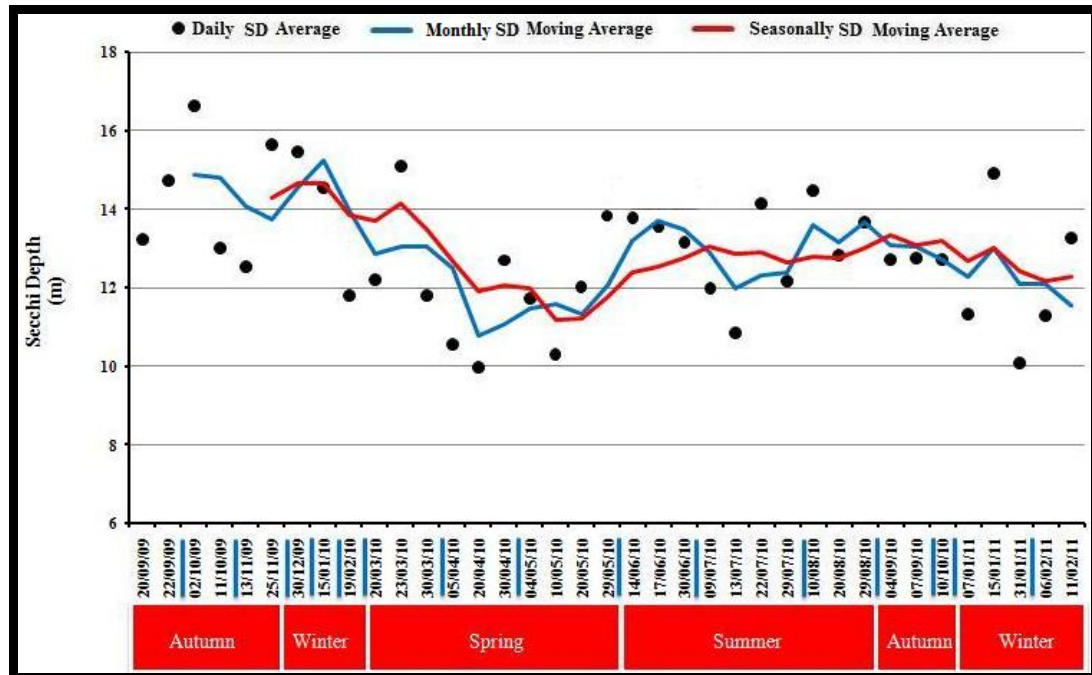


Figure 3.14 Average values of SD in sampling days and their monthly and seasonally moving averages in the study area

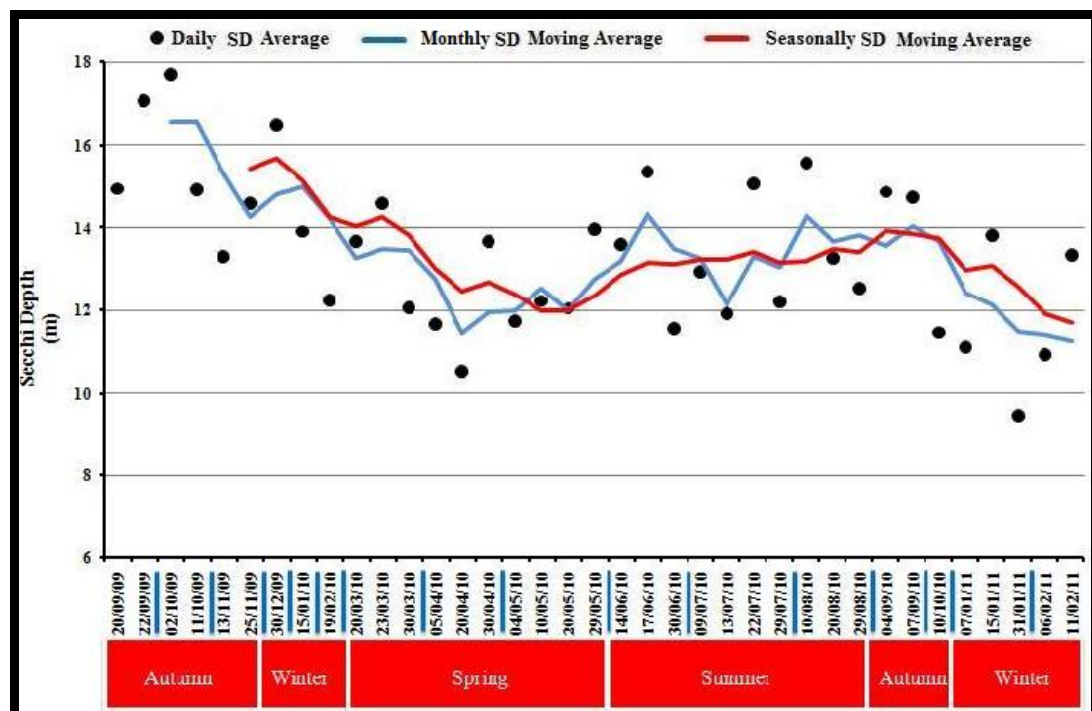


Figure 3.15 Average values of SD in sampling days and their monthly and seasonally moving averages in aquaculture region of the study area

3.6 Results for Sea Surface Temperature in the Study Area

Result of test of the SST algorithm shows a limitation in the SST algorithm. It has valid estimations up to 26 (°C). Based on this limitation, SST estimations filtered for values that lower than 26 (°C). The values that higher than 25.99 (°C) were not used for next processes. The sampling days of June, July, August and September include values that are higher than 26 (°C). For these sampling days maximum SST values may be higher than 25.99 (°C).

Delimited estimations of the SST algorithm were used for creating maps of distribution of sea surface temperature in the sampling day. Daily distribution maps of SST are shown in Appendix 2. Seasonally distribution maps are also created by averaged value of sampling days in a season. SST seasonally distribution maps are presented in Figure 3.16.

The same area (Fig. 3.9) used for TSM and SD were utilized to calculate average SST value of the study area.

Overall average of SST of sampling days is 20.53 (°C) during study period. In Sampling days, SST value in maximum is 25.99 (°C) in August 10th 2010 and in minimum is 10.58 (°C) in January 31th 2011.

Sampling days in August contain a lot of estimations higher than limitation value. Thus, it could not be possible to show SST characteristic of these days. The sampling days of June, July, August and September also include values that are higher than 26 (°C), but not dense as the days of August. This limitation may be reason lower values in calculation of the average and maximum values of these days.

Comparison SST with weather temperature shows relation of both of these parameters. As expected, weather temperature has wider range than SST. Difference in temperature is more in summer and winter (Table 3.18)

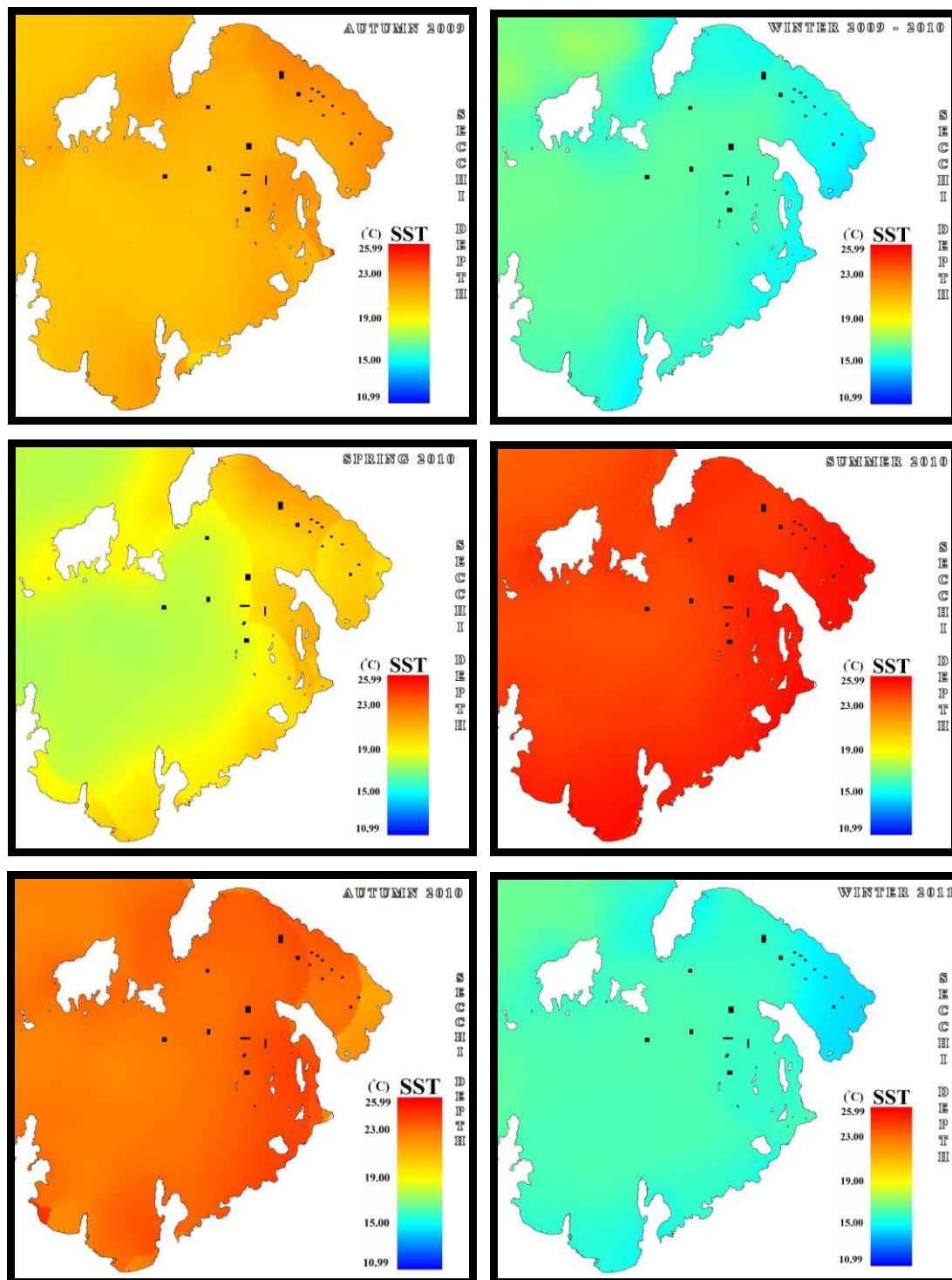


Figure 3.16 Seasonal distribution of sea surface temperature

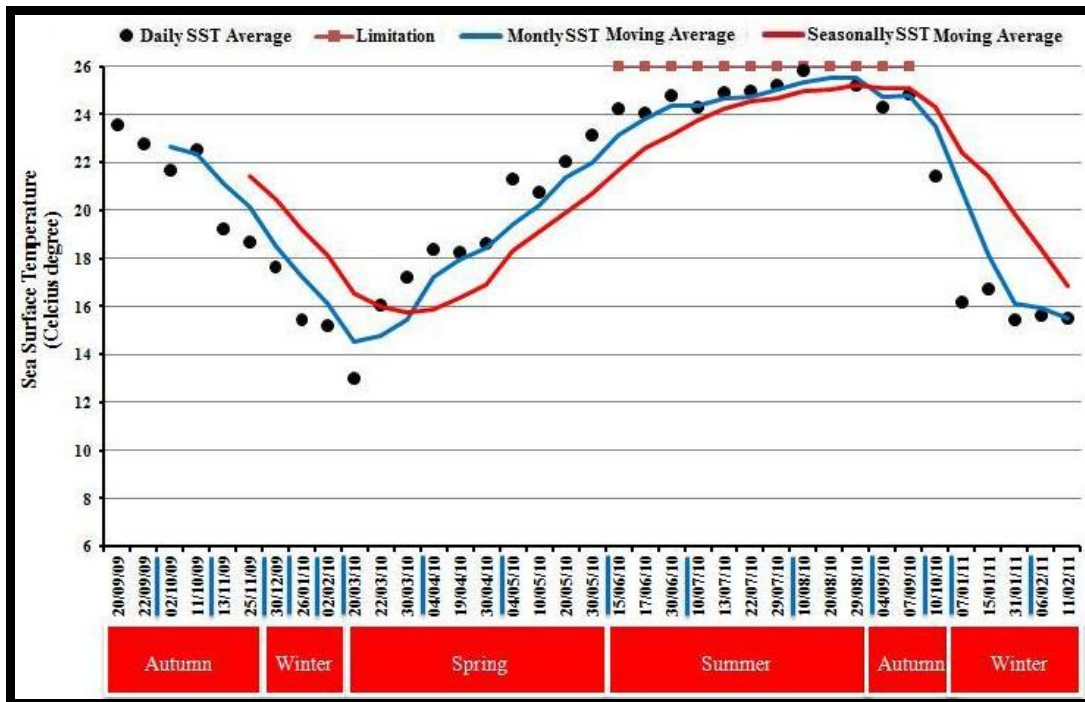


Figure 3.17 Average values of SST in sampling days and their monthly and seasonally moving averages in aquaculture region of the study area

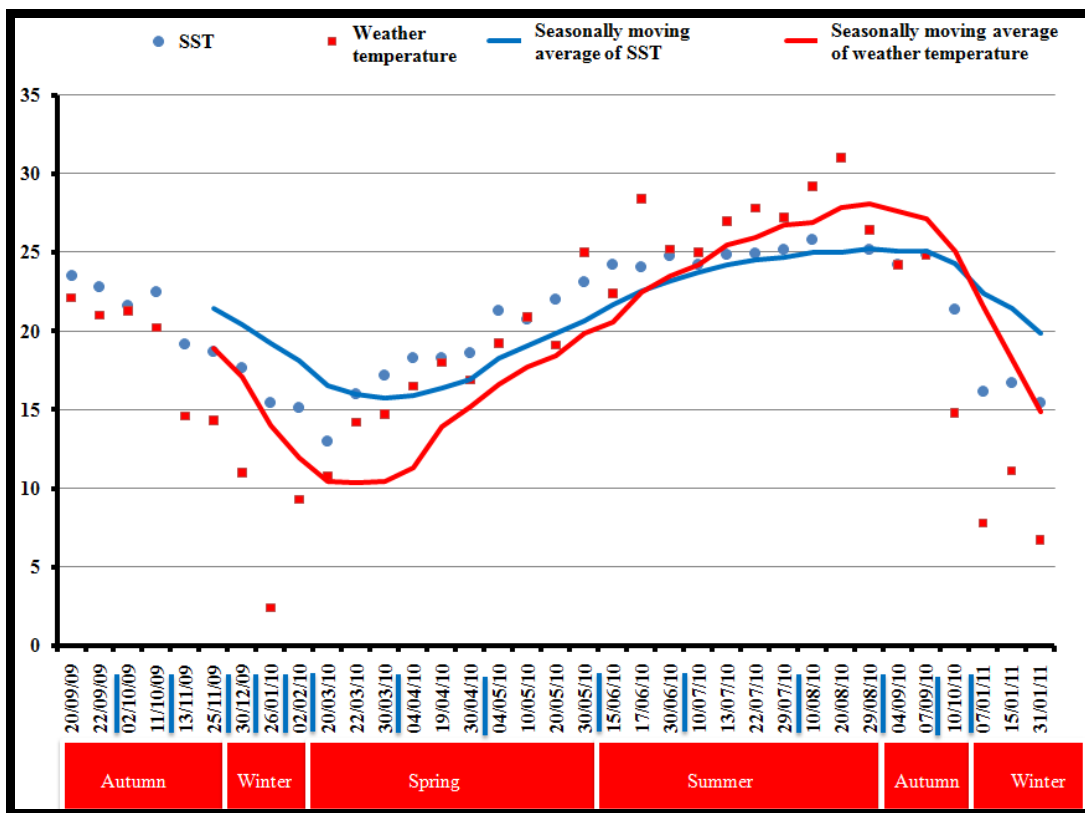


Figure 3.18 Distribution of SST and weather temperature in sampling days

3.7 Total Suspended Matter versus Secchi Depth

As listed by Preisendorfer (1986), first in ten laws of the Secchi disk is “the depth of disappearance of the disk varies inversely with the average amount of attenuating material between the surface and the disk”. That shows the importance of TSM concentration in disappearance depth of the Secchi disk. Remotely sensed data make available to evaluation relationship between TSM concentration in surface and Secchi depth. For this reason, scatter plots of TSM concentration and SD were created (Appendix 3). Correlation coefficients are also shown in Figure 3.19. Results of matches present these both parameters don’t show high correlation in whole area. Only some sampling days have weak correlation such as days of March and May 2010. Results show TSM in surface is not main influence for the SD, but in some sub-region it may be main role to determine SD. Layers which locate under surface may have important impact the SD, considering other impacts are corrected in preprocessing step of the images.

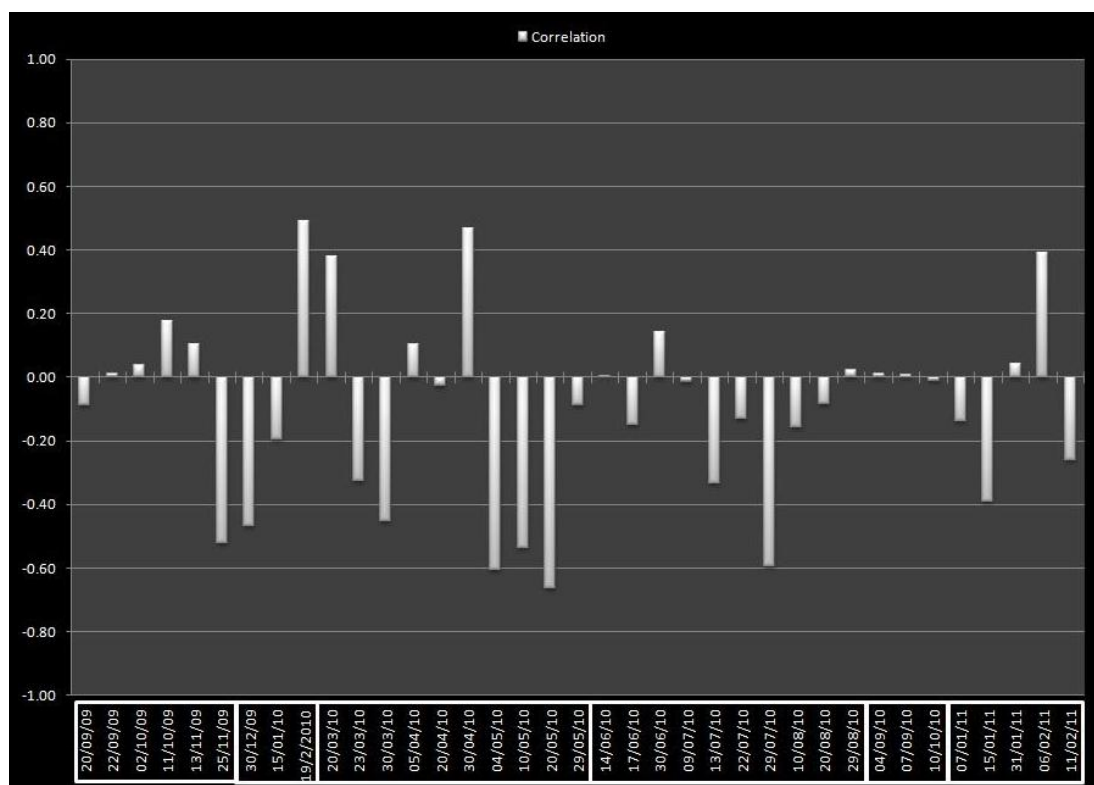


Figure 3.19 Correlation coefficient graphics of TSM versus SD in sampling days

CHAPTER FOUR

DISCUSSION

4.1 An Overview of the Parameters

In a study carried out in a section of Ildırı Bay by Başaran, Aksu & Egemen (2006) Secchi depth ranges between 10.5 m and 32.9 m were found. The Secchi depth is between 6 m and 20 m in this study. Temporal differences may have caused changes in ranges of SD of both studies. Figure 4.1 shows decreasing seasonal trend in Secchi during the study period. Another reason may be differences in measurement methods of SD. Another study from Izmir Bay, which is an important study area for many studies and one of the geographically closest to Ildırı Bay, SD ranges 3 m to 26 m in a period from 1996 to 2005 (Sayın, Adalıoğlu & Eronat, 2007). These ranges encourage using the NN empirical algorithm for other bays of Aegean Sea, but it is pointed out that the algorithm may not be required in maximum and minimum if range is wide in other locations.

Compared to another study from the aquaculture area in Izmir Bay (Aksu, 2005), SD ranges were found between 3.15m and 9.45m and the SD range is from 7.03m to 19.94m in the aquaculture regions of this study. Başaran et al. (2006) defined average SD as 19.94 m (± 2.27) in a station located in aquaculture region in Ildırı Bay, while it is 13.38 m (± 1.86) as average SD of aquaculture region in this study. As seen in both studies, important differences were not observed in aquaculture regions in terms of visibility of water.

As highlighted by Başaran et al. (2006), cages a long distance from land and in deeper water may cause dilution in impact of aquaculture activities to marine ecosystem.

TSM concentration in Ildırı Bay had a seasonal trend during the study period. The lowest concentrations were in winter. Increase in concentration starts in late winter and continues till early summer and begins again to decrease. When looking at

dominant wind directions, it is clear that spring and summer have dominantly northern directions and rest have dominantly southern directions. When considering this, wind directions may be one of the major influences in distributions of TSM in surface in the area. TSM distribution in the study area shows that TSM comes from sources outside of the bay, especially in spring and summer. Another reason can be seasonal biomass increase of plankton. Spring bloom trends were generalized by Cebrian & Valiela (1999) and they pointed out mostly peaks in spring and late summer for bimodal cycles; in summer in unimodal cycles in enclosed coastal systems. In accordance with these trends, TSM concentrations in the study area are higher between spring and summer and seem two modes in early spring and late spring-early summer. Relative increase of correlation coefficient between TSM and SD and its frequency in negative trend in spring also support leading plankton biomass to seasonal trend of TSM concentration. As preliminary results of the study of B. E. Inanan (personal communication, 17 June 2011), phytoplankton amounts show increases from February 2011 to April 2011 in surface layer of Ildırı Bay (Figure 4.2). When taken into account the ratio between main groups of phytoplankton, parallel to rising in negative correlation between TSM and SD, individuals under group of Bacillariophyceae cover higher percentage of a total of phytoplankton individuals in March 2010 (Figure 4.3). This suggests that shape and features of species of Bacillariophyceae may affect optical properties such as scattering or absorption in water. Further study should be conducted to determine phytoplankton changes to understand this harmony but anthropogenic impacts such as aquaculture or tourism activities should not be ignored, as well. This study does not have the capability to understand sources of particulate matter.

Table 4.1 shows maximum and minimum values of bays from Aegean Sea. The studies show the bays of Aegean Sea have narrower range than this study for TSM concentration, excluding Izmir Bay. This situation suggests that the algorithm can validate the usability of the other bays of Aegean Sea. Differences in water composition of these bays can be another limitation for validation of the algorithm.

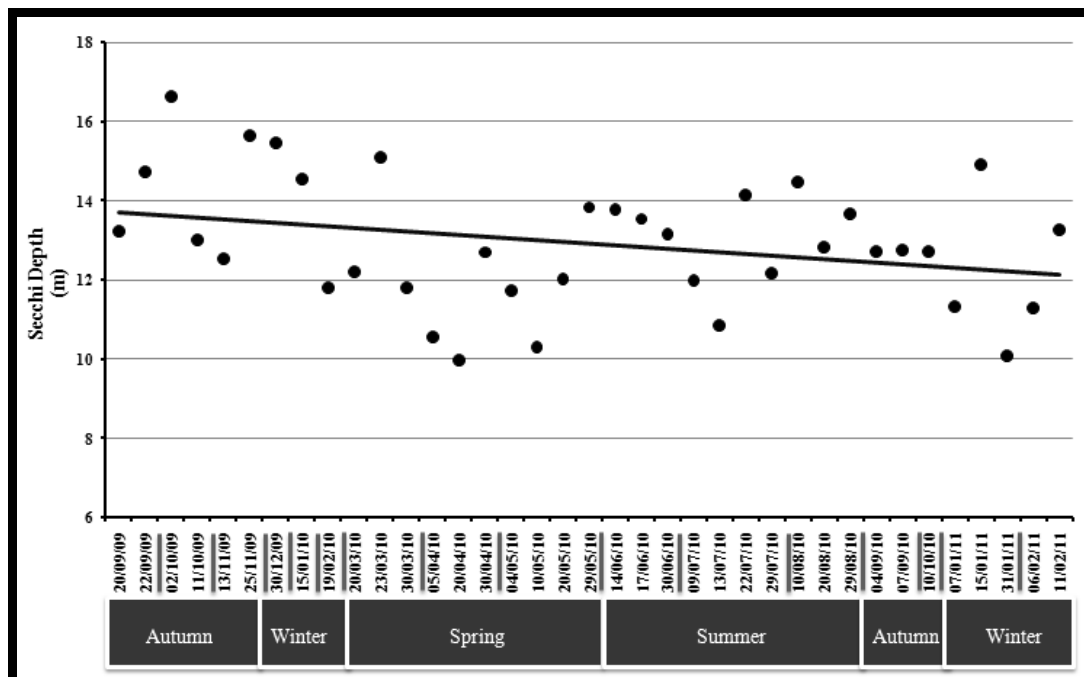


Figure 4.1 Decreasing trend in Secchi during the study period

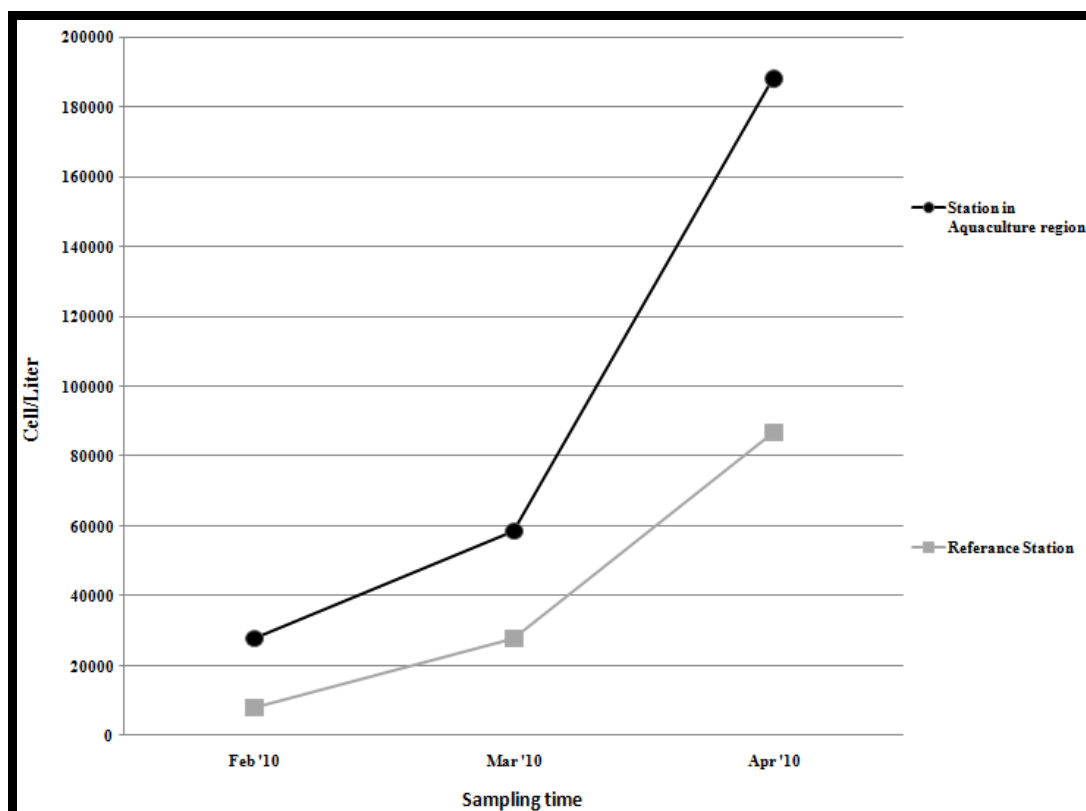


Figure 4.2 Increasing trend in phytoplankton amount between February 2010 and April 2010 in Ildırı Bay, as B. E. İnanan (Personal communication, 17 June 2011)

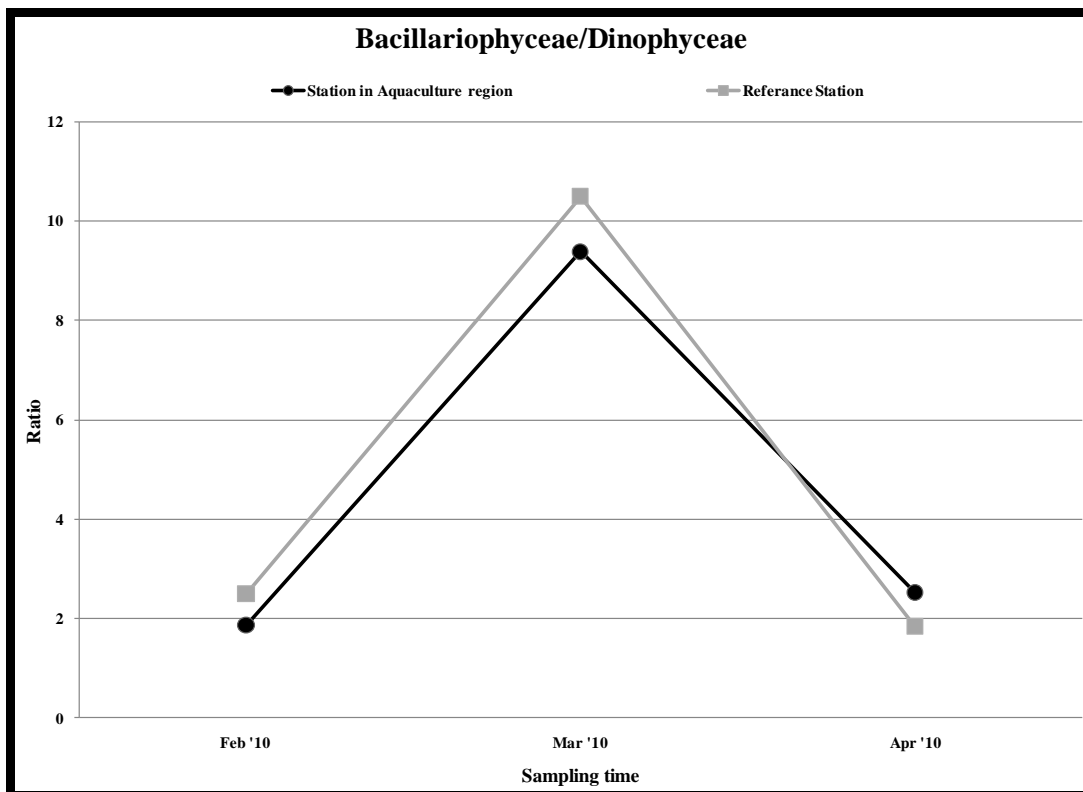


Figure 4.3 Ratio between main phytoplankton groups in Ildırı Bay, as B. E. İnanan (Personal communication, 17 June 2011)

Average TSM concentration is 1.97 mg/l (± 0.91), while it is 1.88 mg/l (± 0.78) as average TSM concentration of aquaculture region in Ildırı Bay. Results of this study, the aquaculture regions do not show major differences than whole area of the bay either total suspended matter or visibility of water (SD). This resolution of remotely sensed data is concluded to be unable to determine these differences. The TSM distribution in the bay seems to have strong relation with the Chios Strait for particulate inflowing or out flowing in surface layer especially in spring and summer seasons. The idea may be strengthened when possible particulate sources for Chios Strait are examined (Figure 4.4). These sources also probably effect TSM distribution in the study area. These fluctuations of particles make it impossible to observe local increases in TSM such as impacts of aquaculture areas in this resolution. Only in semi-closed part of study area, which is Gerence Inlet (at northern side), has some local increases which are around aquaculture areas in TSM concentration. These local increases point out that local sources may be the reason for formation of the situation. Temporary streams and infrequency of settlements

together with intense aquaculture activities appear the important sources in this region. Semi-close structure may increase impact of aquaculture activity. Detailed study should be carried on that region of Ildırı Bay in near future.

Table 4.1 TSM concentrations in maximum and minimum from Bays of Aegean Sea. *Karageorgis & Anagnostou (2001), **Inanan (2007), ****this study

Area	Max	Min
Thermailos Gulf and Sporades Basin*	4.97	0.03
Northern Aegean Sea*	6.19	0.05
Pagassitikos Gulf*	1.53	0.04
Saronikos Gulf*	1.84	0.09
İzmir Bay**	13.25	0.6
Ildırı Bay***	6.92	0.12

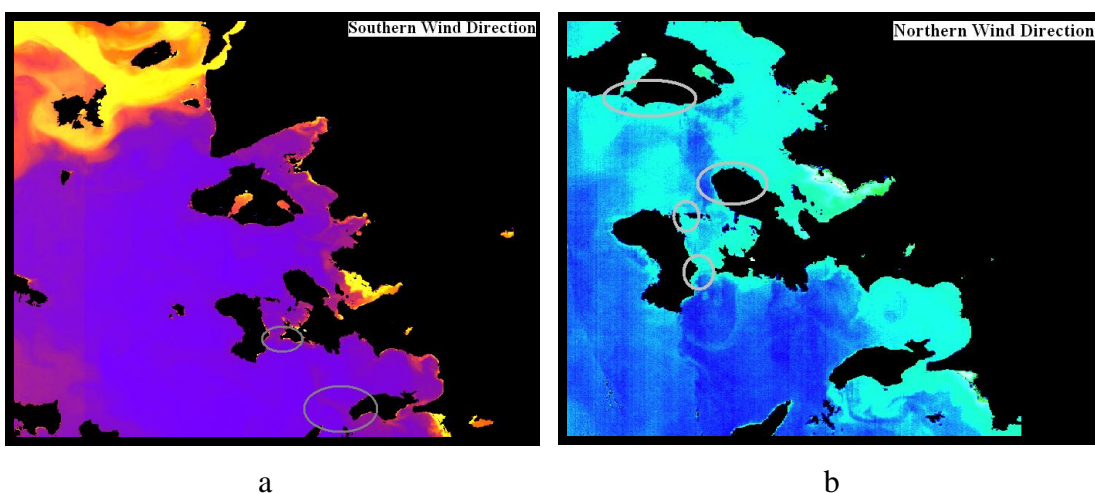


Figure 4.4 Pseudo colour images of MERIS after atmospheric correction. a) Image in southern wind direction, b) Image in northern wind direction

SST results are not as useful as TSM and SD because of lower resolution of MODIS compared to MERIS and limitation in validation of the algorithm. Results show that seasonal pattern in the area is like its climatic features, but the average values were calculated without higher than limitation value and this may change the range and may cause calculations at low values in June, July, August and September. Beside of validation failed higher than 25.99 ($^{\circ}\text{C}$), these invalid pixels are related

with near to land pixels in their spatial distribution. Figure 4.6 shows classification of stations according to their geographic locations. Invalidated data area contains only stations (pixels) which are classified as near to land. This temperature limitation may relate with land interactions in coastal areas. 1 km resolution is not fair enough for the Ildırı Bay, considering its spatial area is small and include many small islands to contaminate pixels. This pixel size is also not available to observe local changes and impacts. Taken into account limitations in the area that is close to land, MODIS images with this algorithm required extra measurements in days which include temperature values higher than 25.99 ($^{\circ}\text{C}$) in area closer to land. In further studies, the algorithm should be tested in region away from coastal area. This makes it possible to evaluate the practicality of the algorithm in open waters of Aegean Sea and its geographically suitable bays. On the other hand, another way may be using DMI data. Figure 4.5 presents relation between DMI weather data and MODIS SST data. If this relation is considered, maximum sea surface temperature would be 26.84 ($^{\circ}\text{C}$) during study period.

Compared to neural network method, linear relations between water leaving reflectance and the parameters are not strongly significant (Table 4.2). This fact shows neural network methods are more appropriate for this study. Result shows that the estimation accuracy for characteristics of water leaving reflectance using the neural network is much better than those from linear methods. Similar results, emphasizing better performance of neural network method were also stated by Zhang et al. (2002).

Table 4.2 Linear relations of TSM and SD values with water leaving reflectance

	TSM				SD			
	r	r ²	t	p	r	r ²	t	p
reflec_1	0.273667	0.074894	2.397482	0.019141	-0.335752	0.112730	-3.00345	0.003685
reflec_2	0.230428	0.053097	1.995315	0.049847	-0.457119	0.208958	-4.33070	0.000048
reflec_3	0.121754	0.014824	1.033604	0.304829	-0.631582	0.398895	-6.86410	0.000000
reflec_4	0.044538	0.001984	0.375653	0.708295	-0.683763	0.467532	-7.89566	0.000000
reflec_5	-0.041846	0.001751	-0.352910	0.725201	-0.686053	0.470669	-7.94554	0.000000
reflec_6	-0.060593	0.003672	-0.511507	0.610583	-0.660741	0.436578	-7.41726	0.000000
reflec_7	-0.057146	0.003266	-0.482312	0.631068	-0.663075	0.439668	-7.46395	0.000000
reflec_8	-0.056534	0.003196	-0.477131	0.634735	-0.661650	0.437781	-7.43540	0.000000

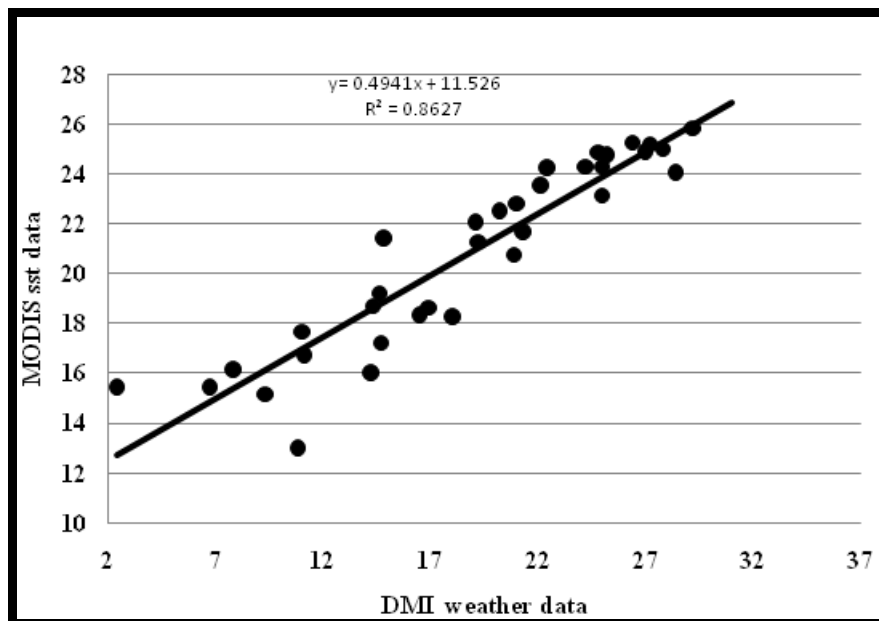


Figure 4.5 Relationship between DMI weather data and MODIS SST data

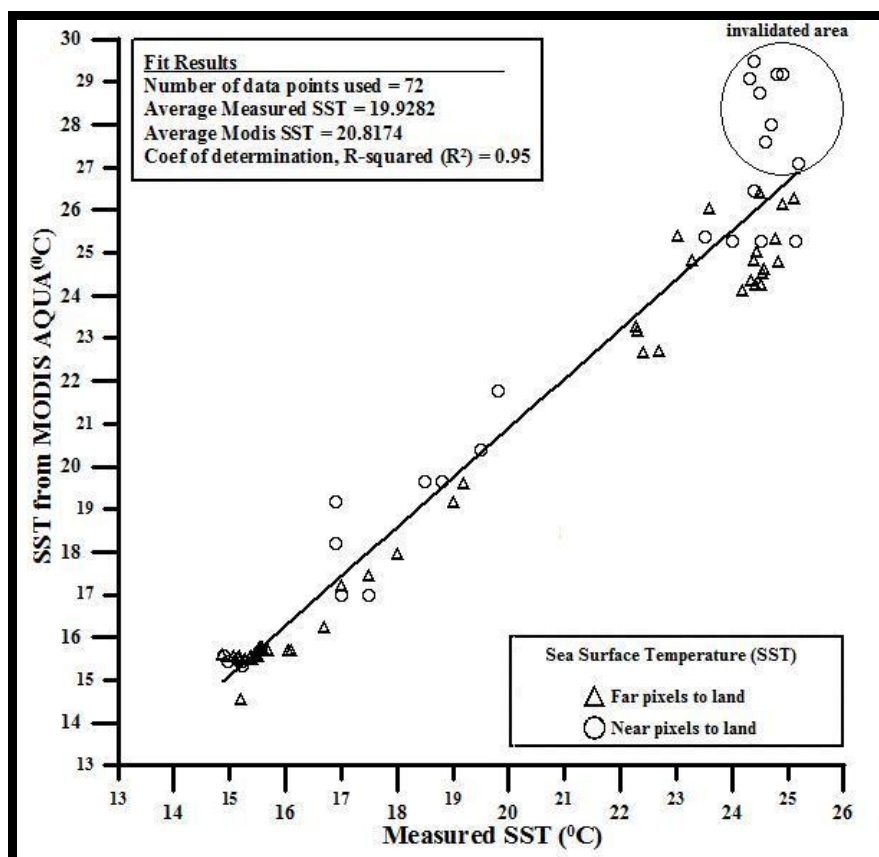


Figure 4.6 Overall data classified according to their geographical locations.

4.2 Impact of Aquaculture on Marine Ecosystem

MERIS full resolution products that were used in this study have 0.3 x 0.3 kilometer spatial resolution. That means every pixel cover 0.009 km² area on sea surface. Aquaculture regions in the area have a range between 0.0792 km² and 0.0066 km². To compare aquaculture regions with MERIS pixels, the largest aquaculture region covers approximately 12 pixels, while the smallest region covers less than 1 pixel. A total area of aquaculture region in the bay covers approximately 59 pixels. Study area, which is defined in Figure 3.9, covers 18,800 pixels. Very small percentage of Ildırı Bay is used for aquaculture activities. Considering that aquaculture regions cover very small areas and MERIS pixels cover relatively big areas, MERIS full resolution products are not very sensitive for observing aquaculture activities in Ildırı Bay. It can not be very sensitive for local changes unless they are large facilities and capacities in the area. But, it may help to observe wide scale changes such as algal blooms or harmful algal blooms. To evaluate impact of aquaculture, current model of the study area should be determined. Thus, impacts of local sources may be detected such us particulate inputs by aquaculture activities, besides natural distribution of suspended matter.

Great potential of Remote Sensing in application of aquaculture studies were pointed out by IOCCG (2009). This application can classify simply such as site selection, warning system for harmful algal bloom, ecological and spatial models. While aquaculture site selection in open water has been generally based on the use of medium spatial-resolution sensors, IOCCG (2009) also mentioned that “site selection for near-shore aquaculture sites has been routinely based on the use of multispectral images from high spatial-resolution sensors”.

Even though having more advantages of high resolution sensors in use for near shore aquaculture for site selection studies, their costs do not make them feasible for time series studies which need monthly, seasonal or annual changes in variables and their pattern in characteristic of marine ecosystems in aquaculture areas. Low cost of medium resolution sensors makes available more sampling to determine relevant

variables characteristic of marine ecosystem. On the other hand, medium resolution may not sense spatial change in aquaculture area. MERIS FRS is one of the best products in medium resolution sensors. Using medium resolution sensors should be preferred such a type of study, because of availability to produce time series data, despite their relatively lower resolutions. The study will probably provide important input for possible model studies, in design of further studies or the study will be a support as a complementary in field studies to increase understanding.

An information system including data on aquaculture activities in Turkey will help to increase benefit of this type of remotely sensed data. According to a notification published in the Official Gazette of the Republic of Turkey in 2007, existing or planned facilities have to provide the requirements for site selection which are cages not to be located within less than 0.6 nautical mile off shore, below 30 m depth (under cages) and with a minimum current of 0.1 m/sec. Moving duration was completed in last quarter of 2009 in Ildırı Bay. Unless having field observation, it was not possible to know moving of cages. This fact brings to light importance of an extensive information system on aquaculture in Turkey.

Insufficiency of this study was that it did not focus enough on chlorophyll pigment. Chlorophyll pigments are too important for application of remote sensing in aquaculture such as warning system for harmful algal bloom, identification high chlorophyll zone, characterization production capacity (IOCCG 2009). Additionally, TSM may be used for observing wide ranged algal blooms, besides chlorophyll pigment. They will be complementary to each other, when these two parameter distribution are monitored.

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APPENDICES

APPENDIX 1 Some studies on impacts of fish farms on marine ecosystems in the Mediterranean Sea

Location	Impact on	Publication	Parameters	Result
Aegean Sea and Black Sea (Turkey)	Benthic (Macrofauna)	Mantıkcı, M. A., 2009	Benthic organisms and organic enrichment	As a result, enrichment of the sediment beneath the fish cages results to disrupt the structure of macrozoobenthic communities in Ordu - Perşembe and İzmir - Gerence Bay
Tyrrhenian Sea (Italy)	Benthic (Meiofauna)	Mazzola et al., 2000	Organic enrichment and High biodeposition, benthic organisms	Benthic habitat under the cage were a large accumulation of primary organic material, changes in sedimentary organic matter composition, and a strong reduction of redox potential values, which resulted in a significant reduction of meiofaunal penetration depth into the sediments
Western Mediterranean (Spain)	Benthic (Sea grass)	Ruiz et al., 2001	Light attenuation coefficient, water-column dissolved nutrients, Organic content of sediments	Fish farms are a potential cause of seagrass decline, since they can affect light reduction, epiphyte overgrowth, overgrazing, sediment resuspension and sediment redox changes
Western Mediterranean (Spain)	Benthic (Sea grass)	Delgado et al., 1999	Organic content and redox potential of sediments	An increased organic load, caused by excess fodder and fish faeces, seems to be the immediate cause of the seagrass decline.
Ionian Sea and Aegean Sea (Greece)	Benthic environment	Karakassis et al., 2000	Macrofauna and Geochemical variables	The results indicate that impacts of fish farming on benthos in the Mediterranean vary considerably depending on site characteristics
Aegean Sea (Greece)	Decomposition of <i>Posidonia oceanica</i> litter	Apostolaki et al., 2009	Carbon, nitrogen, phosphorus, oxygen,	The lower decomposition of litter originated from cages suggests that seagrass tissues under the cages accumulate chemical deterrents, possibly in order to confront high grazing pressure, which on the other hand reduces the rate of decomposition
Adriatic Sea (Croatia)	Foraminiferal community	Vidović et al., 2009	Total phosphorus and nitrogen, grain size and foraminiferal community	According to this study, foraminiferal community composition can be used as indicator of organic enrichment caused by fish farm activities

Mar Piccolo (Italy)	Heterotrophic bacteria and coliforms	Zaccone et al., 2005	Total heterotrophic bacteria, faecal coliform, temperature, salinity, oxygen	In the benthonic environment the aquaculture activity increased the biodeposition of the sediment, causing changes in the abundance and the composition (stridia ratio) of microflora
Ligurian Sea (Italy), Adriatic Sea (Italy), Tyrrhenian Sea (Italy) and Levantine Sea (Cyprus)	Microbial assemblages and organic matter composition	Danovaro et al., 2003	Redox potential discontinuity (RPD) depth, organic matter content and composition, bacterial cell counting,	In all systems investigated, organic matter accumulated in aquaculture impacted sediments and bacterial and total microbial density increased significantly in impacted sediments
Ionian Sea and Aegean Sea (Greece)	Plankton community structure, water chemistry	Pitta et al., 1999	Temperature, salinity, photosynthetic pigment, water-column nutrients, community of phytoplankton and microzooplankton	A significant increase in concentrations of phosphate and ammonium was detected within the cages over the control site in one of the farms but without any significant effect on chlorophyll concentration. Plankton abundance for the major taxonomic groups, microplankton species diversity and community structure were also determined by the effects of season and location rather than by fish farming
Ionian Sea	Seasonal variability in sediment profiles	Karakassis et al., 1999	Organic matter, Organic carbon/nitrogen, Chlorophyll, Phaeopigments, Water content and Total phosphorus)	The black coloured top layer (farm sediment) showed high concentrations of organic matter, phaeopigments and total phosphorus as well as high water content while the compact subsurface layer had concentrations close to (or lower than) those at the control site. The thickness of the farm sediment layer under the cages varied with season, while in all seasons it decreased rapidly with increasing distance from the cages
Western Mediterranean (Italy)	Sediment chemistry	Porello et al., 2005	Water current speed, Sediment water content, Porosity, Total volatile substance, Sulfide, Redox potential, Total nitrogen, Total and organic carbon, Total phosphorus, and Total sulphur	The strong but spatially limited organic enrichment found. High levels of organic enrichment were observed in the stations just beneath the cages; moderate impact was present in the area 50 m around the cages and no disturbance was observed further away from this area

Aegean Sea (Greece)	Sediment properties	Mac Dougall and Black, 1999	Acoustics measurements, water current speed, deposition	Sediment traps collected significant quantities of waste solids beneath marine fish cages at a fish farm site in Greece but, low benthic impact at this site. These results may be explained partly by the large number of fish present around the cages feeding on farm wastes
Mediterranean Sea (Italy, Spain and Greece)	sediments and macrofauna associated with seagrass meadows	Apostolaki et al., 2007	Redox potential, mean diameter and silt/clay percentage of sediment, chlorophyll a, total organic carbon and nitrogen and total phosphorus, macrofauna counting	Chlorophyll a and organic carbon were occasionally enhanced in the vicinity of the cages and nitrogen remained almost constant between the stations. Phosphorus consistently showed a decreasing trend towards the reference station. Macrofaunal biomass peaked at an intermediate distance from the fish cages
Aegean Sea (Turkey)	Water quality	Başaran et al., 2006	Physico-chemical parameters and nutrients	In conclusion, significant changes were not detected in water quality because cages are situated offshore and consequently depths are high and feeding is carried out under control.
Aegean Sea (Turkey)	Water quality	Demirak et al., 2006	Temperature, oxygen, nutrients, chlorophyll,	Water quality was highly reduced in the entire study area dependently on the presence of intensive fish farming.
Aegean Sea (Turkey)	Water quality and benthic community structure	Yücel-Gier et al., 2007	Secchi disc depth, particulate matter, dissolved oxygen, pH, temperature, salinity, nutrients, organic carbon, major benthic groups, grain size	This study indicates that responses to changes in the natural environment due to fish farming activities have been observed both in water quality parameters and in benthic organisms in Engeceli Bay. Seasonal changes were observed for most physicochemical variables, for the number of individual polychaeta and the total group. Significant differences among stations regarding nitrate, chl a concentrations and organic carbon content in sediment were found in Engeceli Bay

Aegean Sea (Turkey)	Water quality and benthic community structure	Yücel-Gier et al., 2007	Secchi disc depth, particulate matter, dissolved oxygen, pH, temperature, salinity, nutrients, organic carbon, major benthic groups, grain size	This study indicates that responses to changes in the natural environment due to fish farming activities have been observed both in water quality parameters and in benthic organisms in Engeceli Bay. Seasonal changes were observed for most physicochemical variables, for the number of individual polychaeta and the total group. Significant differences among stations regarding nitrate, chl a concentrations and organic carbon content in sediment were found in Engeceli Bay
Ionia Sea (Greece)	Water quality and sediments	Belias et al., 2003	Total organic carbon, nutrients, salinity, temperature, oxygen, pH, trace metals	No clear eutrophication incidents have been identified, although the water column near the fish farms was enriched in nutrients and organic carbon. A sludge 'blanket' covers considerable parts of the seabed and is enriched in colloidal organic carbon and trace metals (Cd, Cu, Fe and Zn) that come from unused fish food. The biodegradation of this sludge leads to the development of anoxic conditions followed by the formation of undesirable gases, precipitation or remobilization of metals and the extinction of benthic fauna.
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Adriatic Sea (Croatia)	Water quality parameters and macrobenthic communities with and without artificial barriers	D'Agaro and Lanari, 2006	Water salinity, temperature, oxygen, ammonia, nitrate, nitrite and phosphorus concentrations, macrofaunal and bacterial counting, visual census	Water quality parameters were not significantly influenced by the fish cages. The artificial barriers favoured the establishment of a rich epiphytic fauna that took advantage of the presence of organic matter derived from fish cages. The two species <i>Nucula nucleus</i> and <i>Neanthes caudata</i> and the total bacterial counts were identified as potential indicators of pollution under the fish cage farms
Aegean Sea (Greece)	Wild fish assemblages	Machias et al., 2004	Biodiversity indices	the release of nutrients from fish farming in nutrient-poor systems can have a positive effect on local fisheries with no visible negative change in species composition or biodiversity

APPENDIX 2 Distribution of TSM, SD and SST, wind charts of the Ildırı Bay in sampling day and precipitation of sampling period

Season 1 - Autumn in 2009

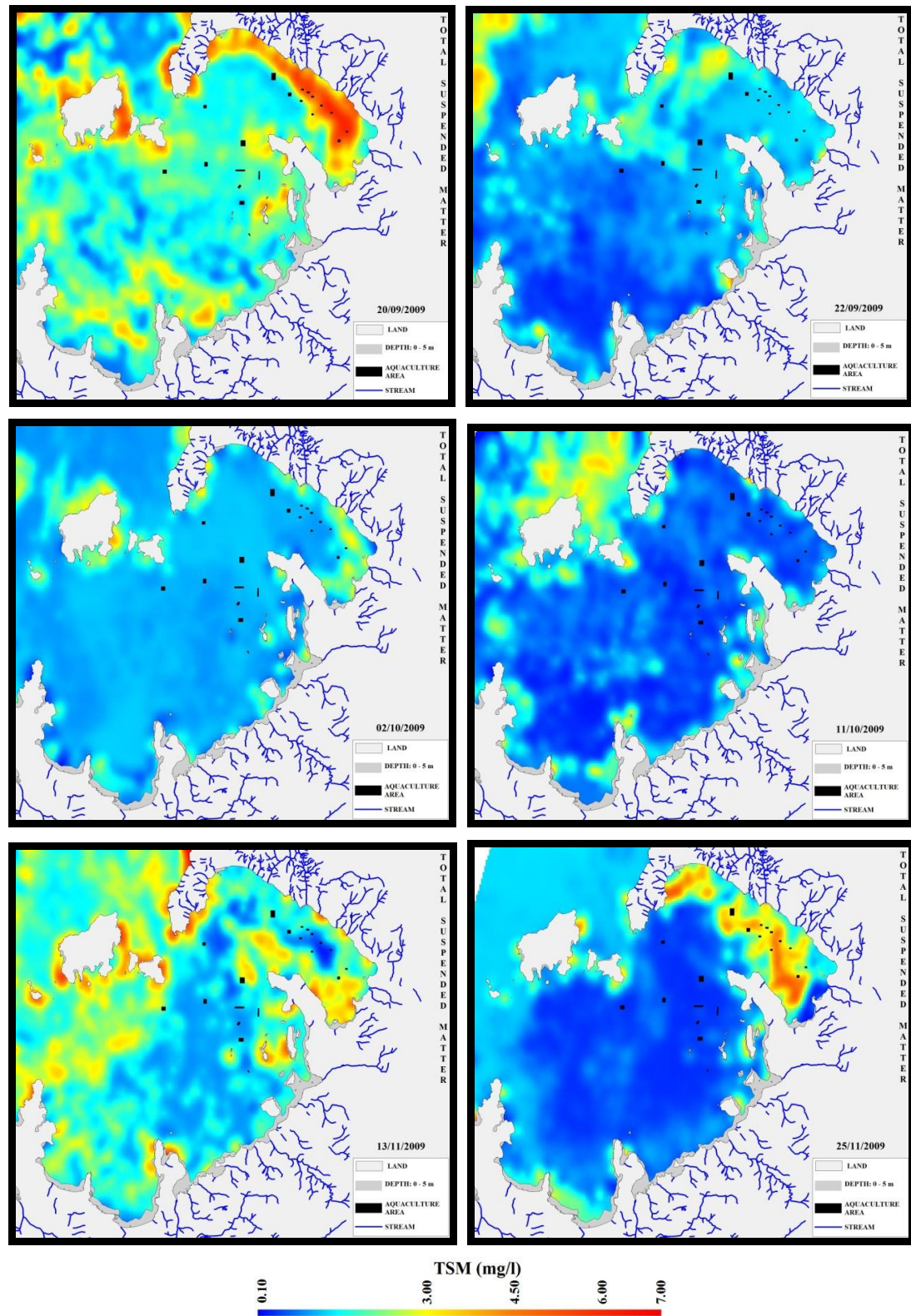


Figure 1.1 Total suspended matter distribution of Ildırı Bay in autumn 2009 from MERIS images

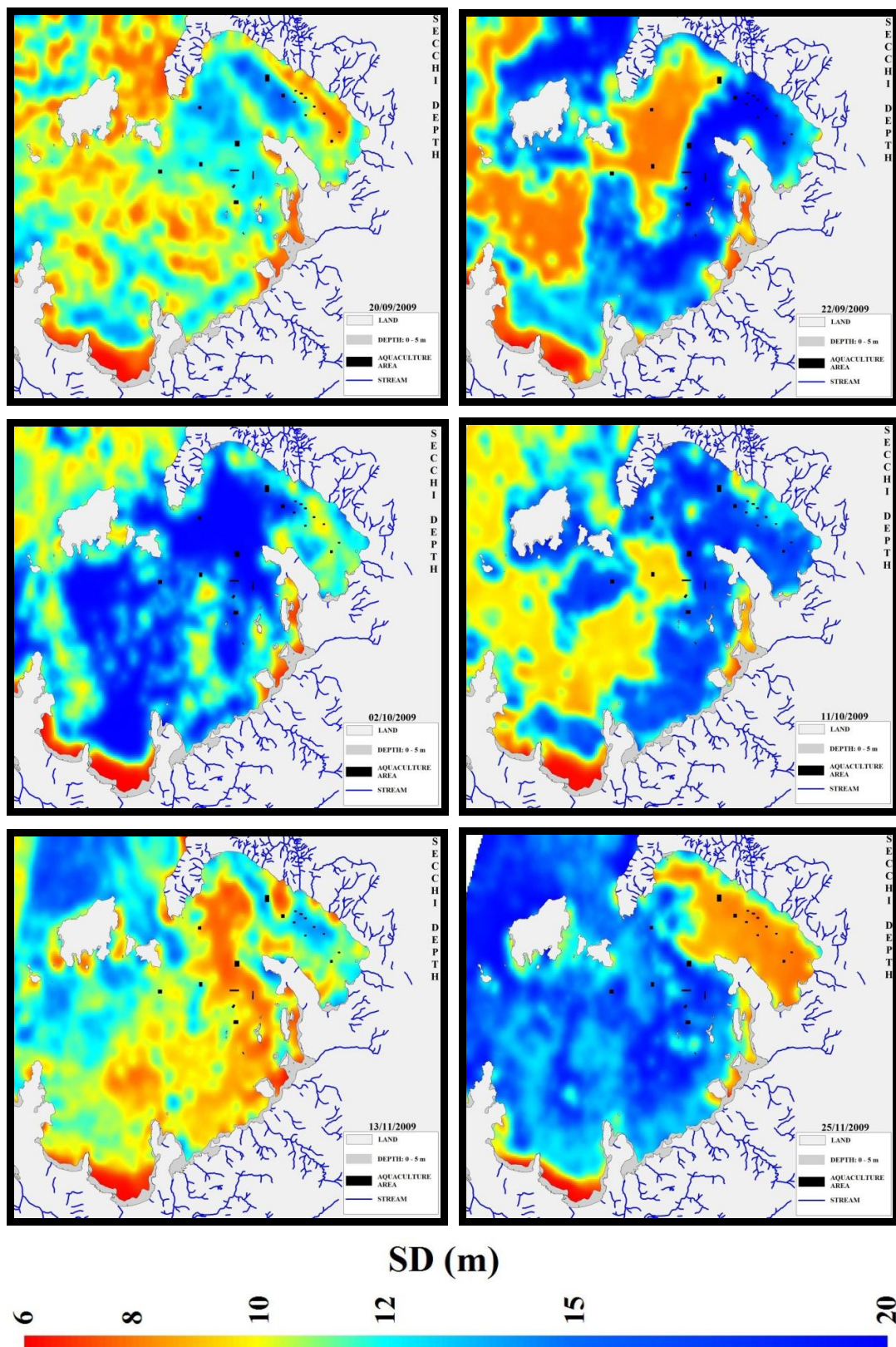


Figure 1.2 Secchi depth distribution of Ildırı Bay in autumn 2009 from MERIS images

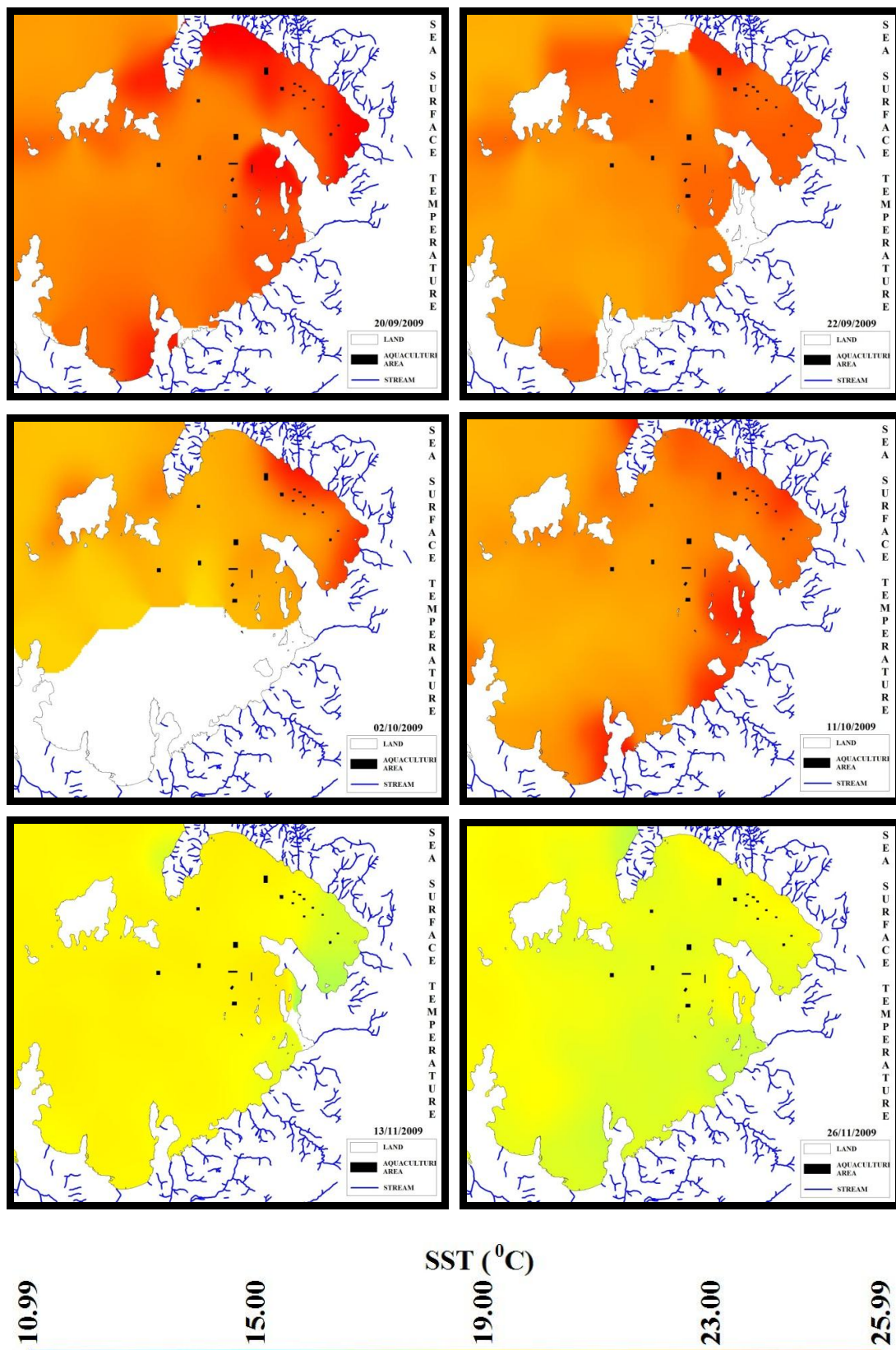


Figure 1.3 Sea surface temperature distribution of Ildırı Bay in autumn 2009 from MODIS images

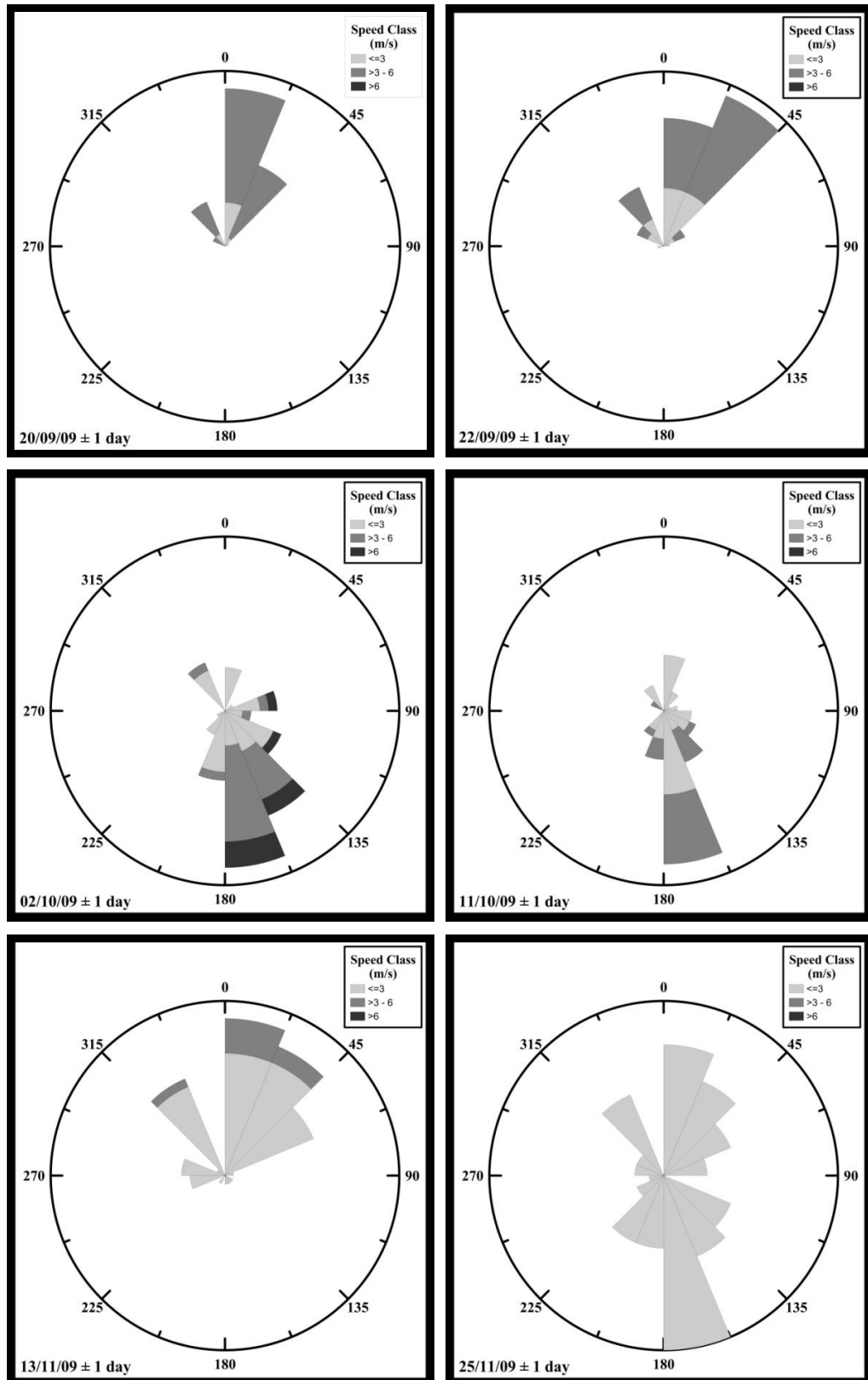


Figure 1.4 Wind chart of Ildırı Bay in sampling days of autumn 2009

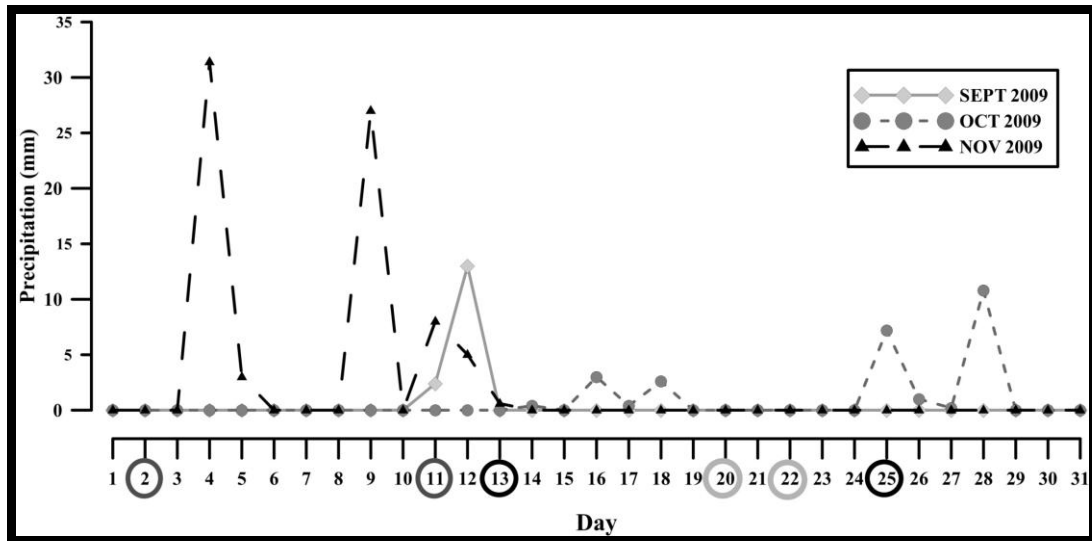


Figure 1.5 Precipitation of days in autumn 2009

Season 2 - Winter in 2009-2010

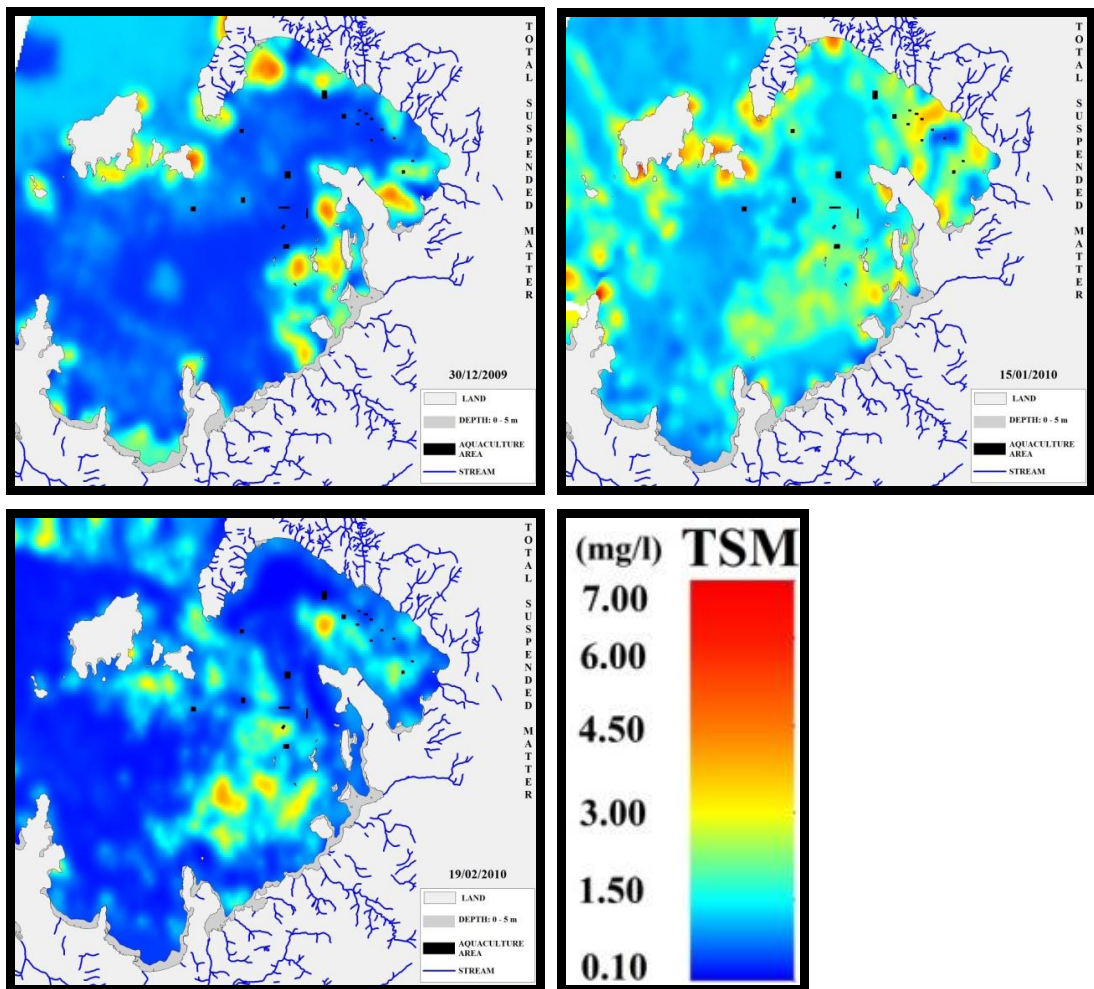


Figure 2.1 Total suspended matter distribution of Ildırı Bay in winter 2009-2010 from MERIS images

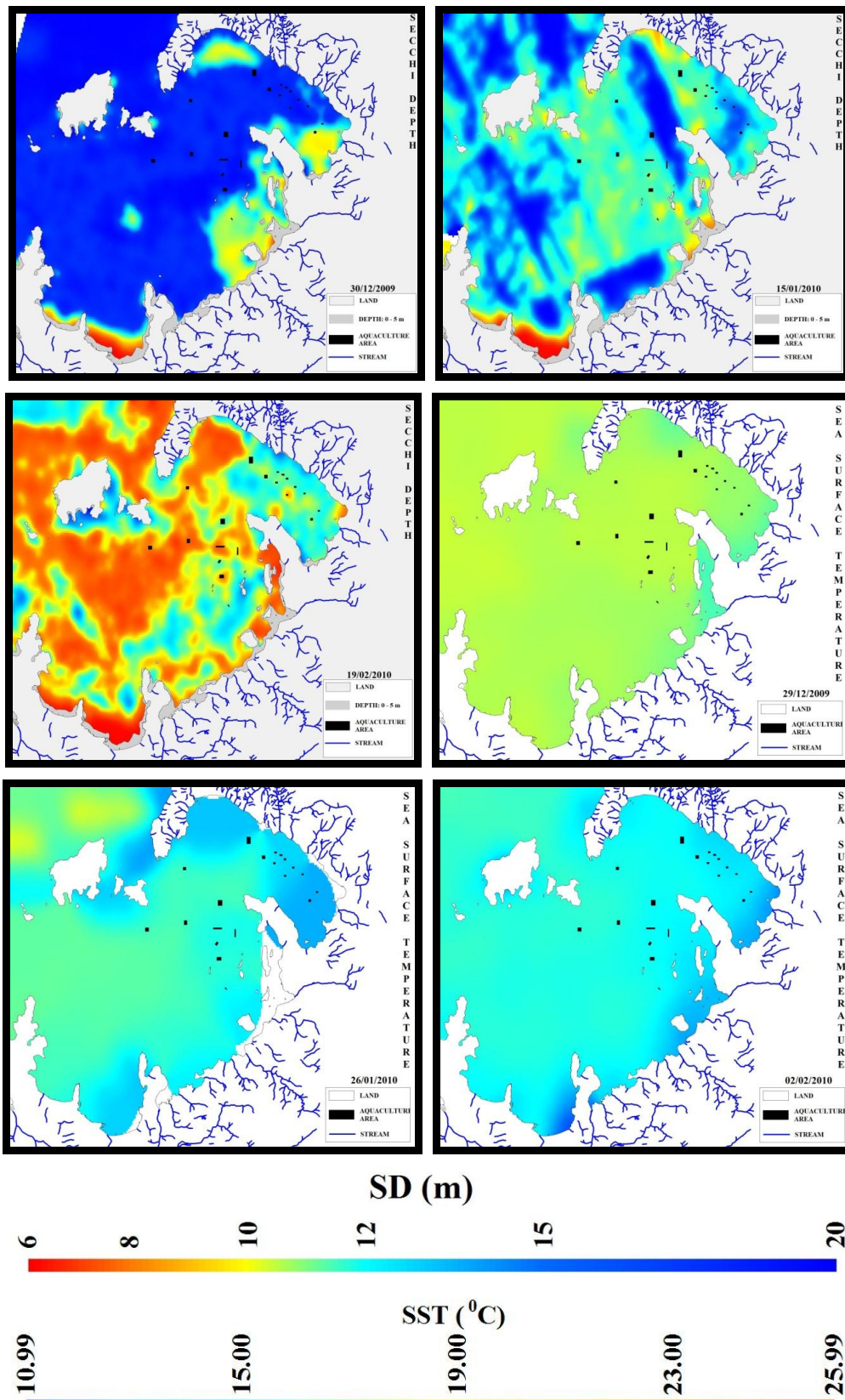


Figure 2.2 Secchi depth and sea surface temperature distribution of Ildırı Bay in winter 2009-2010 from MODIS images

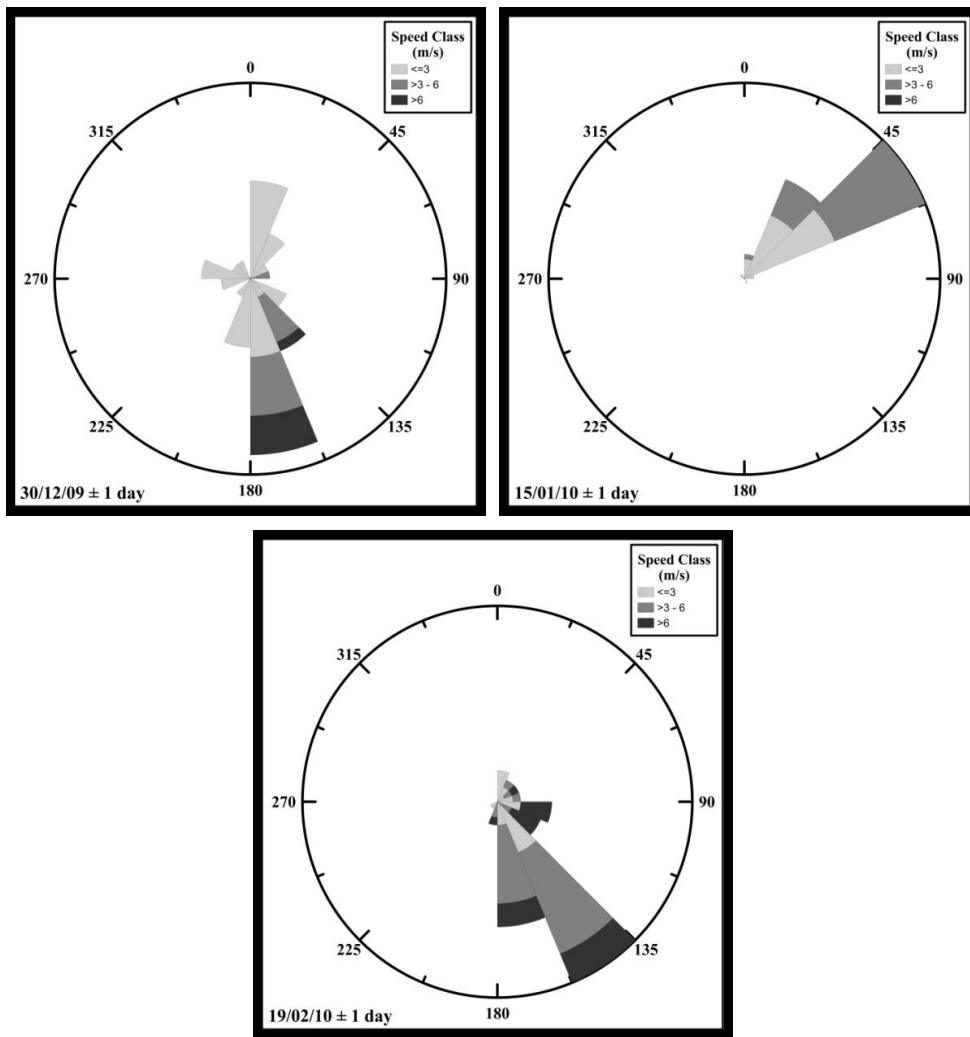


Figure 2.3 Wind chart of Ildırı Bay in sampling days of winter 2009-2010

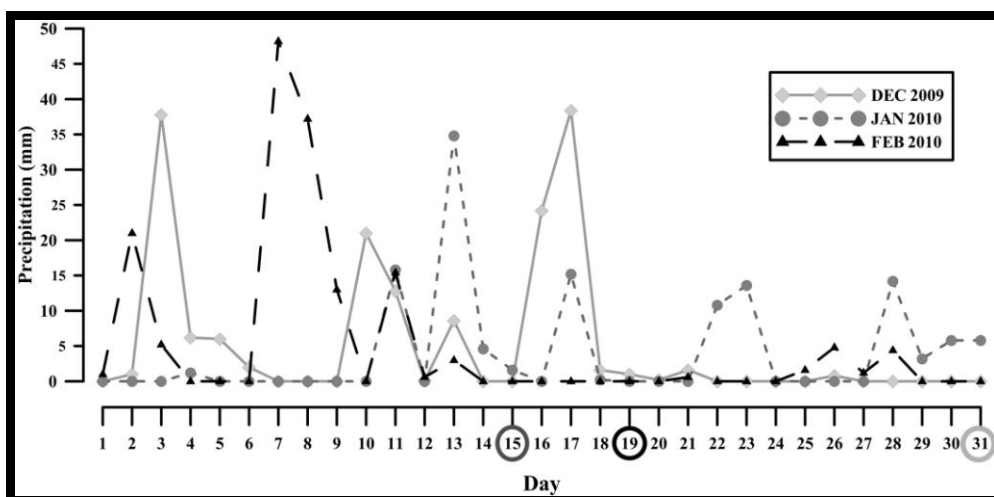


Figure 2.4 Precipitation of days in winter 2009-2010

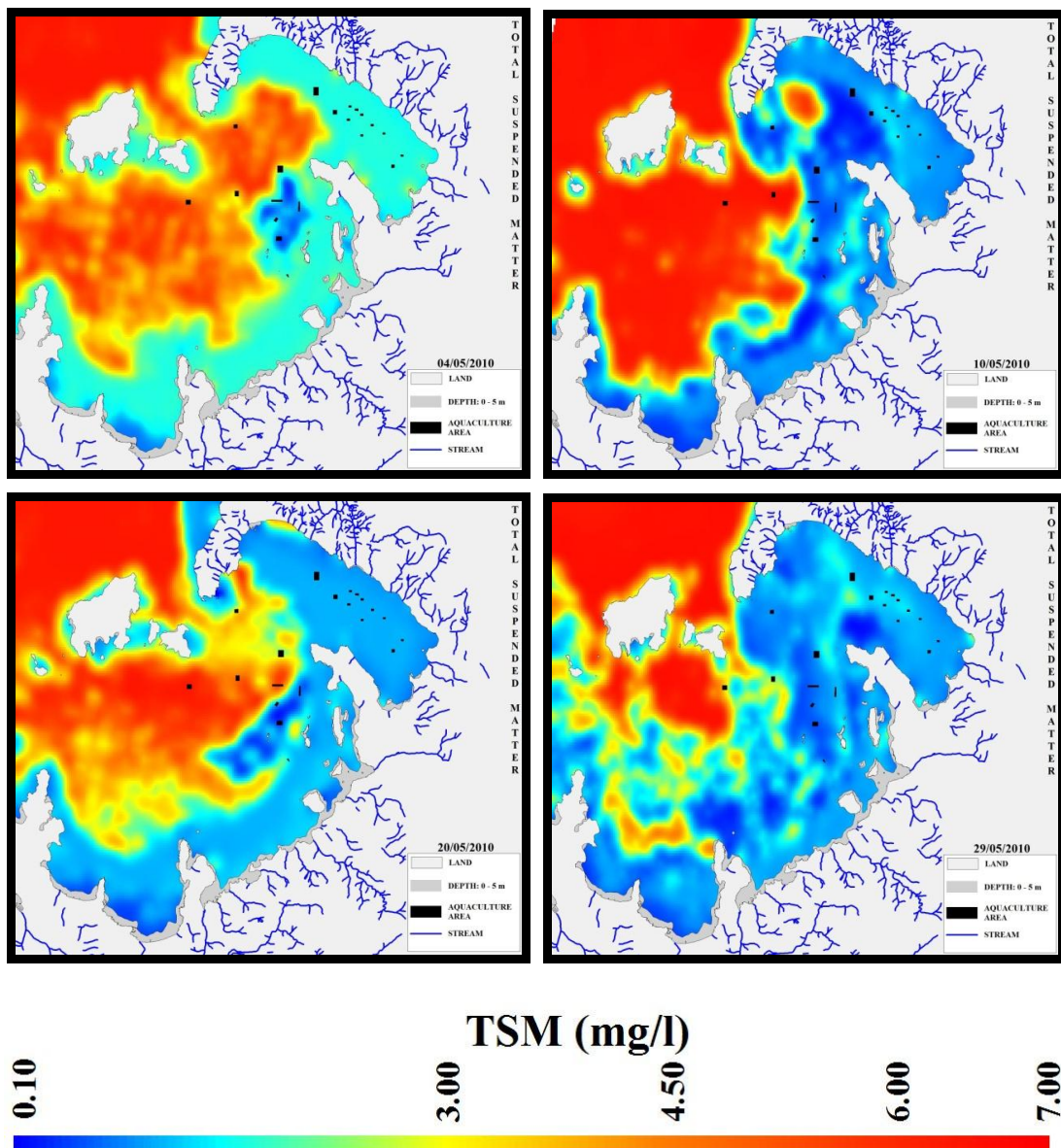


Figure 3.1 (Continues)

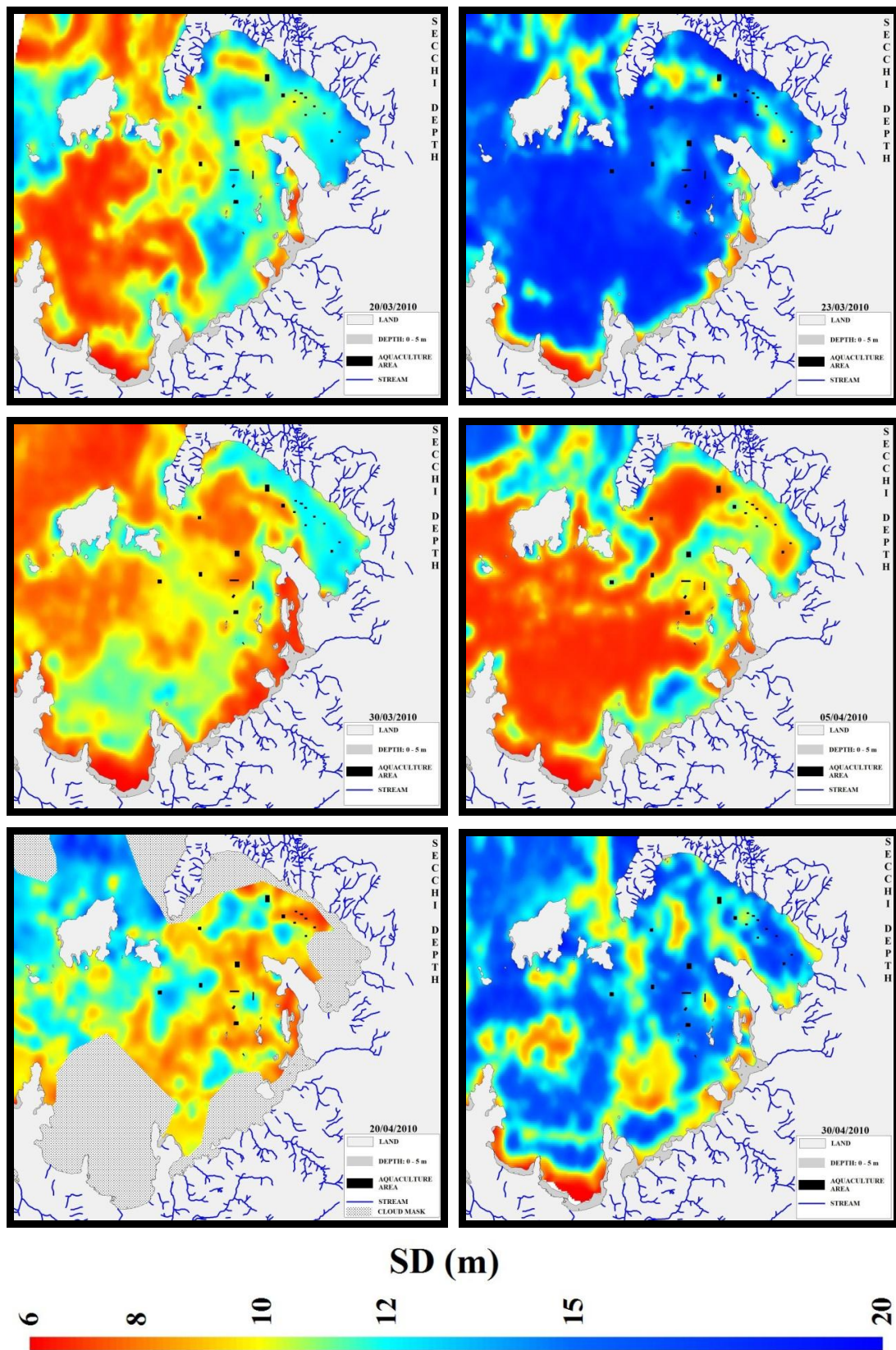


Figure 3.2 Secchi depth distribution of Ildırı Bay in spring 2010 from MERIS images

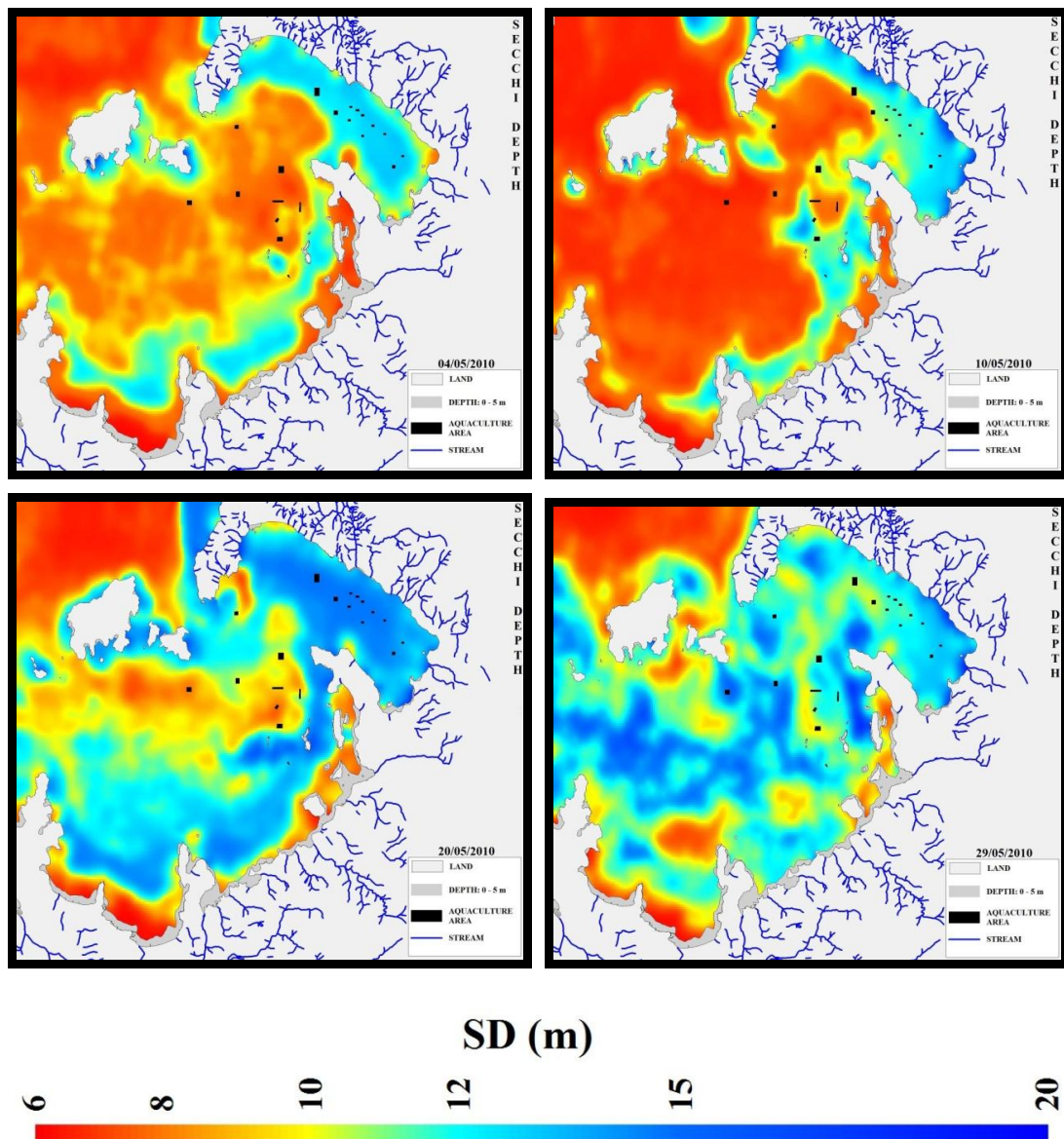


Figure 3.2 (Continues)

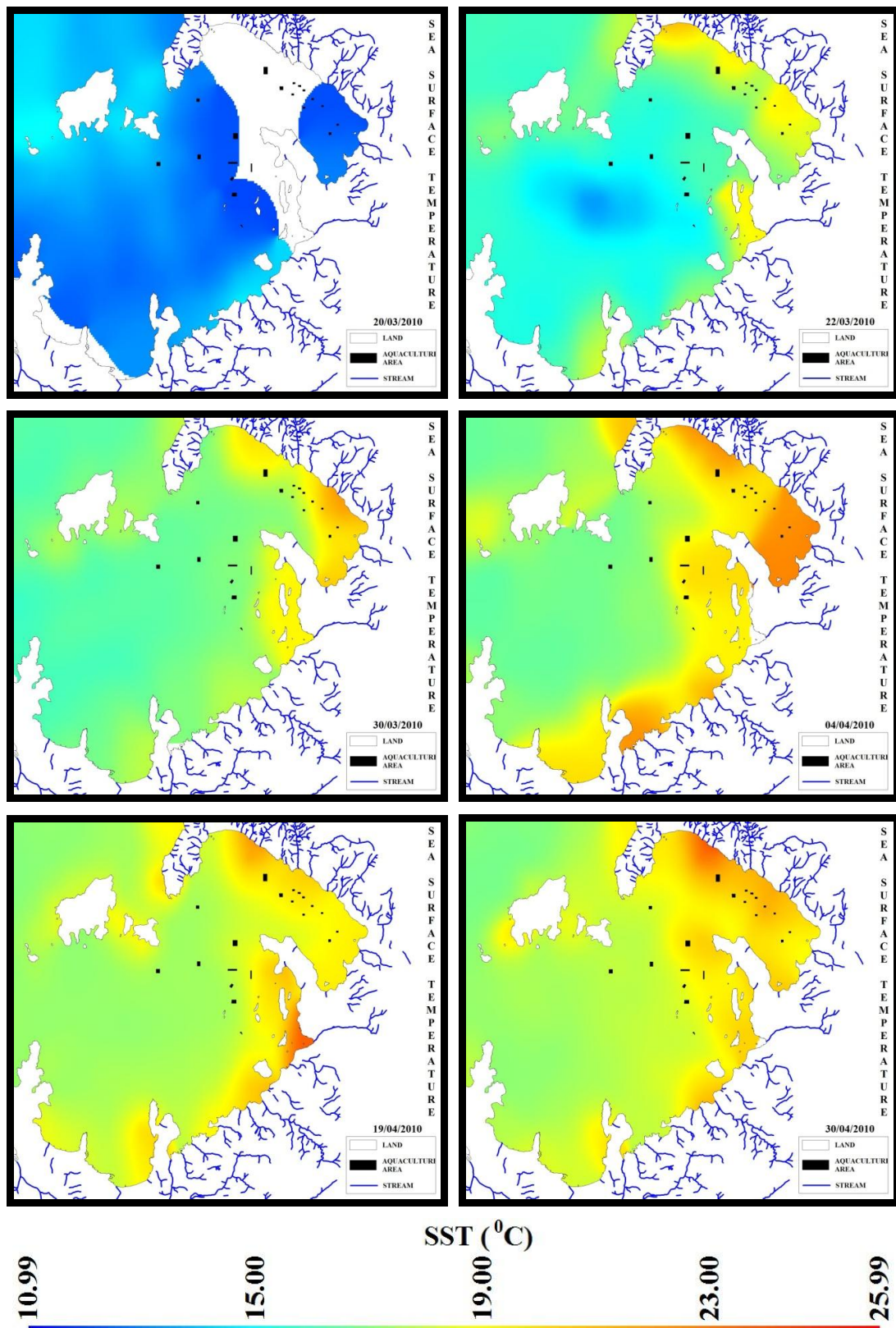


Figure 3.3 Sea surface temperature distribution of Ildırı Bay in spring 2010 from MODIS images

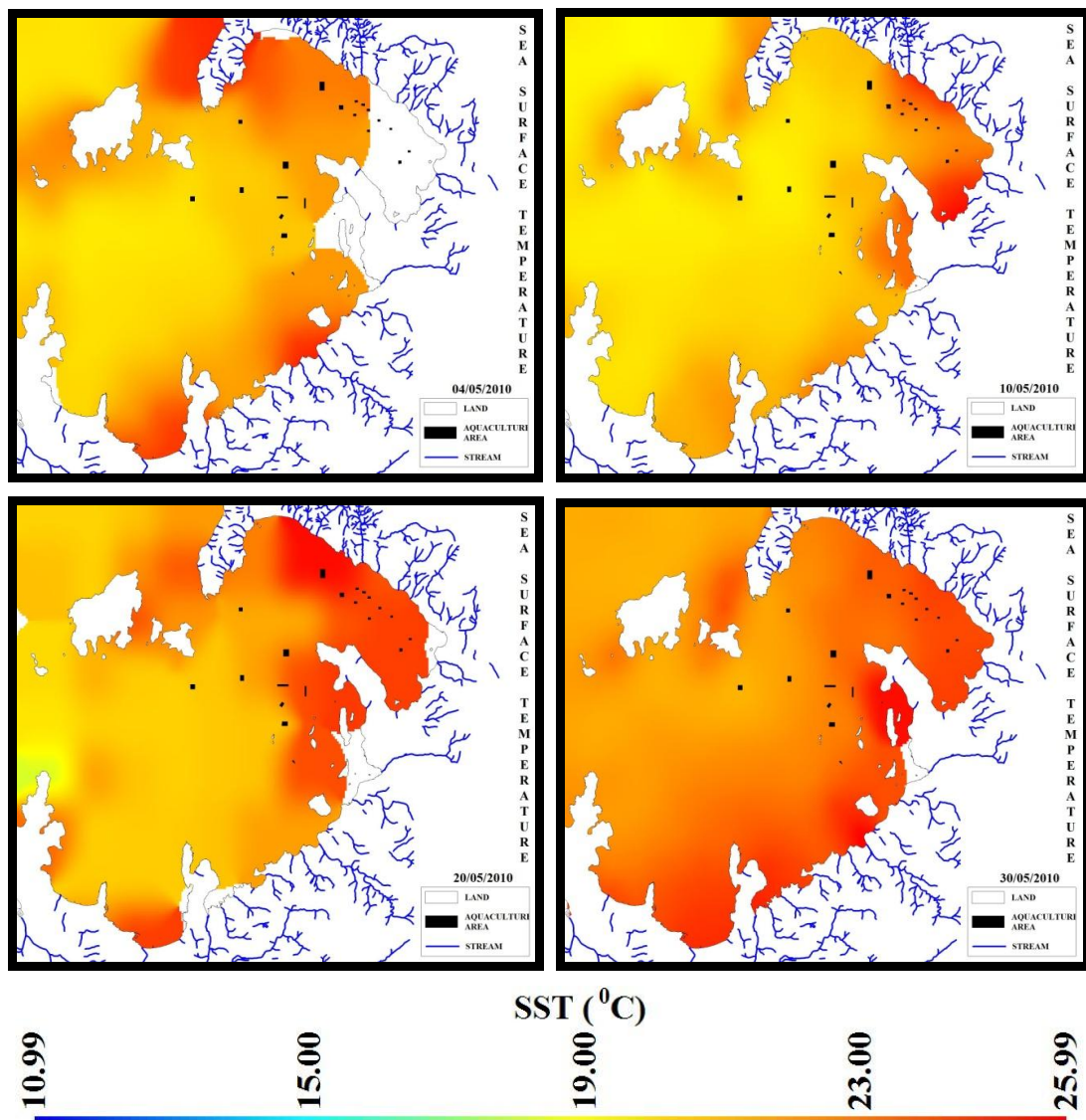


Figure 3.3 (continues)

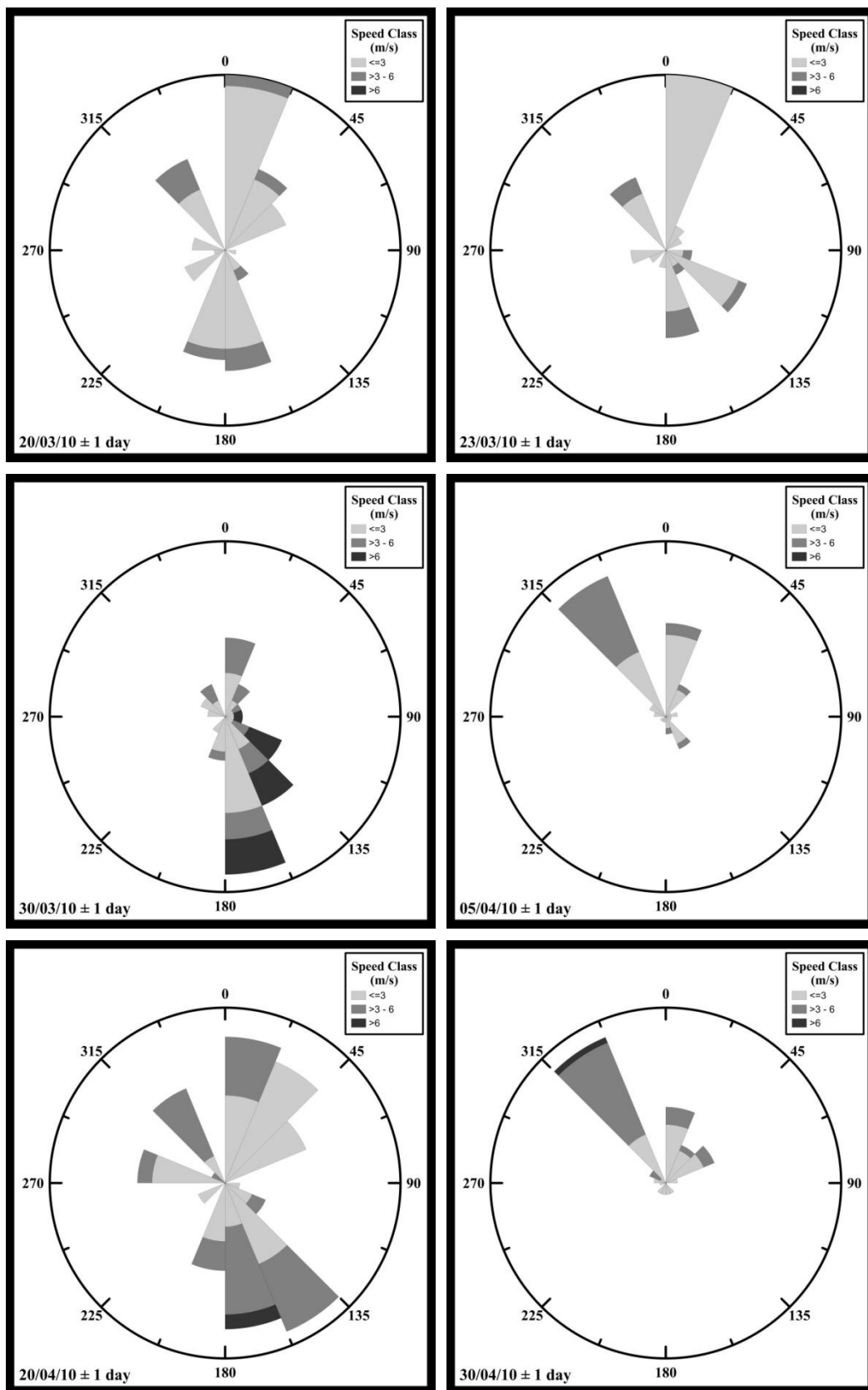


Figure 3.4 Wind chart of Ildırı Bay in sampling days of spring 2010

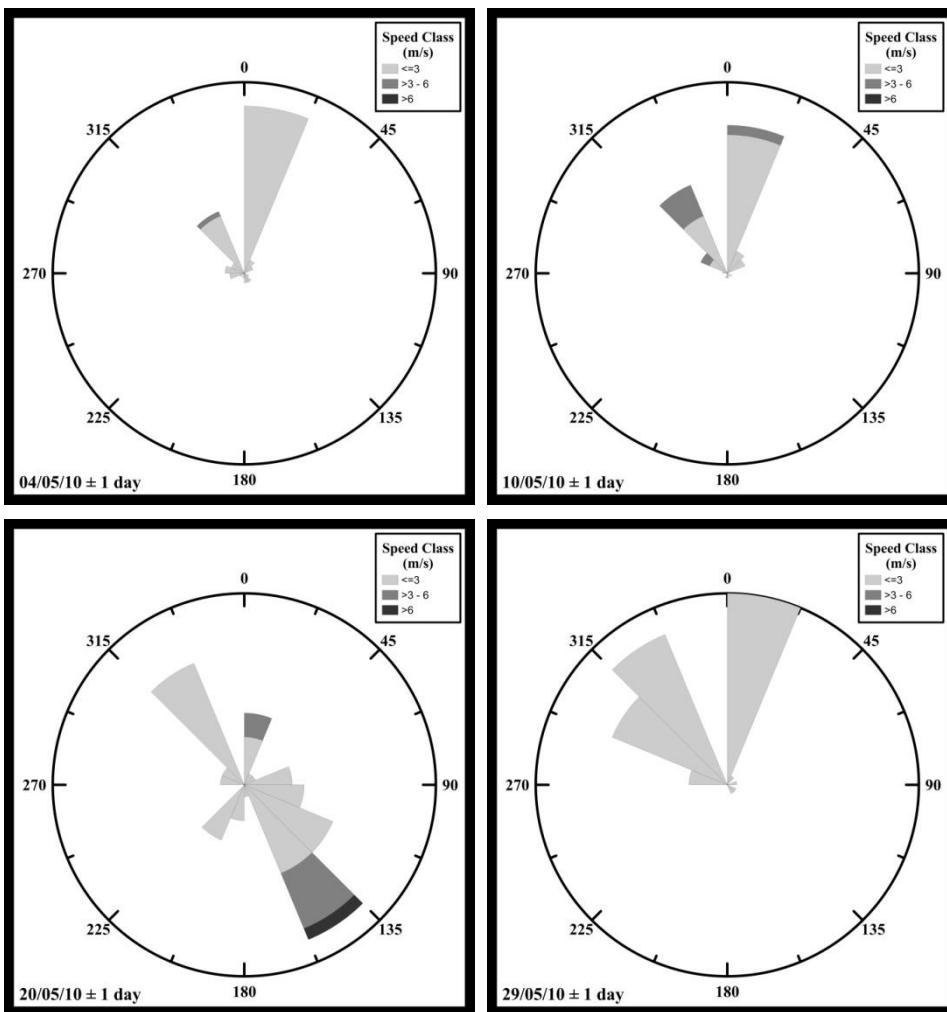


Figure 3.4 (continues)

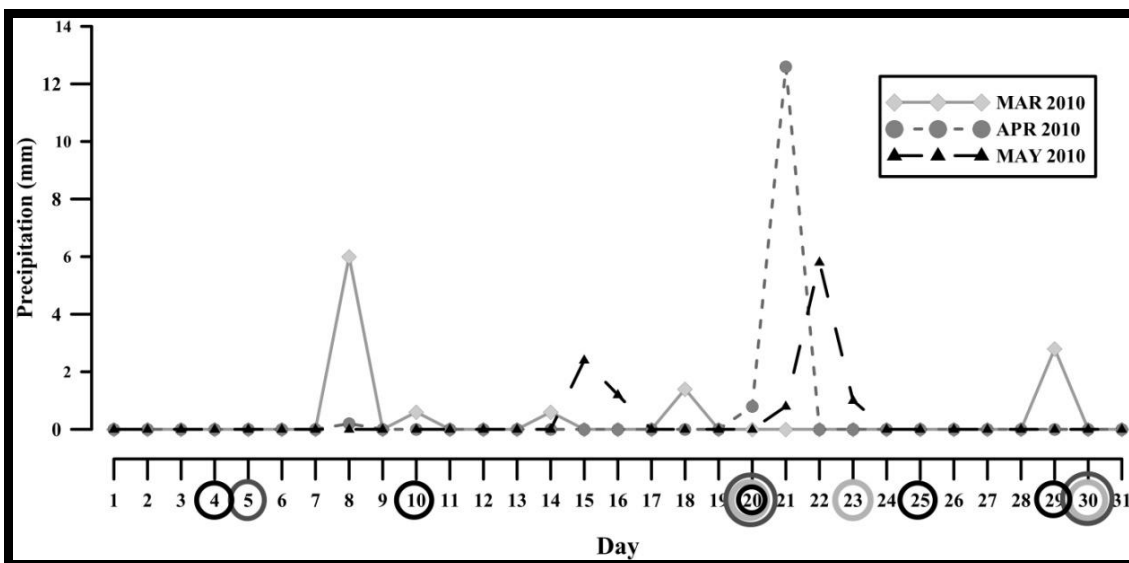


Figure 3.5 Precipitation of days in spring 2010

Season 4 - Summer in 2010

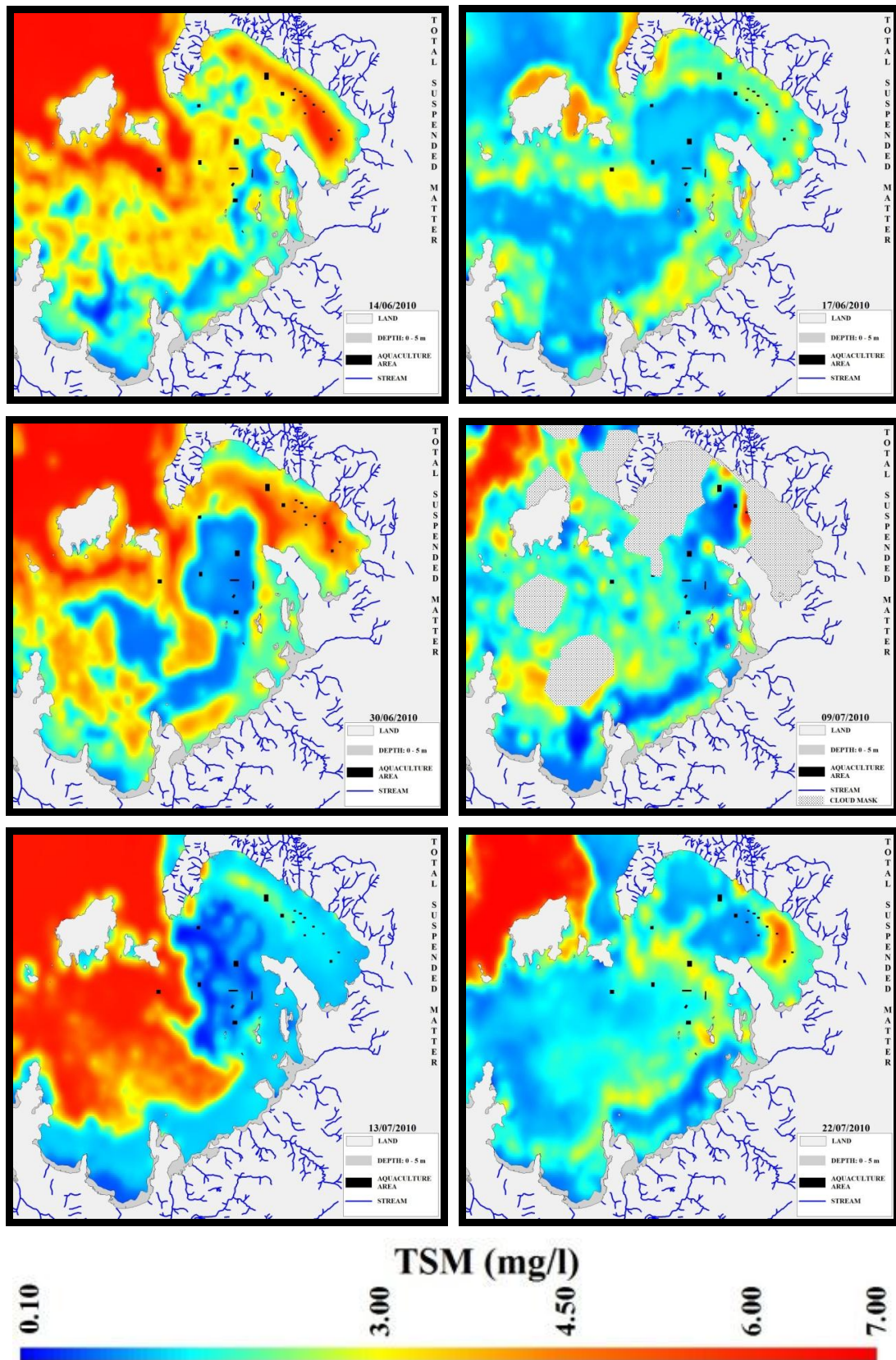


Figure 4.1 Total suspended matter distribution of Ildırı Bay in summer 2010 from MERIS images

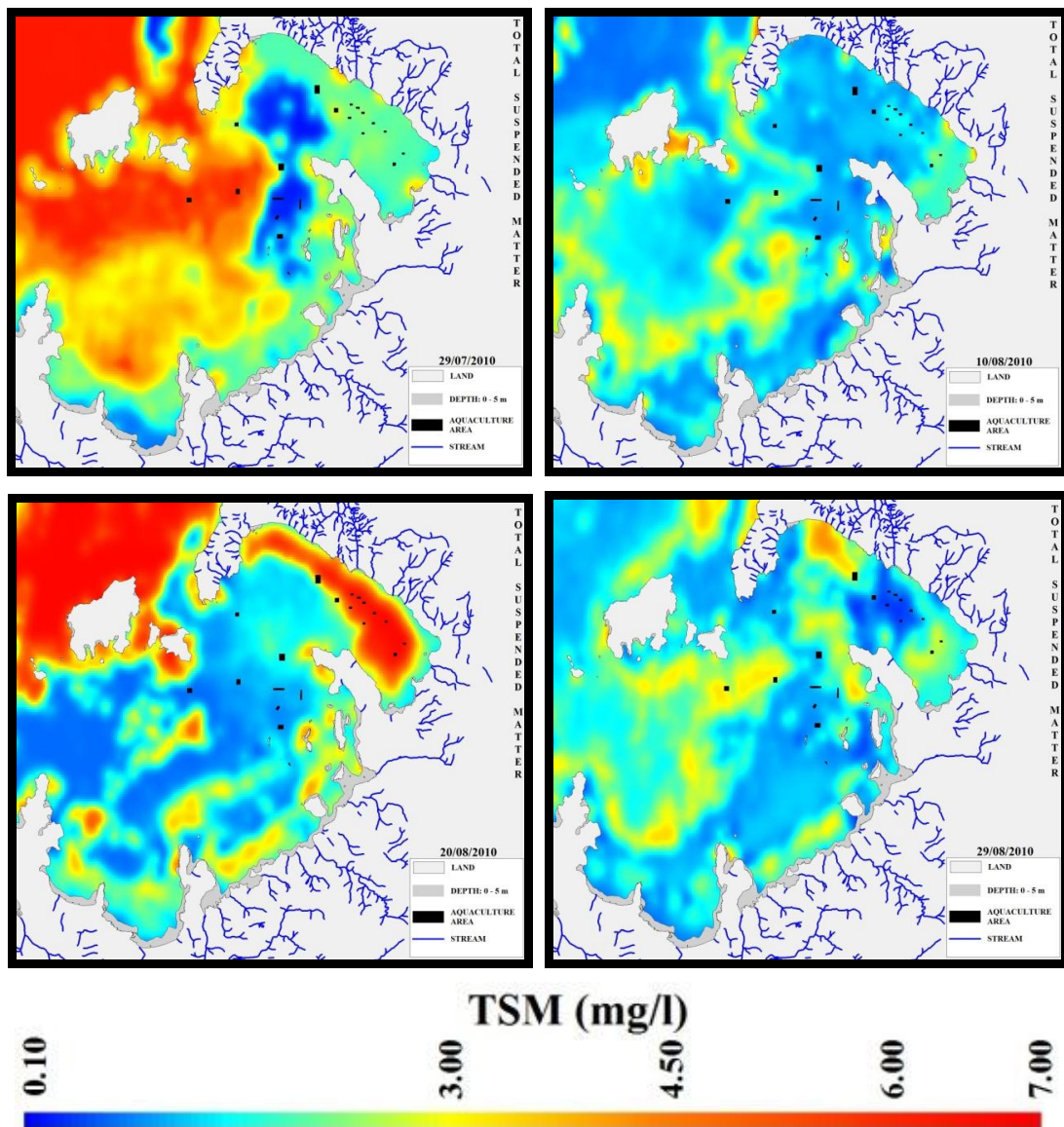


Figure 4.1 (continues)

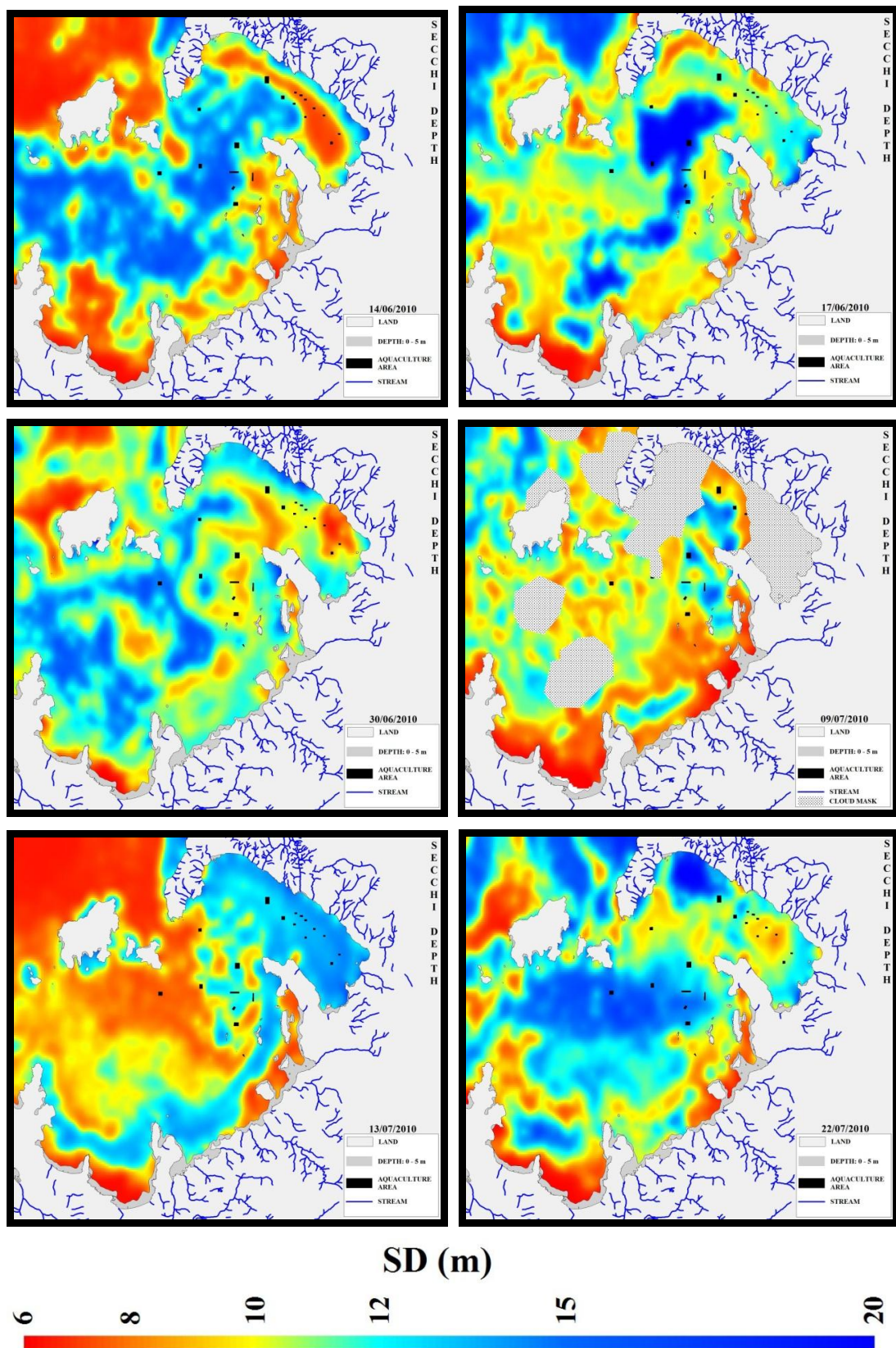


Figure 4.2 Secchi depth distribution of Ildırı Bay in summer 2010 from MERIS images

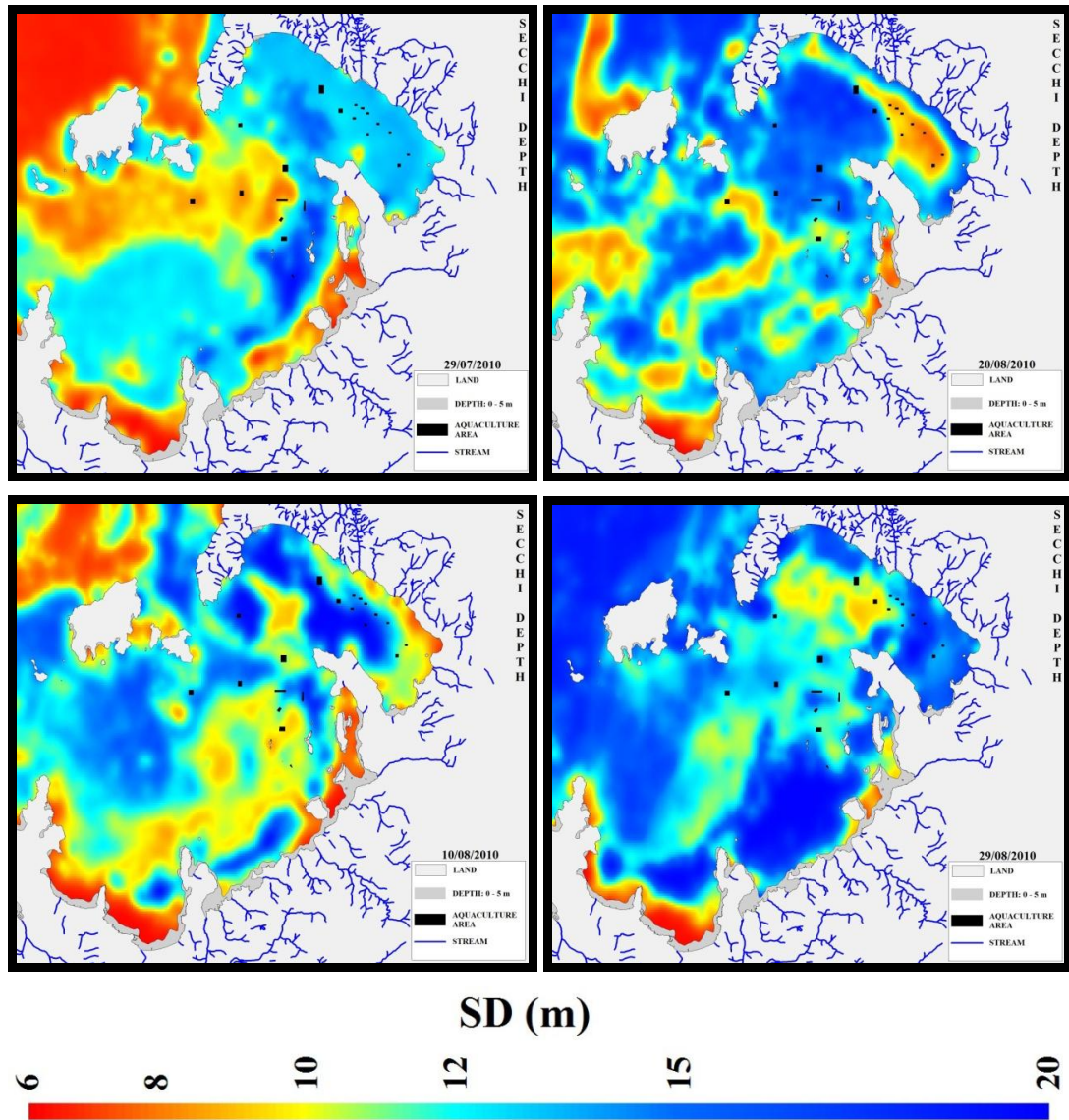


Figure 4.2 (continues)

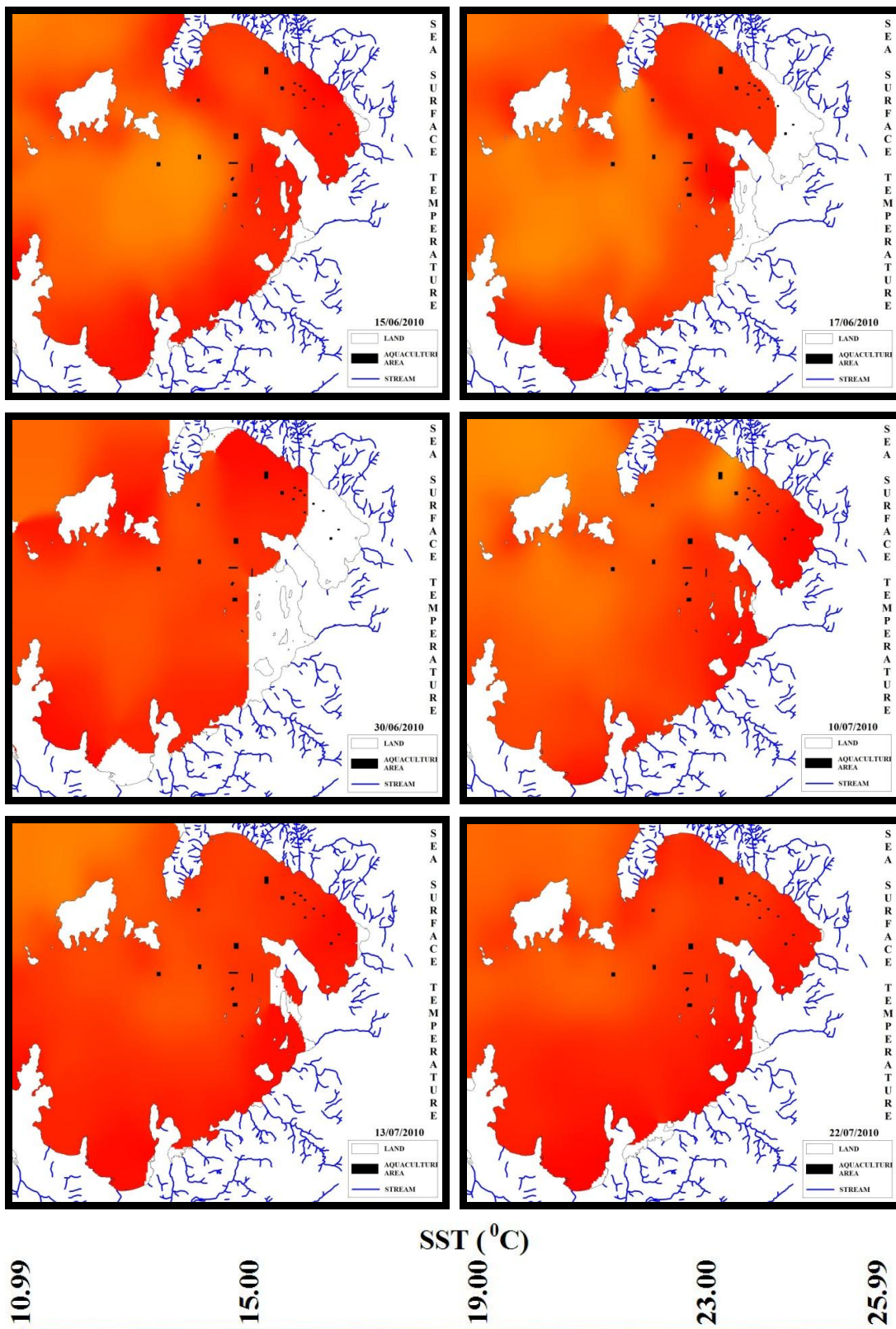


Figure 4.3 Sea surface temperature distribution of Ildırı Bay in summer 2010 from MODIS images

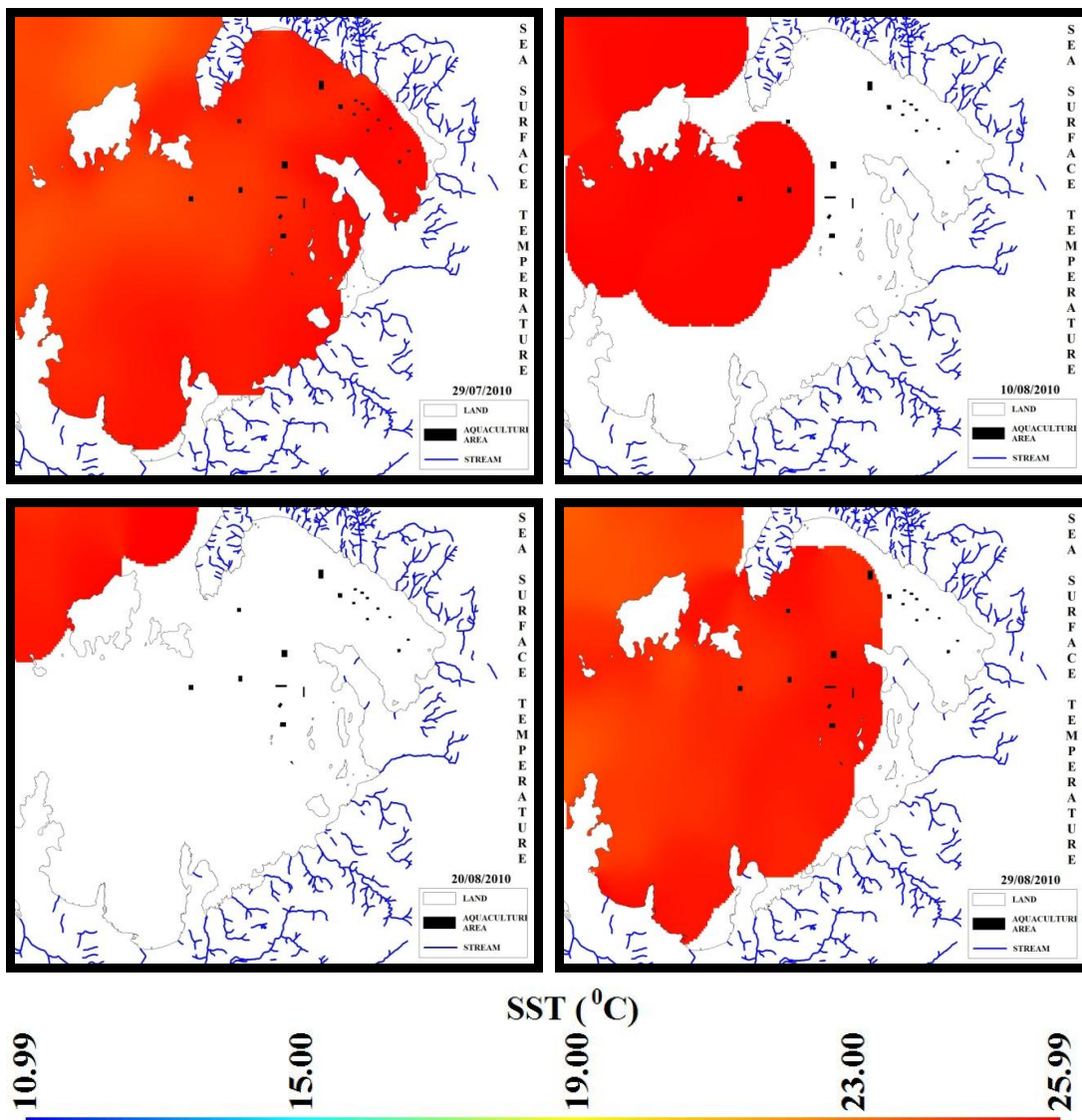


Figure 4.3 (continues)

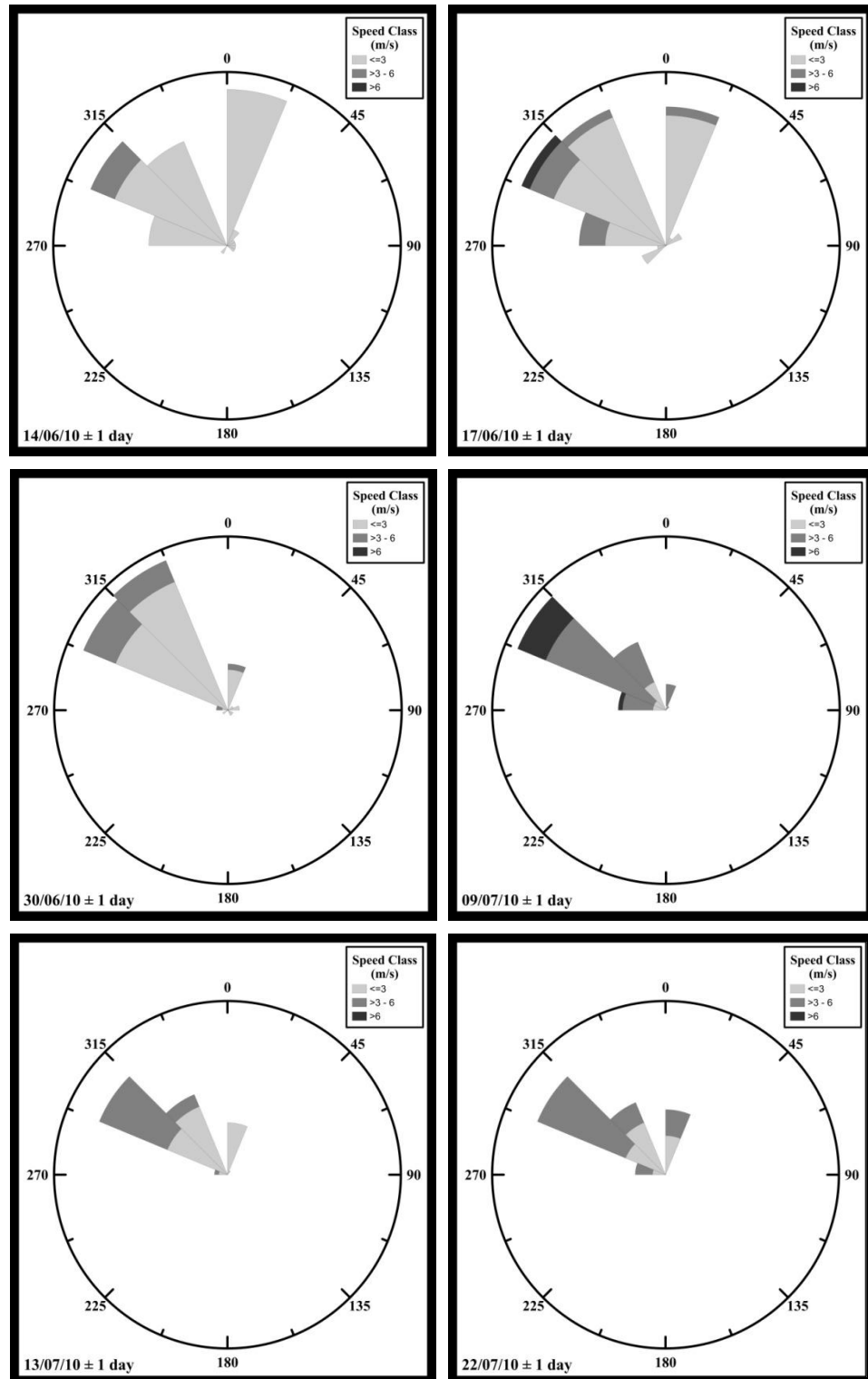


Figure 4.4 Wind chart of Ildırı Bay in sampling days of summer 2010

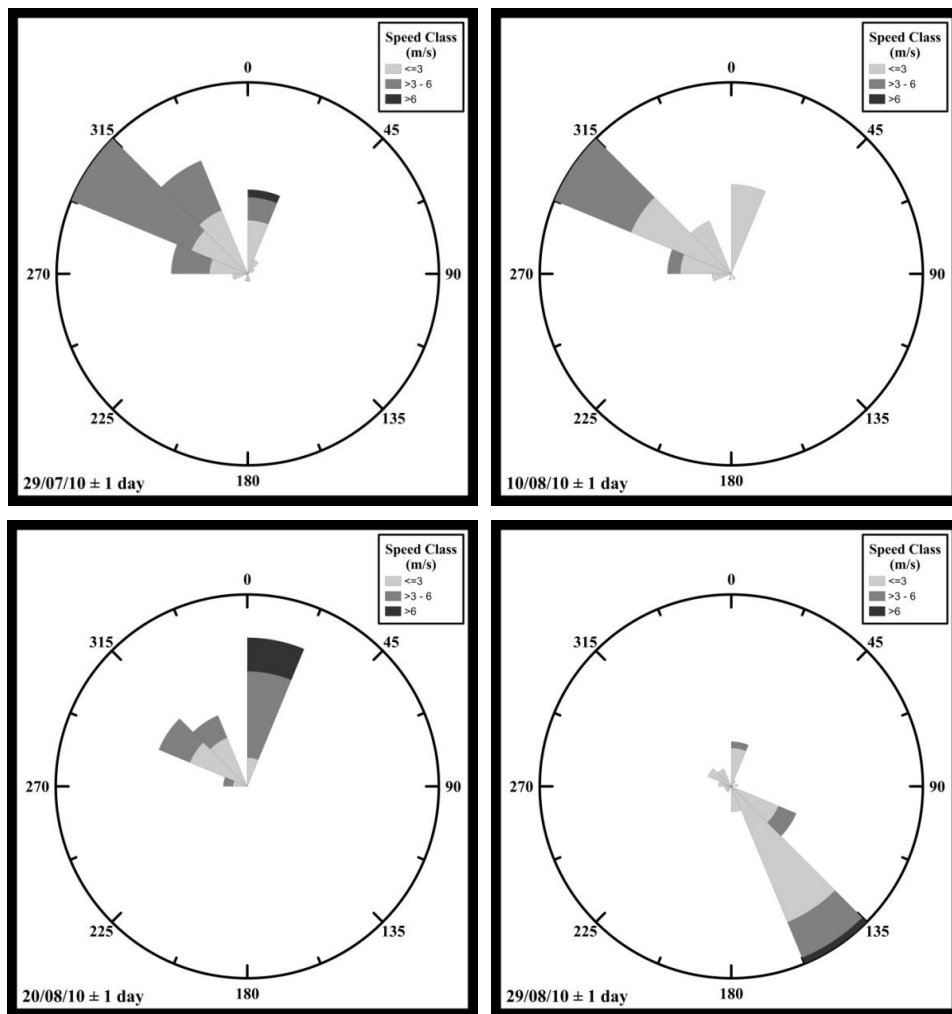


Figure 4.4 (continues)

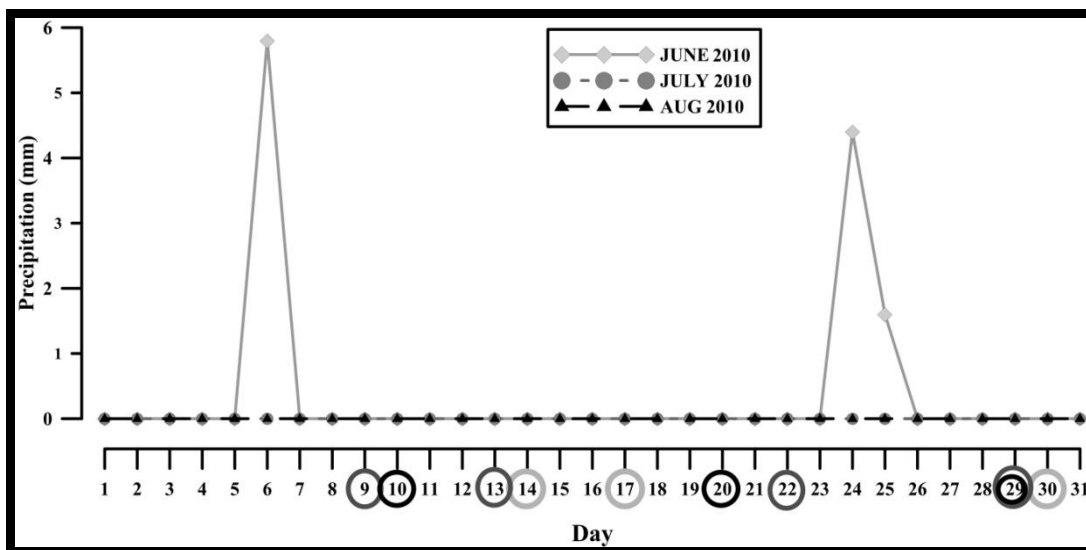


Figure 4.5 Precipitation of days in summer 2010

Season 5 - Autumn in 2010

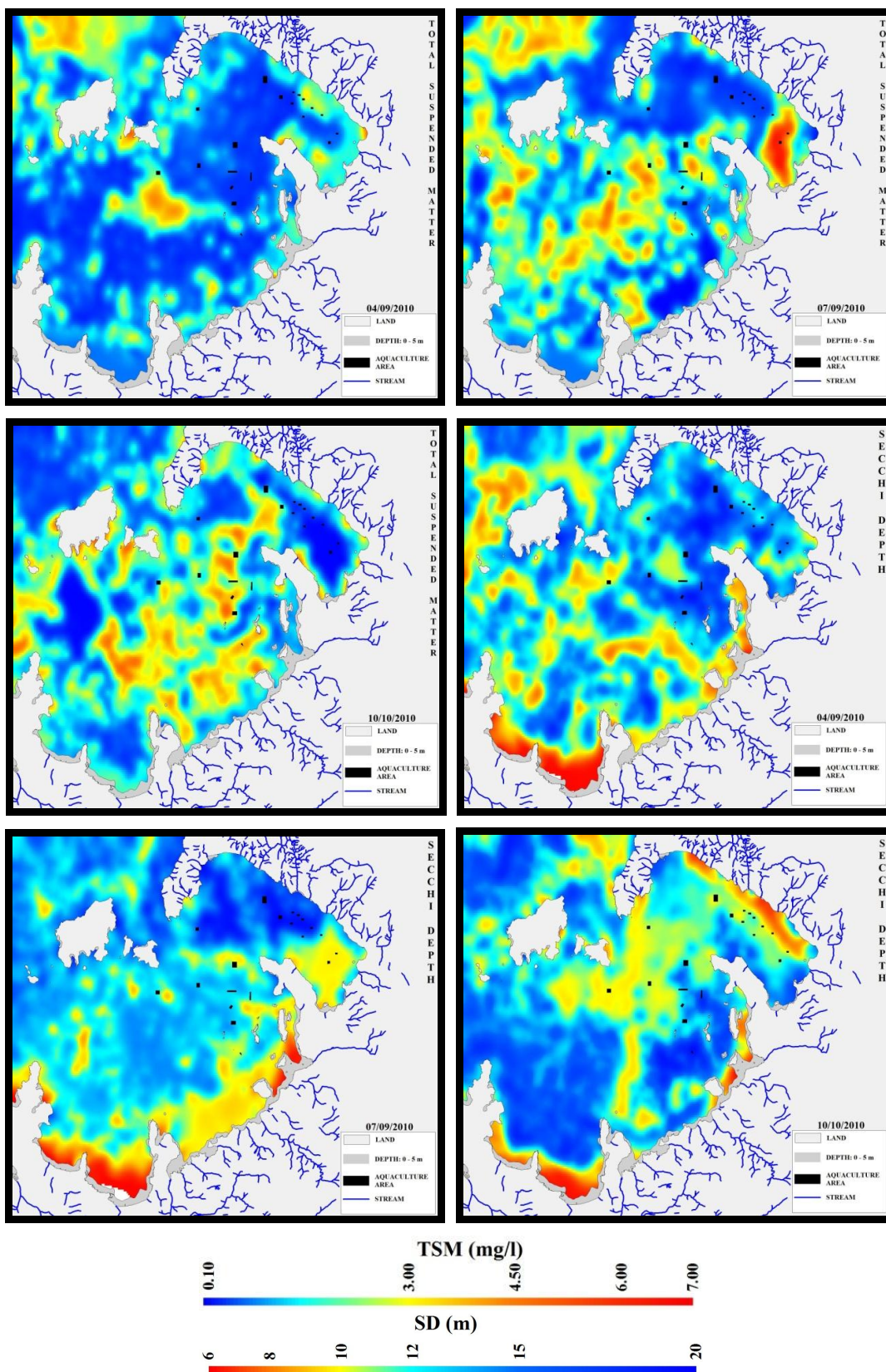


Figure 5.1. Total suspended matter and Secchi depth distribution of Ildırı Bay in autumn 2010 from MERIS images

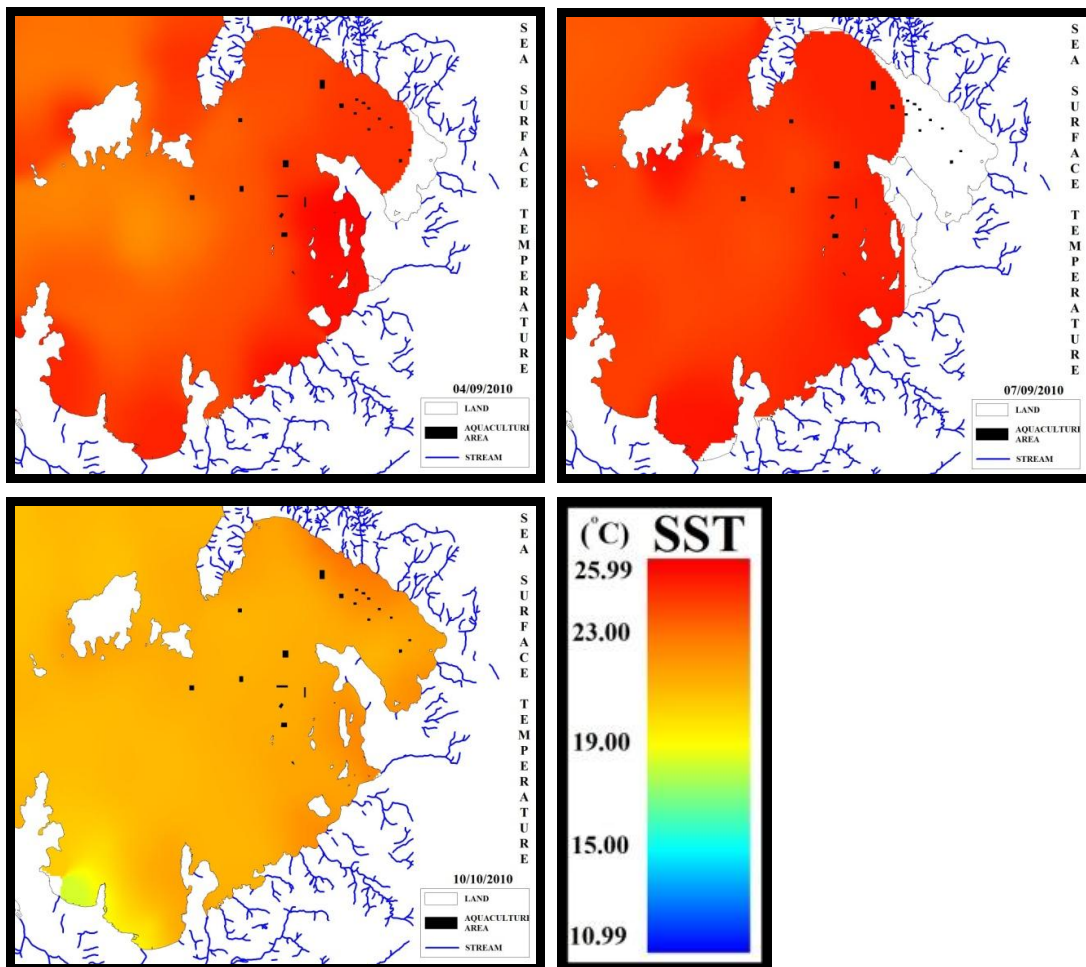


Figure 5.2 Sea surface temperature distribution of Ildırı Bay in autumn 2010 from MODIS images

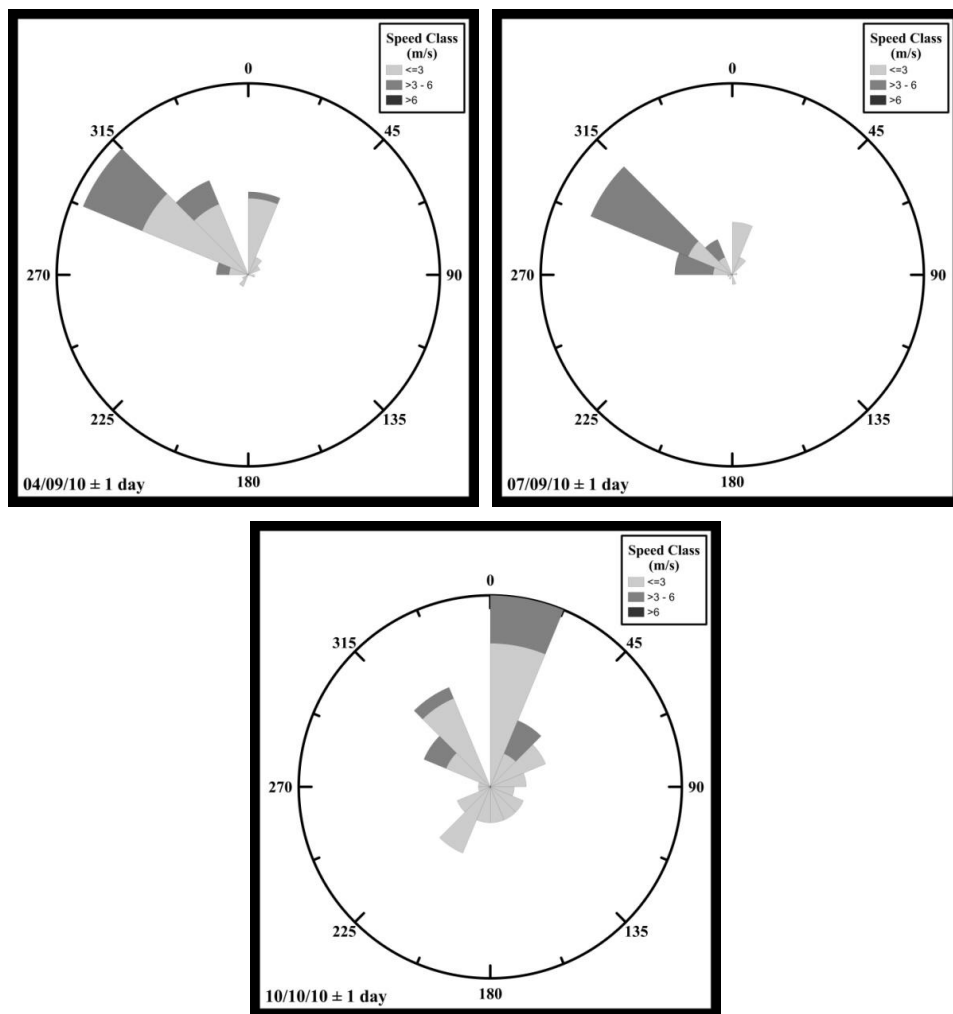


Figure 5.3 Wind chart of Ildırı Bay in sampling days of autumn 2010

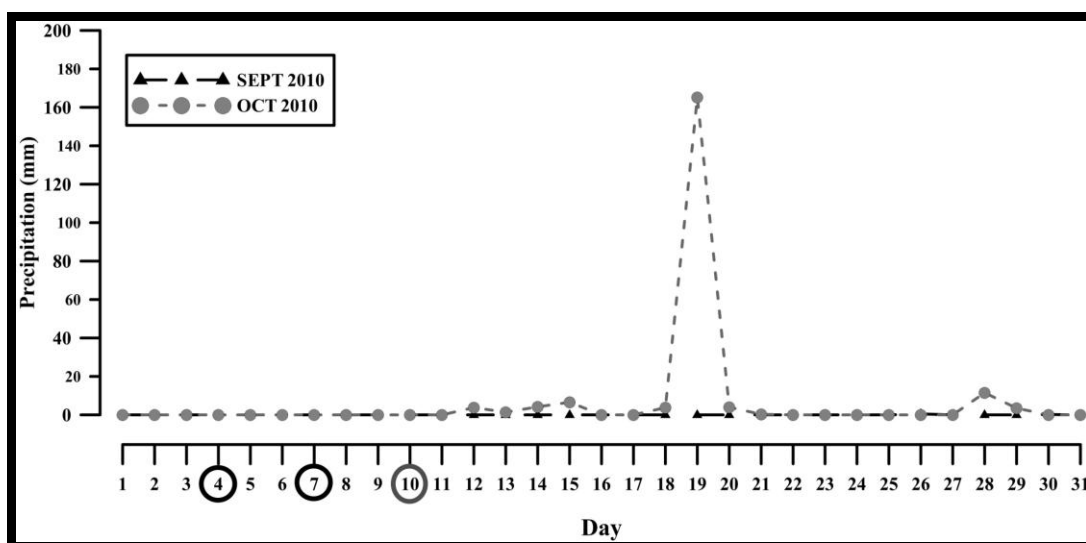


Figure 5.4 Precipitation of days in autumn 2010

Season 6 - Winter in 2011

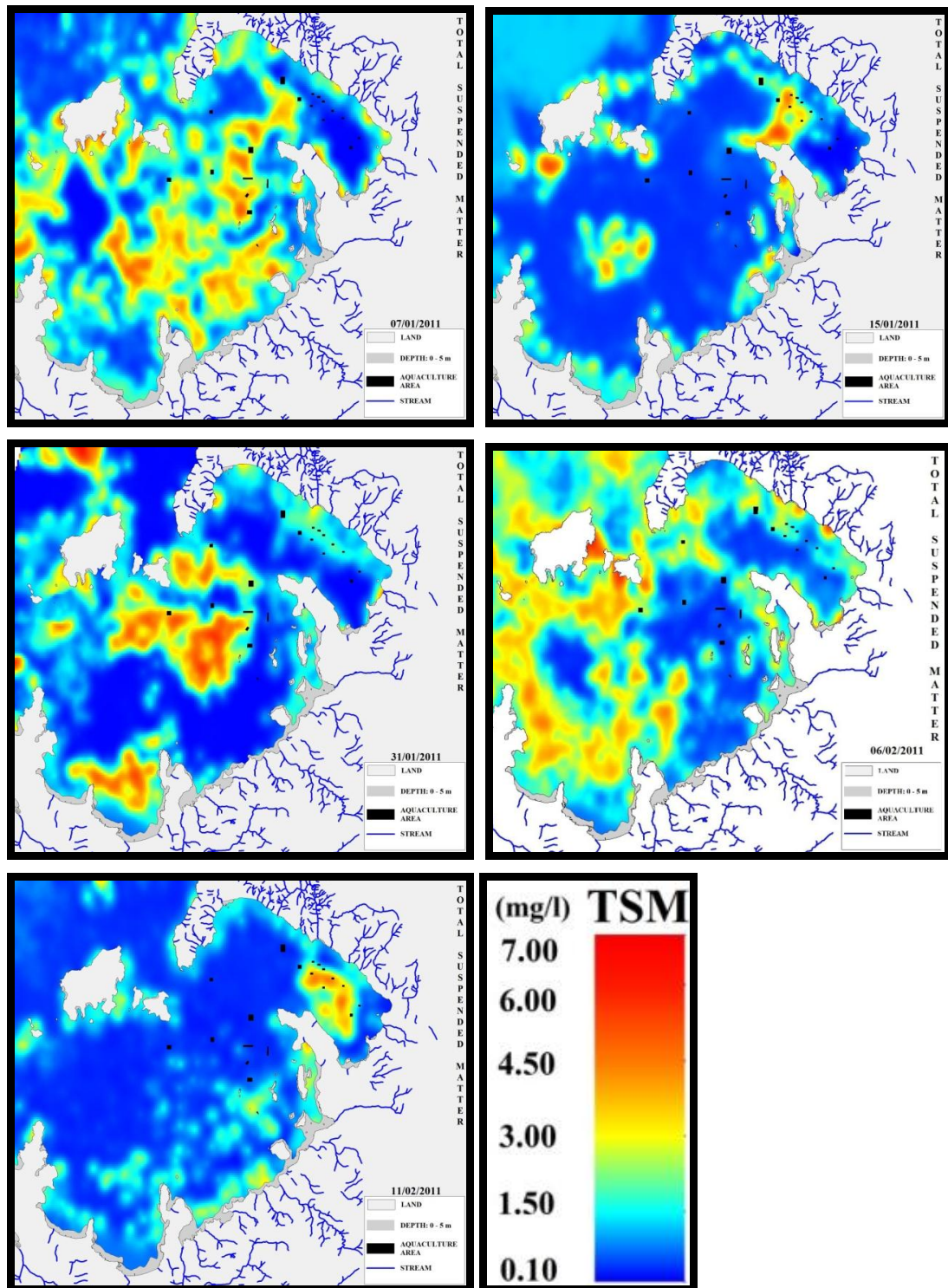


Figure 5.1 Total suspended matter distribution of Ildırı Bay in winter 2011 from MERIS images

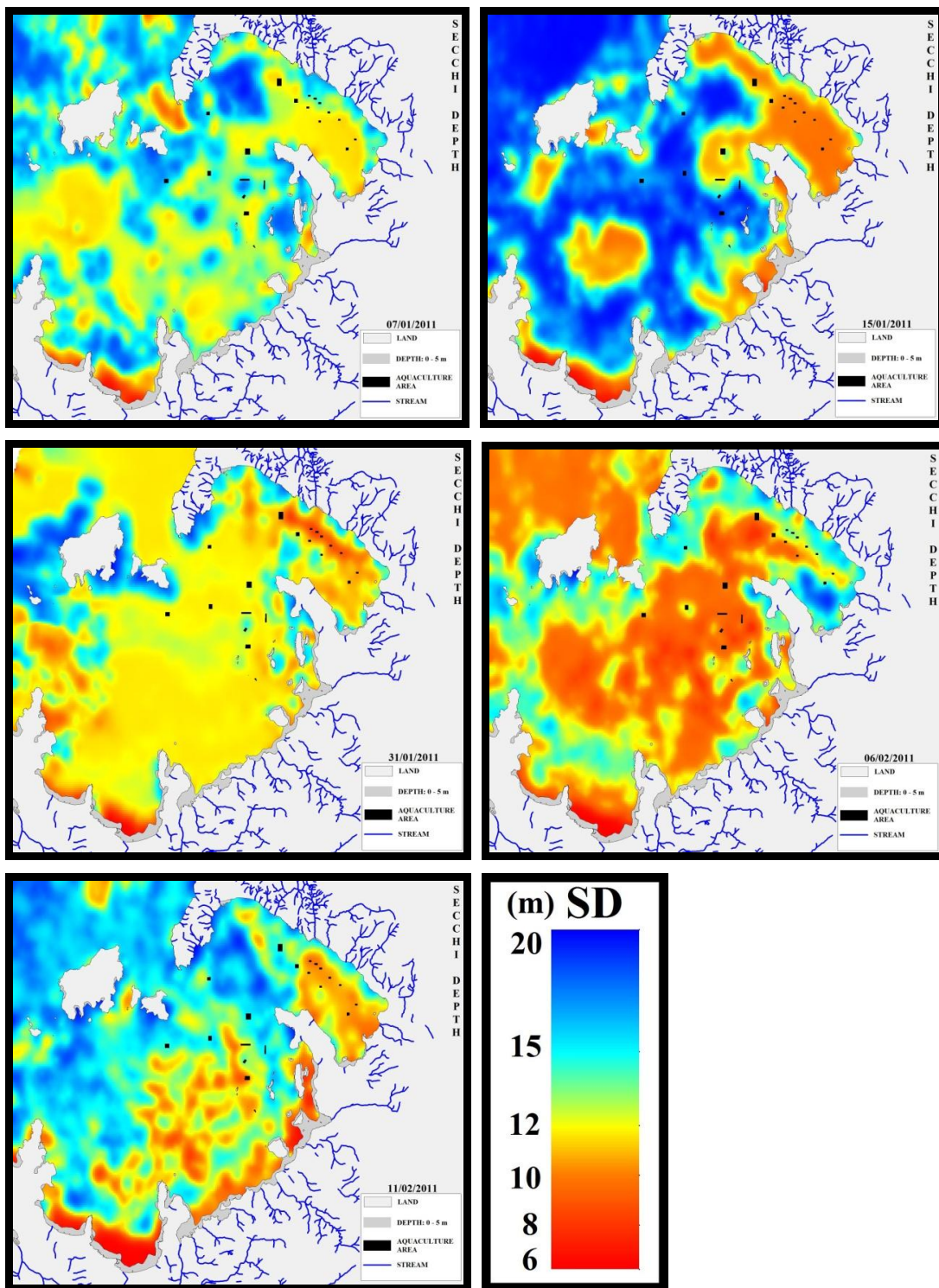


Figure 5.2 Secchi depth distribution of Ildırı Bay in winter 2011 from MERIS images

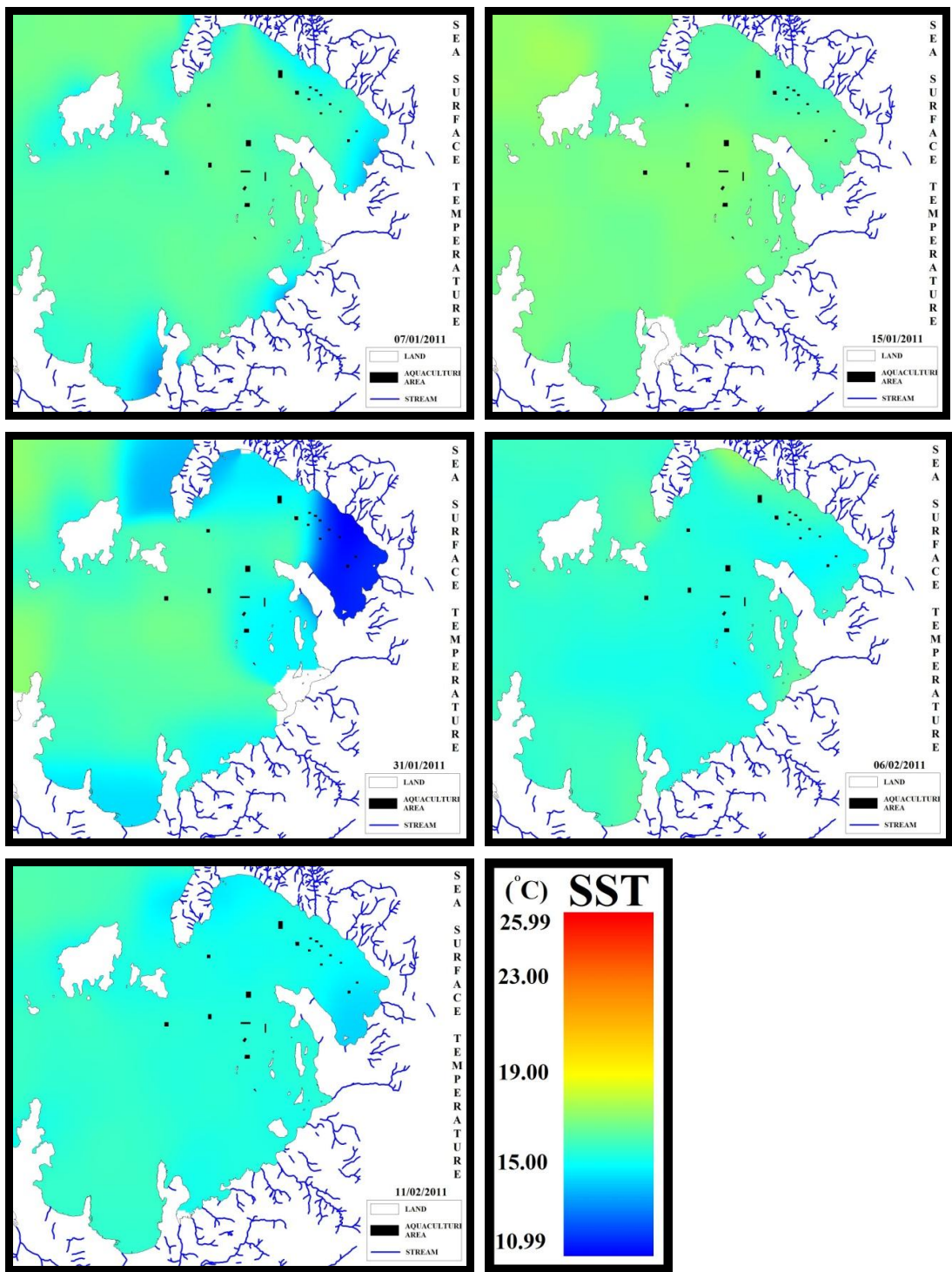


Figure 28. Sea surface temperature distribution of Ildırı Bay in winter 2011 from MODIS images

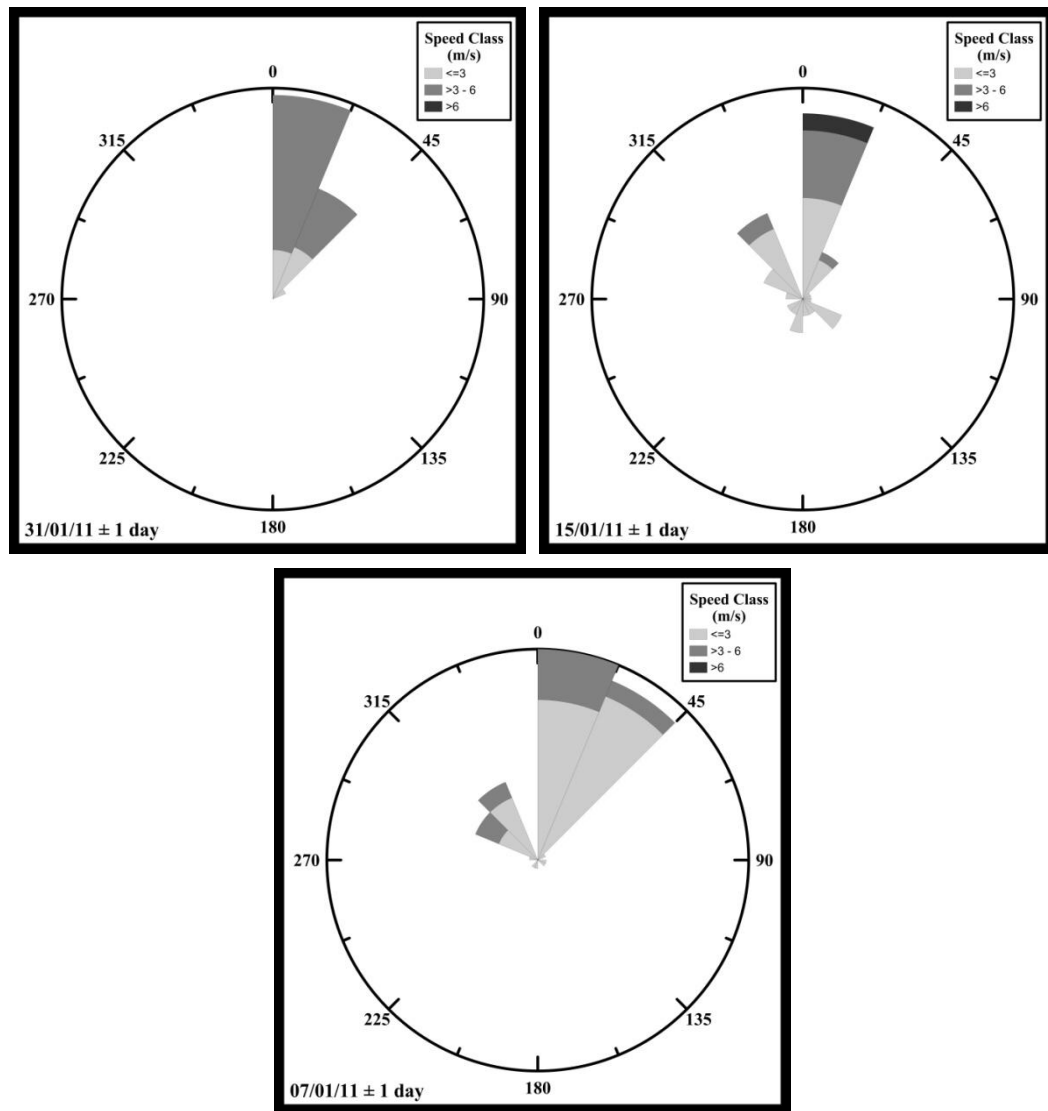


Figure 29. Wind chart of Ildırı Bay in sampling days of January 2011

APPENDIX 3 Relation plots between TSM and SD in sampling day

