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TITLE:

CLIMATOLOGY VIA APPLIED SATELLITE REMOTE SENSING

CHLOROPHYLL BLOOMS IN THE NORTH AEGEAN SEA

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“You must live in the present, launch yourself on every wave, find your eternity in each moment”

“What’s the use of a fine house if you haven’t got a tolerable planet to put it on?”

Henry David Thoreau, American Essayist, Poet and Philosopher, 1817-1862

“Life is the hesitation between an exclamation mark and a question mark. After doubt, there is a full stop”

Fernando António Nogueira de Saão Pessoa, Portuguese Poet, Writer, 1888-1935

Dedicated to those led a lonely path, either by clear choice or by lack of choices due to moral dispute.
Dreamers and visualizers of everyday living
Not too many, not too few.
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Declarations

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

STATEMENT 1
This dissertation is being submitted in partial and vital fulfillment of the requirements for the degree of Master of Science in “Environmental Oceanography”, Graduate program “Geosciences & Environment”, Faculty of Science, Department of Geology, University of Patras, Greece.

STATEMENT 2
This dissertation is the result of my own independent work and investigation, except where otherwise stated. Other sources are acknowledged by citations giving explicit references. References are appended.

STATEMENT 3
I hereby give consent for my dissertation, if accepted, to be available for photocopying and for inter-library loan, and for the title and abstract to be made available to outside organizations in retrospect of the judgment of my examining committee.

Georgakas Konstantinos
Oceanographer

Γεωργάκας Κώστας
Acknowledgements

First and foremost, I would like to thank my senior advisor Dr. Chronis Themistoklis, Senior Researcher in the Institute of Oceanography of the Hellenic Center for Marine Research and Researcher in the National Space Science and Technology Center, NASA-University of Alabama, Huntsville, USA, for his irreplaceable, open hearted, open minded assistance and feedback. During the past few months, and since 2008 when I first met his acquaintance, I am indebted to Dr. Chronis Themistoklis, as he supported and advised me without any hesitation and with pure academic and human values.

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Abstract

The current study focuses on the phenomenon, mostly accounted within the past recent time, of the algae blooms (chlorophyll burst) in the area of the North Aegean Sea. The study attempts to coincide and amplify the approach of Satellite Remote Sensing monitoring, as means of applied oceanographic methods, in order for possible seasonal, spatio-temporal trends of this phenomenon to be identified, thus making the correlation of the indices-variations, though interdisciplinary, to be explained to an extend plainly, in terms of ‘why’ and ‘why-then’ they occur.

The North Aegean Sea is directly influenced by the outflow of the Black Sea water masses, through the Dardanelles Strait. Secondary, riverine discharge is into account, along with special hydrodynamic characteristics of the basin. This Black Sea contribution to the North Aegean basin is cold, brackish and rather rich in biomass and nutrients and via the eutrophic blooms, fluctuate the relative meso-poor nutrient character of the basin.

The environmental impacts and causes of the occurrences have a multidisciplinary analysis. They affect local ecology systems, water quality, coastal regions, the ichthyo-stock, the eco-balance on food-dependable species and ultimately the human health. The current study leans emphasis on the meteorological-oceanographic analysis for the algae blooms in the North Aegean Sea, depending on the use of satellite derived data and optical color imaginary, concerning the area under study. The preliminary concern, along with secondary conclusions, among the variable instability of the local biogeochemical recycling of the phenomenon, the prolonged temporal time of its dispersion and its correlation with surface winds and meteo-characteristics, was verified.

Data from Giovanni, that is a Web-based application developed by the GES DISC (Goddard Earth Sciences Data and Information Services Center) Interactive Online Visualization ANd aNalysis Infrastructure-NASA, where used for the analysis, in order for possible correlations between oceanographic and meteorological variables to be identified, such as: Chlorophyll-a concentrations, Precipitations rates, Euphotic Zone Depth, Colored Dissolved Organic Matter, Absorption coefficient for phytoplankton, Sea Level Pressure, Surface Pressure and Northwards wind component.

Key words: Climatology, Satellite Remote Sensing, Sea-Air Interactions, Chlorophyll-a, Algae Blooms, North Aegean Sea, Oceanography
The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA’s Aqua satellite captured this image of a massive phytoplankton bloom off the Atlantic coast of Patagonia on December 21, 2010. Scientists used seven separate different spectral bands to highlight the differences in the plankton communities across this swath of ocean. This milky green and blue bloom developed on the continental shelf off of Patagonia, where warmer, saltier coastal waters and currents from the subtropics meet the colder, fresher waters flowing up from the south. Where these currents collide—known to oceanographers as a shelf-break front—turbulent eddies and swirls form, pulling nutrients up from the deep ocean. Also, the nearby Rio de la Plata runs off the land and deposits nitrogen and iron-laden sediment into the sea just north of the area shown in the image. Add in some strong summer sun, and you have a bountiful feast for the phytoplankton that form the base of the ocean food web. Phytoplankton become food for everything from microscopic animals (zooplankton) to fish to whales. Though it is impossible to say for sure without direct sampling of the water, most of the phytoplankton blooming in this image are coccolithophores, single-celled algae that form calcite scales. (Calcite is a carbonate mineral often found in limestone chalk.) Blooms of coccolithophores are common in these waters in southern hemisphere's spring and summer. Diatoms also form part of the mix of phytoplankton during this period.

(d). It is not always possible to identify the type of phytoplankton present using space based remote sensing. Coccolithophores, however, are a group of phytoplankton that are identifiable from space. These microscopic algae armor themselves with external plates of calcium carbonate. Called coccoliths (a ball of which is shown above magnified 13,000 times), these plates can give the ocean a milky white or turquoise appearance during intense blooms. A ball of coccolith plates surrounds each coccolithophore algae cell. Typically there is a single layer of about 10 coccoliths around the cell, but some but some cells accumulate multi-layered coccospores with hundreds of coccoliths. The long-term flux of coccoliths to the ocean floor is the main process responsible for the formation of chalk and limestone.

Figure 2. (a), (b) Bathymetry of the Aegean Basin and the main topographic-bathymetric plateaus. (Papathanassiu & Zenetos, 2005, State of the Hellenic Marine Environment). (c) Bathymetry map of the western section (plateau of Sporades island complex and the deep basin of the North Aegean Sea (Papanikolaou et al.-2002).

Figure 3. (a). Bathymetry map (m) indicating the main features (deep basins, rivers and the Dardanelles Strait) of the North Aegean Sea HYCOM model (NAS) domain. The solid white lines mark the 50 m, 500 m and 1000 m isobaths and the red stars the locations of the Poseidon System buoys. Four major North Aegean sub-areas are indicated with red squares. (b) Frequencies of the surface currents for nine sections, expressing the major North Aegean circulation patterns, for the period from April 2002 to December 2003. The northward, the southward, the westward and the eastward current directions are indicated with red, green, yellow and blue color, respectively. Note that the spots 1,2,5,6 have a southward direction, thus dispersing the blooms and river discharges downwards to central Aegean. Co-functioning with the 3,4,7 spots, they form an almost cyclonic overall flow, thus distributing the surface nutrient throughout the coastal areas of northern, towards central Greece and the islands of the North Aegean.


Figure 5. (1) Map of the mean annual frequencies speeds for the North Aegean Sea. The three circles of the histograms represents frequencies of 20,40, 60% respectively (from inner to out). The black bars indicate the direction, while the numbers in the center show the annual frequency (%). The numbers out of the circles histograms-rose grams indicate the mean annual speed of wind in knots. (Athanassoulis et. al.-2004) (2) Mean annual spatial distribution of α) wave height (m) and β) wind speed (m/sec) (Papathanassiu & Zenetos,-2005).

Georgakas Konstantinos. M.Sc. Environmental Oceanography Thesis. University of Patras, Faculty of Science, Department of Geology
Satellite display of the North Aegean Sea, where one can point out the drift and circulation of the income masses from the Dardanelles Strait, a significant fragment of its heads north of Limnos island (due to Coriolis effect) (Hatzikostantinou, Angelidis, Kotsosvinos, 2005).

(a) Generalized pattern of surface circulation of the sea masses in the North Aegean Sea (Zervakis et. al., 2005, Lykousis et. al., 2002) (b) Surface circulation (15m), during May 1997 in Thermaikos Gulf and the Sporades island complex (Kontoyannis et. al., 2003) (c) Typical profiles of temperature and salinity for Winter (left) and Summer (right), as recorded by the POEM project (Papathanassiou & Zenetos, 2005).

Average spectra aPH (thick solid line), aNP (dashed line) and aYS (dotted line) and aPH normalized to 443 nm (thin solid line, right ordinates scale); (b,d,f,h,j) Fraction of the total (minus water) absorption of PH (solid line), NP(dashed line) and YS (dotted line) (J.-F. Berthon et al., 2008).

The top image shows NASA Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) chlorophyll concentration in June 2005. Reds, yellows and oranges indicate higher chlorophyll concentrations, while blues and purples are lower concentrations. The middle image shows Aqua MODIS nighttime sea surface temperatures in June 2005. The green areas indicate higher temperatures. The bottom image is a map of the probability of potential M. leidyi presence in June 2005; colored regions indicate a higher probability that the ctenophore could be present. The map incorporates data on depth, temperature, and productivity (Siapatis, A., et al., 2008).

(a) Widespread algal bloom at Kavala bay (northern Greece), 2010 (b) Plankton Dead fish Kavala bay, 2010.


Seasonal Chlorophyll Concentration Climatology 2002-2012, from Aqua-MODIS (4km resolution)-focus on the North Aegean Basin. a. Autumn, b. Winter, c. Spring, d. Summer. Notice the dispersion of the higher concentrations, starting from Autumn and cascading onto the transitional of Winter to Spring and how it is increasingly distributed along the north coastal regions and the islands of the North Aegean Sea.

Chlorophyll-a concentration mm/m3 derived from SeaWiFS (9km resolution), Jul.1997-Dec.2010 (mission terminated). The first two peaks in early 2006 and early 2010 are displayed.

Chlorophyll-a concentration mm/m3 derived from MODIS-Aqua (4km resolution), Dec.2002-Jan.2013. The first two peaks in early 2006 and early 2010 are displayed and the one (the overall max.) in early 2012. The recorded from Nov. to end May period of ascending has a periodic character.

Updated (Lat-Lon-time averaged map plots) display of the seasonality for chlorophyll-a concentration per year, extending from 2003-2012. Easily, the season pattern of November to end of May of the spatio-distribution is outlined. It is also clear the peaks of 2006, 2010 and 2012 derived also from the aforementioned time series. MODIS-Aqua, 4km res. Dec.2002-Jan.2013.


Precipitation rate (mm/hr) time series, derived from TRMM L-3 V6 and V7 Inter-comparison. Dec.2002-Jan.2013.


1. Introduction - Motivation

As the base of the marine food chain, phytoplankton—microscopic single cell algae and bacteria that carry on photosynthesis—are important indicators of change in the oceans. These marine flora, in the process of photosynthesis, also extract carbon dioxide from the atmosphere, and as a result, they play an important role upon the balance of greenhouse gases that control global climate. Though incredibly small as individual cells, their vast numbers influence both the primary production of the oceans and consequently the world’s climate.

The overall eutrophic character of the basins of the Mediterranean, since they receive the waters and fertile material from large rivers and/or smaller water outfalls derived from agricultural and industrial activities, characterizes the complexity of the claims and trends of these phenomena.

The current study emphasizes on an even more distinctive environment of the meso-oligotrophic Aegean Sea (meso to higher values in the case of the North Aegean). Eutrophication when accounted triggers various physical and chemical changes in the marine environment and exerts a pressure on algal populations, allowing the intensive growth of certain harmful-toxin producing species or nuisance blooms that may create problems in the structure of the ecosystem and public health.

These blooms are collectively called Harmful Algal Blooms (HABs) by mainly dinoflagellates, but evidence has been provided for several species of other taxa (diatoms, flagellates, cyanobacteria, prymnesiophytes, raphidophytes), suggesting that they belong in this category. Certain algae, 16 out of 61, (Ignatiadis&Gotsis, 2010) were associated with the occurrence of important HAB incidents, causing damage in the marine biota and the water quality in North Aegean/ South Aegean/ Ionian Sea, from data analysis encompassing 1977-2008. There is a strong indication that these incidents were eutrophication-induced phenomena, but sporadic in time-space and recurrence of the causative species.

There are extensive studies since the early 70’s upon this issue, other emphasizing directly onto the biological statistics, species categorization and monitoring, other in the recent years trying to emphasize the multi-structural analysis of causes on geo-bio-chemical basis and the current modeling groups of spatio-temporal trend analysis, by remote sensing and optical techniques.

Remote sensing involves the use of instruments or sensors to "capture" the spectral and spatial relations of objects and materials observable at a distance—typically from above. An aerial photograph is a common example of a remotely sensed (by camera and film) product. Phytoplankton blooms that occur near the surface are readily visible from space, enabling a global estimation of the presence of chlorophyll and other pigments using satellite images. The images are mainly taken by either NASA's Moderate resolution Imaging Spectroradiometer (MODIS) aboard the Terra or Aqua space crafts, or the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) aboard the OrbView-2 satellite. SeaWiFS was launched August 1, 1997 (ended December 2010), the Terra satellite December 18, 1999, and Aqua May 4, 2002.

The initiative for this study, in the moderate advance of a M.Sc. dissertation, will effort to advance the recordings of such indices in the North Aegean Sea, in retrospect these have held sudden trend appearance in the area overlapping time-space analysis, trying to state the tendencies of these phenomena and the correlation between main oceanographic-meteorological variables.
Emphasis is held on the climatic meteorological characteristics that rolled out a main role in the blooms outcome, thus introducing a new integration of approach. After all, (Van Mol1, et. al.,-2007) in the case of Noctiluca scintillans-red tide algae blooms in the sea of Marmama, Turkey, suggested that even the species detection by remote sensing is possible, if the concentration is sufficiently high and if the spatial resolution of the sensor is fine enough to resolve patches.

These phytoplankton blooms, have not only aesthetic value for the tourists and permanent population. These indices have decadal mean of (1960-2009) simulated chlorophyll values, between the first and the last decade respectively, the lowest and the highest value found, with the difference being significant (Garcia-Gorriz&Stips,-2011). This has an essential consequent meaning for a semi-closed basin such as the North Aegean Sea, further on displaying a more of a key role onto the local ecosystem, for possible toxicity, for the natural ichthyo-stock, even for the implicit role of plain ship trafficking.

This implicit role of ship trafficking, could be a path that may lead (or already led) to alien fixation of natural flora inhabitants, thus reducing the eco special habitation of higher food chain members, since toxic but and of higher concentration algae, could stuck onto passing ship bottoms, functioning as phyto-flora alien species. Imagine in this way, the bottom-up analog phenomenon of Lessepsian migrants that is recorded in the Suez Canal, appearing in the North Aegean, with lead-role of the nutrient-enrichment Dardanelles Strait. Finally, since they occur more and more suddenly and often, algae blooms, can be one of the key variables of investigation for regional and globalized climate –fluctuation-alternation trends.

Some examples that triggered the motivation:

![Fig.1](a). On April 15, 2006, after weeks of snowmelt and rain the Danube River reached its highest level in 111 years flooding parts of Romania, Bulgaria, Hungary and Serbia. This June 10, 2006, MODIS/Aqua image shows the entire Black Sea covered with intense phytoplankton blooms following almost two months of heavy run-off.
(b). Peacock in color, but more reminiscent of a mighty dragon's head, the swirls of blue and green iridescent phytoplankton in this image make it hard to imagine they are formed by countless tiny organisms that grow explosively from Iceland to the shores of France.

(c). Off the coast of Argentina, two strong ocean currents stirred up a colorful brew of floating nutrients and microscopic plant life just in time for the summer solstice. The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA’s Aqua satellite captured this image of a massive phytoplankton bloom off the Atlantic coast of Patagonia on December 21, 2010. Scientists used seven separate spectral bands to highlight the differences in the plankton communities across this swath of ocean. This milky green and blue bloom developed on the continental shelf off of Patagonia, where warmer, saltier coastal waters and currents from the subtropics meet the colder, fresher waters flowing up from the south. Where these currents collide—known to oceanographers as a shelf-break front—turbulent eddies and swirls form, pulling nutrients up from the deep ocean. Also, the nearby Rio de la Plata runs off the land and deposits nitrogen and iron-laden sediment into the sea just north of the area shown in the image. Add in some strong summer sun, and you have a bountiful feast for the phytoplankton that forms the base of the ocean food web. Phytoplankton becomes food for everything from microscopic animals (zooplankton) to fish to whales. Though it is impossible to say for sure without direct sampling of the water, most of the phytoplankton blooming in this image are coccolithophores, single-celled algae that form calcite scales. (Calcite is a carbonate mineral often found in limestone chalk.) Blooms of coccolithophores are common in these waters in southern hemisphere's spring and summer. Diatoms also form part of the mix of phytoplankton during this period (Garcia, V.M.T., et. al.-2008; Painter, S.C., et. al., -2010).

(d). It is not always possible to identify the type of phytoplankton present using space based remote sensing. Coccolithophores, however, are a group of phytoplankton that is identifiable from space. These microscopic algae armor themselves with external plates of calcium carbonate called coccoliths (a ball of which is shown above magnified 13,000 times). These plates can give the ocean a milky white or turquoise appearance during intense blooms. A ball of coccolith plates surrounds each coccolithophore algae cell. Typically there is a single layer of about 10 coccoliths around the cell, but some cells accumulate multi-layered coccospheres with hundreds of coccoliths. The long-term flux of coccoliths to the ocean floor is the main process responsible for the formation of chalk and limestone.
2. Area Under Study

2.1. Overview

The Aegean Sea is a Pelagos that functions as part of the Mediterranean Basin. The basin stands as the 1% of the global sea budget and its near shoreline population is around 82 million, with the prospect of reaching by 2025 the amount of 150-170 million. Thus, the Aegean Sea is a sea of $7.4 \times 10^4$ km$^3$ and is the third in terms of spatial advance sea of the Eastern Mediterranean (after the Ionian Sea and the Sea of Levantine) of 240,000 km$^2$. It is characterized by its complex shoreline and the existence of moreover of 2000 small and larger islands.

The intense submerged sea portrait of the Aegean Sea, that includes an extensive continental ridge between Thermaikos Gulf, island of Samothraki and the island of Limnos, but furthermore, deep sea basins, as the North Aegean Sea Basin (max depth of 1600m) and the Chios island Basin (max depth 1160m), is with no doubt a most interesting terra nova for scientific study.

The North Aegean Sea (as subpart of the Aegean Sea) neighbors the overall Mediterranean basin via the Rhode island-Turkey and Peloponnisis-Kythera island aqua-entrances (NE and NW of Crete island, respectively).

The meteorological conditions of the Mediterranean (respectively with the localized ones in the north section of the Aegean Sea), are shaped by the overall climatological (in long-time term) and the annual, seasonal (in short-time term) conditions, which are in immediate correlation with the continental meteorological trends. These trends seem to withhold a most important role in the transitional profile of the sum of the meteorological indices, ending up and recycling to and from the sea.

This takes lead in understanding the main and secondary topographic regions that constitute the overall mosaic of the Aegean and the North Aegean Sea. These regions are:

North Section. Sub-basin of the Mount Athos (max dept 1100m) with the sub regions of the continental self of Thermaikos Gulf and island of Samothraki.

Sub-basin of island Limnos (max depth 1611m).

Sub-basin of North Sporades island complex (max depth) 1500m.

Moving southern. Sub-basin of Chios island (local depth spot of 370m) with sub regions of the eastern part of the North Evia (deep sea basin of 1044m), northern basin of Skyros island (max depth 1018m), southern basin of Skyros island (max depth 1000m), Lesvos island basin (max depth 734m), North and South basins of Ikaria Island (1168m, 643m, respectively), short shelf of Limnos, Chios and Cyclades complex islands and extended ones of Lesvos, Chios, Samos, Ikaria islands.

South. Sub-basin of the Cretan pelagos (max depth 2500m)
Fig. 2. (a), (b) Bathymetry of the Aegean Basin and the main topographic-bathymetric plateaus. (Papathanassiou & Zenetos, 2005). (c) Bathymetry map of the western section (plateau of Sporades island complex and the deep basin of the North Aegean Sea (Papanikolaou et al., 2002).
2.2. Characteristics of the Aegean Sea and distinctive ones in the North Aegean Sea

North Aegean Sea, in synopsis, is constituted by:

1. The deep sea basin of the North Aegean (max 1500m) with the area of the Sporades island complex and the continental shelf of Thrace (max depth 1000m).
2. The Chios basin (max depth 1100m).
3. The continental shelf of Cyclades islands complex (functioning as the south frontier of the northern section (max depth 200m)), with the shallowest regions of Samothraki island and Thermaikos Gulf. (Lykousis, et.al.-2002).

The North Aegean Sea is surrounded by the east, as line of Asia Minor, by the north of the east Macedonia and Thrace, by the western of the east shoreline of central Greece and finally southern frontier the fictitious line between Chios-Skyros islands, (Sotiropoulou, P.-2004).

Fig.3. (a) Bathymetry map (m) indicating the main features (deep basins, rivers, islands and the Dardanelles Strait) of the North Aegean Sea HYCOM model (NAS) domain. The solid white lines mark the 50 m, 500 m and 1000 m isobaths and the red stars the locations of the Poseidon System buoys. Four major North Aegean sub-areas are indicated with red squares (Androulidakis, et.al-2012)

(b) Frequencies of the surface currents (essential for the dispersion of blooms) for nine sections, expressing the major North Aegean circulation patterns, for the period from April 2002 to December 2003. The northward, the southward, the westward and the eastward current directions are indicated with red, green, yellow and blue color, respectively (Androulidakis, et.al-2012). Note that the spots 1,2,5,6 have a southward direction, thus dispersing the blooms and river discharges downwards to central Aegean. Co-functioning with the 3,4,7 spots, they form an almost cyclonic overall flow, thus distributing the surface nutrient throughout the coastal areas of northern, towards central Greece and the islands of the North Aegean.

The climatological conditions presented in the Greek geospatial territory between the 34th and 42nd N. Latitude are time-space altered in terms of North to South orientation. In general, the climate is characterized as sub-tropical Mediterranean, meaning calm rainy winters, especially in November-March, with warm and dry summers, especially between May-September. October and April have a more of a transitional character. The localized differentiations as of vertical analysis, where the dry climate of Attiki and the eastern Greece turns into the humid profile of North and western Greece, are explained mainly by the fact that the Greek territory is one of the few worldwide examples with such distinctive “micro-climatic” differential (Flokas, A.,-1997).
2.3. Climatic, Meteorological and Oceanographic characteristics in the North Aegean Sea

The main characteristics (precipitation, temperature, wind, humidity and sea circulation) in the area of the North Aegean Sea are:

1. The rain height measured declines with the vertical north to south profile with min. values over the Cyclades island complex (310 millimeters). Average annual value of 500 mm/yr and the overall precipitation-vaporization in 1460 mm/yr (Kallos, G.-1988).

2. The annual average temperature increases as topographical vertical north to south profile, with values between 16-19.5°C. Min. values in February (up to -25°C) and max. values at the second half of July (up to 45°C). Regionally, warmer areas are the northwester and southwester, which are and the ones least influenced by the summer winds Etisie (northerlies). The North Aegean Sea is, in comparison, a relatively cold area. The temperature profile is finalized as in two main temporal, the cold season, with January and February as the coldest (min. values of 5–10°C near shore, 0–5°C in inner continent), and the warmer season, where Spring short lasts and summer starts early, in respect of long time series that refer to the area.

3. Main wind profile is the north, with frequencies and speed higher in winter as expected. At summer time, wind speeds of over 7 Beaufort (known as Etisie) are met. Winds that reduce the overall moisture and contribute positively in the general sea surface circulation. In retrospect, winter prevailing winds have a polar and arctic relevance, coming into the system via the ‘Bardaris’ zone (near river Axios, in northern Greece), having a significant role in the North Aegean as down-hilling between rivers Nestos, Strymonas and Axios, finally out bursting in the north basin (Kallos, G.-1988).

4. The annual relative humidity stands between 65%–75%.

5. The overall hydrological circulation is cyclonic (counter-clockwise) on the surface sea layers, with significant wind contribution, as and with temporal turbulent formations (Georgopoulos, D.-2002). The water masses budget is positive (+1.0 m/yr). The incoming fresh masses replace the 20% of the deep basin ones, following the overall east Mediterranean values. The currents in depths lower than 100 m have less intensity than the ones of deeper layers. The main topographic spots are the Dardanelles strait and at the southern, the Cretan Arc stream. The cold brackish masses from the Black Sea via the Dardanelles Strait, with western and then northern direction, follow the Limnos-Imvros island path, where they mingle with the warm and saline water of the Levantine Sea and reach Limnos island, with parallel southern to this point on further move. Skyros island represents often an anti-cyclonic (clockwise) turbulent flow, from the northern Sporades complex to the Thermaikos Gulf. East of Samothraki island, we meet a main contributing anti-cyclonic flow, but further smaller ones are met in inner spots of the North Aegean Basin. Deeper layers stand out of the flow-mechanic aforementioned rule, in terms of forced sub-sea terrestrial “roads” where mass-current speeds come out up to 50 m/s. Additionally, in the North Aegean Sea river-water masses outflow (rivers of Evros, Nestos, Strymonas) in the plateau of Samothraki island, (rivers Axios, Gallikos, Pinios, Aliakmonas) outflow in the plateau of Thermaikos Gulf, (Sperchios river) outflows in the northern Gulf of Evia. These are accompanied by Turkish river flows such as Karamenderes-Dardanelles strait, Bakirkay outflows in the area of Mytilene island, Bujuk Menderes outflows in the Samos island area, Geniz Nehri outflows in the Smyrni Gulf. River discharge masses stand up to the 7% (20,43 km³/yr) of the Dardanelles Strait contribution, but have a significant nutrient and organic positive verification (Georgopoulos, D.-2002).
Fig. 4 Rivers discharge continental delta formations in the Aegean. 1: Sperchios river, 2: Pinios river, 3: Aliakmonas river, 4: Axios river, 5: Strymonas river, 6: Nestos river, 7: Evros area, (Meric river) 8: Karamenderes river, 9: Bakircay river, 10: Gediz river, 11: Kujuk Menderes river, 12: Buyuk Menderes river (Poulos & Chronis, 1997).
2.4. Sea-Air interactions in the North Aegean Sea

In the North Aegean Sea, N-NE components of wind are dominantly met, within the whole annual period. These winds are accompanied by mean annual frequencies of 18%-38% (Athanasoulis et.al.-2004). The relative smaller annual frequency of 7%-20%, is met within the southern wind components. Often, there comes a kind of random direction fluctuation of 6-16%.

The larger annual frequencies (35-38%) of winds blowing from northern directions, within the whole area of the North Aegean Sea, are located between the area of Skyros and Chios islands. Their speed comes up to 16knots (1Knot=1m/s=1 Beaufort=2 Km/h=1mile/h). In the same area there is also a significant from southern directions of frequencies up to 20% and mean annual speed of 14knots.

Over the Thracian Pelagos, NE direction of winds are dominantly met, with annual frequency of 25-30% and wind speed reaching 17 knots, around the area south of Evros delta. These are dry-cold winds of great stability, which are mostly known as “Etisie”, blowing mostly from May until October (Poulos et al., 1997).

East at the area near Limnos islands, there are northerlies predominant, with frequencies of 26% and speeds of 15knots. In the same area, often 20% are and the NE, of speeds near 17knots. Westerly, in the area of of Halkidiki, dominant winds are northerlies (‘Bardaris’ called) of frequencies over 20%. Northerlies dominate and in the area of the plateau of Sporades island complex, with large wind speeds profile of 14knots and frequencies of 18%. Even more predominant, in the same area, are the NE wind compound directions of mean speeds of 14knots and frequencies of over 20%.

It’s obvious from the aforementioned that the mean wave profile is determined by this wind profile, something that makes its distinguishing a complex procedure. Predominant winds are northerlies followed by the southerlies, and the western and eastern ones having a much lower frequency profile. During summer “Etisie” are a wind pattern of large scale and of spatio-open sea climax, that are coming from the north and their effect on wind profile is obvious, especially during July and August. By the end of Autumn, these winds are reduced and the Aegean Sea is under the influence of rapid-rough pressure low storms. Relatively calm periods of wind-wave state are mostly ones of September and October, with the last one being a more of a transitional month, as from November until February the wind stake becomes more intense.

To conclude, as far as the wave stake of the North Aegean Sea, wind-waves (thus and in the results chapter there has been an emphasis on the southern wind profiling phenomena, in retrospect with their correlation towards the chl-a peaks. Profiles that are predominant to the transportation of algae blooms to the northern Greece’s coastline - as winds are the predominant factor for the surface masses dynamics-, of mean height 0.6-1.5 m, coming mostly from northern and northeastern directions of annual frequencies up to 30%. Similar mean wave heights are met (0.5-1.7m), which come from southern directions, of frequencies up to 18%. In addition to the relative prolonged state of their appearances (the southerlies) and the alternating profile they present, in retrospect of their indices met with rough storms, high precipitation rates and with higher frequencies, met mostly within the last 15 years, along also with their relative lower overall frequency profile (as far as northern ones are considered) and their significance on the effects (especially on the northern Greek shoreline) (Georgakas, K.,-2012), these southern winds, as we will see and in the data analysis chapter, play a most interesting role and onto spatio-temporal dispersion of the algae blooms in the North Aegean Sea.
In times of strong winds (mostly between April-September), the wave height of wind-wave induced spectra, could as in means of extreme event, reach over 4m (with a relative low frequency of 0.1-1%) due to the northern winds met. When these winds of 18-20knots are met, waves of large heights are met also of northern and southern directions in the area of Skyros Island, St. Eftstratos and Sporades island complex (although with bellow 7% frequency). Respectively, similar wave heights are met when southerlies blowing, with frequencies 22% and speed of 15-17knots, during mostly February until March (the predominant main period also for the algae blooms, as indicated and in the results chapter in accordance to the map lat-lon. time averaged maps, displayed per season/year and annual climatologically).

Fig 5 (1) Map of the mean annual frequencies speeds for the North Aegean Sea. The three circles of the histograms represents frequencies of 20, 40, 60% respectively (from inner to out). The black bars indicate the direction, while the numbers in the center show the annual frequency (%). The numbers out of the circles histograms-rose grams indicate the mean annual speed of wind in knots. (Athanassoulis et. al.-2004)

(2) Mean annual spatial distribution of a) wave height (m) and b) wind speed (m/sec) (Papathanassiou&Zenetos,- 2005).
2.5. Hydrological circulation of sea masses in the North Aegean Sea

The hydrological circulation in the area is a complex and rather differential procedure to analyze. This, due to the spatial distribution of island spots and complexes, the rather irregular topography of the sea bottom, deep water masses formation, the seasonality and attenuation of the hydrological factors and/or of atmospherically indicators, the presence of different masses, the outflows from the Black Sea, the presence of intense meteorological phenomena etc. that can change the regional profiles of circulation.

Atmospheric constitutes as well as the spatial and temporal differential they present, play a significant role upon the definition of the coastal areas in terms of e.g. where sea level raises, something directly influenced by annual winds.

The surface circulation of sea masses is mainly influenced by low salinity masses incoming from the Black Sea. Winds constitute on the sea level rise up, along the western coastal regions and the islands of East Aegean. During Summer, this cold brackish masses appears in the area, from the southern frontier of Rhodos island up to Limnos island plateau. During winter, the warmer masses, which originate from the southern, expand on the same area, while cold masses via Dardanelles Straight, expand to Samothraki island.

The circulation of these surface masses is in general cyclonic (counter-clockwise), due to mainly the income of masses from the southeastern straights of the Aegean, which originate from the Sea of Levantine in the East Mediterranean. These masses as incoming, move towards north along the eastern coastal zone transported by the draft of Asia Minor (Theocharis et. al.,-1993) and then move western to outcome finally towards the south via the Crete-Kythera island complex.

Nevertheless, the regional dynamic specific characteristics are cyclonic and anti-cyclonic turbulent flows of medium scale range. The spatial-time differential of these is not yet fully known. Some of these appear to be permanent (e.g. the cyclonic turbulence of the plateau south of Chios island), while others have a more of periodical character.

Upon the surface layers, the sea masses circulation is general cyclonic. It is characterized as warm-saline, with the wind playing a significant role. The currents speeds, for depths below 100m are larger than the lower ones. The masses of the cold brackish waters from Dardanelles in the northeastern Aegean head western, mingled with the much more saline and warm surface masses, which originate from southeast. These masses then head to the south, following the eastern continental Greece, reaching up to the Kythera-Antikythera island complex, finally outflowing to the Ionian Sea.

The layer of low salinity from the Black Sea enters the North Aegean Sea, while simultaneously a sub-layer of masses of the Aegean enters the Sea of Marmara (Unluata et. al.,-1990). That is, that the Mediterranean interchanges with the Black Sea via double layer formation. The mass budget for the Aegean is positive, for the reason that via mingle of vertical profile procedures; a large amount of these masses turns back onto the Aegean.

The max. net flow of masses towards the Aegean is approximately 300 Km³/yr, with seasonal fluctuations and max. values during Summer (Unluata et. al.,-1990). The low salinity masses from Levantine, sink deeper, thus creating a thin surface layer of mass (of 20m) with low salinity covering a large amount of the North Aegean Sea (Zodiatis,-1994, Georgopoulos,-2002).
There is a two direction pattern of currents that outflow the Straight, one heading northwest between Limnos-Imvros islands and one heading southwest, from western-south of Limnos island, turning further west, while part of it finally heading north to Athos peninsula plateau.

Except from the general cyclonic circulation there is also an anticyclonic formation of Samothraki island, in the northeastern part of the North Aegean Sea and an anticyclonic one, near Athos peninsula. The first one accumulates the masses of the northwest current of the Black Sea, drifting them towards the eastern part of Samothraki island. This behavior, which dominates in the area of northern Limnos-Imvros islands and around Samothraki island, is correlated with the diffraction-infraction phenomenon of the rough flow of Evros river to the east (Georgopoulos, 2002).

The vertical columned profile of sea masses in the North Aegean Sea is constituted by three main layers. The surface layer of low saline masses from the Black Sea, the sub-layer mass of depths mainly 100-400m of higher salinities and temperatures, coming from Levantine Sea and finally the third deep masses which dominate the basins of the area, masses of dense and high salinity (Zervakis et. al., 2000, Lykousis et. al., 2002).

The North Aegean Sea is a dominant area of deep water masses formations for the eastern Mediterranean. After seasonal climatic fluctuations of low temperatures, due to strong northerlies blowing over the peninsula of the Balkans (Zervakis&Georgopoulos, 2000), there is an intense interchange (vaporization), between the surface masses and the atmosphere, leading as a result to the creation of dense masses (of high salinity) in the in-between layers of the area. These dense masses by sinking induce the upwelling of older deep ones that are enclosed to the deep basins. When this occurs, they dominate the in between layers and when
surpassing the layers of <400m depth, follow the general circulation, which leads them southern, out of the northern section (Georgopoulos,-2002).

Fig. 7 (a) Generalized pattern of surface circulation of the sea masses in the North Aegean Sea (Zervakis et al.,-2005, Lykousis et al.,-2002)
(b) Surface circulation (15m), during May 1997 in Thermaikos Gulf and the Sporades island complex (Kontoyannis et al.,-2003)
(c) Typical profiles of temperature and salinity for Winter (left) and Summer (right), as recorded by the POEM project (Papathanassiou & Zenetos,-2005)
2.6. Ocean color Remote Sensing in complex sea systems

Taking into consideration that an important fraction of their surface, the European seas, and moreover the North Aegean Sea, is distributed over the coastal shelf or in enclosed basins, someone can imagine the complexity of the analysis under study. In such waters, the origins of particulate and dissolved materials, playing a significant optical role, are manifolds. They result in a high variability of the marine inherent optical properties, from the strongly absorbing Baltic waters to the scattering North Sea waters and the transparent Eastern Mediterranean Sea waters, furthermore complicating the inversion of the remotely sensed water-leaving signal and the derivation of marine data products.

Consequently, important uncertainties still persist for the retrieval of marine products like the phytoplankton chlorophyll \( a \) (Chl-a) in areas where the absence of covariance among the main seawater components occurs. In these waters, which mostly include coastal regions, the sources of particulate and dissolved materials are numerous (biological production, rivers outflow, bottom re-suspension, atmospheric deposition and so on), contributing to an increase of the uncertainty associated with the inversion of the surface optical signal. The proximity of the continent also induces the presence of specific aerosols (e.g. absorbing aerosols, desert dust, etc.) making the atmospheric correction procedure more challenging (Berthon, J-F., et. al., 2008).

The remote sensing of ocean color can be defined as the derivation from the top-of-atmosphere radiance at a certain wavelength \( \lambda \), \( L_\lambda(\lambda) \), reaching a space sensor, of the spectral upward radiance, \( L_{\text{up}}(\lambda) \), leaving the water surface in the direction of the sensor. \( L_{\text{up}}(\lambda) \) results from the interaction of the downward irradiance \( E_\lambda(\lambda) \) having penetrated the sea surface, with the different optically significant components (particles, dissolved matter, sea water). The so-called atmospheric correction consists in subtracting from \( L_\lambda(\lambda) \) the radiance due to photons having only interacted with the atmosphere (possibly with the sea surface too but without having penetrated it), as well as accurately representing the atmospheric transmission of the photons really emerging from the sea surface. All these processes are wavelength and geometry (sun zenith and sensor viewing angle, sun sensor azimuth difference) dependent. The principles of the atmospheric corrections are not further evoked here and the reader is addressed to (Gordon, H.R., 1997), and to (Ruddick, et.al., 2006) for atmospheric corrections over turbid coastal waters.

The retrieval of in water components involves optical quantities like the “normalized water-leaving radiance”, \( L_{\text{WN}}(\lambda) \) or the reflectance, \( R(\lambda) \). \( L_{\text{WN}}(\lambda) \) is a water-leaving radiance made independent from the illumination conditions. The “just below” surface reflectance \( R(0^-, \lambda) \) is the ratio of the up- to down-welling irradiances just beneath the sea surface, \( E_\lambda(0^-, \lambda)/E_\lambda(0^+, \lambda) \). \( E_\lambda \) is related to \( L_\lambda \), the upwelling radiance (and thus to \( L_{\text{W}} \)) through the so called “Q factor”, which describes the anisotropy of the underwater light field. \( R(0^-, \lambda) \) can be related to the inherent optical properties (IOPs) of the water, namely, the back-scattering coefficient, \( b_\lambda(\lambda) \), and the absorption coefficient, \( a(\lambda) \), according to:

\[
R(0^-, \lambda) = \left[ Q(\lambda) L_{\lambda}(0^-, \lambda) / E_\lambda(0^-, \lambda) \right] = f'(\lambda) b_\lambda(\lambda) / \left[ a(\lambda) + b(\lambda) \right]
\]

Surface sea state, and optical properties of the in water optical components. \( R(0^-, \lambda) \) is thus the surface optical expression of the water content and the quantity from which the different marine products are retrieved, after a proper inversion.

The absorption coefficient, the “optically significant constituents” are classically divided into three classes (Prieur&Sathyendranath, 1981):

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i) The pigmented particulate material originating from the phytoplankton (PH).

ii) The non-pigmented particulate material (NP), containing organic and non-organic particles from different sources.

iii) The colored dissolved organic material (CDOM), also called “yellow substances” (YS), composed of humic substances originating from phytoplankton and/or terrestrial plants. The total absorption (excluding the almost invariant “pure” sea water component) is thus often written:

\[ a(\lambda) = a_{PH}(\lambda) + a_{NP}(\lambda) + a_{YS}(\lambda) \]

Note that the origin of back-scattering is still controversial and phytoplankton is probably a much less efficient back-scatter than its co-varying detrital material. The YS absorption spectra are measured as means in eastern Mediterranean Sea 0.065 ± 0.04 m⁻¹ at 400 nm. For the Black Sea, values at 400 observed went from 0.2 in the open sea to 2 m near the Danube river mouth.

The case of North Aegean Sea is of “Case 2” waters, where the concentration of organic/inorganic particles and/or dissolved organic matter from other origins (river outputs, bottom suspension, atmospheric deposition, etc.) is of essential character (Morel & Prieur, 1977).

The spectral dependency of the absorption by CDOM is classically represented by an exponential function of the type:

\[ a_{YS}(\lambda) = a_{YS}(\lambda_0) \exp(-S_{YS}(\lambda - \lambda_0)) \]

where the reference wavelength \( \lambda_0 \) is generally chosen in the blue or in the UV. Although an important part of the natural variability of S_{YS} reported in the literature has been attributed to the way it has been calculated (Twardowski, MS., et al., 2004), it is nevertheless generally considered dependent on the CDOM composition (fractions of fulvic and humic acids).

Fig. 8 (g,i) Average spectra aPH (thick solid line), aNP (dashed line) and aYS (dotted line) and aPH normalized to 443 nm (thin solid line, right ordinates scale). (b,j) Fraction of the total (minus water) absorption of PH (solid line), NP (dashed line) and YS (dotted line) (Berthon, et al., 2008).
Fig. 9 The top image shows NASA Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) chlorophyll concentration in June 2005. Reds, yellows and oranges indicate higher chlorophyll concentrations, while blues and purples are lower concentrations. The middle image shows Aqua MODIS nighttime sea surface temperatures in June 2005. The green areas indicate higher temperatures. The bottom image is a map of the probability of potential M. leidyi presence in June 2005; colored regions indicate a higher probability that the ctenophore could be present. The map incorporates data on depth, temperature, and productivity (Siapatis, et.al., 2008).
2.7. Chlorophyll. Algae Blooms in the North Aegean Sea

Chlorophyll-a is a type of chlorophyll that is most common and predominant in all oxygen-evolving photosynthetic organisms such as higher plants, red and green algae. It is best at absorbing wavelength in the 400-450 nm and 650-700 nm of the electromagnetic spectrum. Its molecular formula is C_{55}H_{72}O_{5}N_{4}Mg.

Indicators of algal biomass are used to assess water quality in both moving (lotic) and still-water (lentic) ecosystems. Algal biomass in a water body can be estimated in three ways: (1) by quantifying chlorophyll a (CHL a), (2) by measuring carbon biomass as ash-free dry mass (AFDM), or (3) by measuring the particulate organic carbon (POC) in a sample. The CHL a procedure measures photosynthetic pigment common to all types of algae, while AFDM and POC procedures measure the carbon in a filtered water sample.

Chlorophyll is the green molecule in plant cells essential for energy fixation in the process of photosynthesis. Besides its importance in photosynthesis, chlorophyll is probably the most-often used estimator in North America of algal biomass in lakes and streams. Chlorophyll is used to measure algal biomass that is relatively unaffected by non-algal substances. Chlorophyll provides an estimate for measuring algal weight and volume and acts as an empirical link between nutrient concentration and other biological phenomena in aquatic ecosystems. Nutrients and other chemicals in a watershed, together with factors such as temperature and light, affect the biomass production of algae in streams and open systems. Algal production, in turn, affects the entire biological structure of an ecosystem.

Measurement of algal biomass is common also in many river and lake studies and may be especially important in studies that address nutrient enrichment or toxicity. High nutrient concentrations can affect recreational water users when the nutrients produce dense growths of algae and (or) aquatic vegetation, which are aesthetically undesirable. Use of waters for a public water supply can be affected, if algal blooms result in an unpleasant taste and odor in the treated water. Fisheries, up to a point, are positively affected by increased primary algal production resulting from increased nutrient loads. However, when eutrophication begins to reduce dissolved oxygen concentrations substantially, fisheries can be adversely affected. CHL a, AFDM, and POC are measured because they form the direct link between the excessive nutrients and the degradation of recreational waters and ecosystem health.

The relations among algal indicators can provide additional information regarding the condition of an algal community. The chl- a per cell, changes based upon the health-growth status of the cell itself. This means that carbon-to-CHL-a ratios change dramatically based on the physiological status of the algal populations. The carbon-to-CHL a ratio can be used as a diagnostic tool, as can other elemental ratios. The AFDM/CHL a ratio, known as the autotrophic index, has been used to indicate organic inputs (for example, from wastewater) where the higher the ratio, the greater the amount of bacteria, and the lower the quality of water. Consistent field-sampling techniques are necessary to allow for comparisons among studies (or and not so in the modern era).

Over the past few years e.g. the United States has some regulations or guidelines for protecting human health and ecosystem viability from nuisance levels of algal biomass or from cyanobacteria algal blooms, which can be detrimental to water quality when they occur in fresh, estuarine, and marine water environments. For example, North Carolina has a 40 μg/L standard for CHL a in lakes, and Texas uses narrative water-quality standards to prevent nuisance levels of algae (Texas Water Conservation Association, 2005). The U.S. Environmental Protection Agency (USEPA) requires States to establish nutrient criteria levels in order to control excessive algal growth and to provide protection for the aquatic ecosystems in each State. Of course, the closed river-lake systems do prioritize, in terms of detrimental
indices, the semi or open sea ones. The late frequencies tend to lean on the mean above, and the results are near the same to coastal areas (thus, affecting a large amount of the population). In this respect, is there an official criteria-level of control by the Greek infrastructure policy and if not, why not yet stated and documented? Maybe it’s time to be constituted. Some of the U.S. States are considering use of standards for CHL a instead of nutrient standards. Green algae (Chlorophyta) and blue-green algae (Cyanophyta/cyanobacteria) commonly are associated with the nuisance algal blooms, but they are just 2 of 10 algal divisions, each of which contains CHL a and a distinct combination of additional pigments that can be used to assess community composition and algal biomass.

Sampling procedures for determining algal biomass include CHL a quantification, measurement of organic biomass as AFDM, and determination of POC:
Quantifying the amount of CHL a. CHL a provides a measure of the amount of active algal biomass (as periphyton) present per area of stream bottom, or a measure of phytoplankton from a volume of water. CHL a is a photosynthetic pigment present in all green plants and occurs in the chloroplast of most plant cells.
— Pigments that occur in varying concentrations along with CHL a include CHL b, CHL c, phycocyanin, allophycocyanin, and phycoerythrin, depending on the evolutionary line of the algal division. Algae also have secondary or assessoriy pigments and degradation products. Phaeophytin a is the most common degradation product resulting from the loss of a magnesium atom.
— Depending on the objective of a water-quality study, CHL a may need to be distinguished from the other primary and secondary pigments. Measuring the carbon biomass associated with an algal sample as AFDM. The AFDM analysis measures the difference in mass of a dried (dewatered) sample after organic matter in the sample has been incinerated (American Public Health Association, 1999).
— AFDM is recommended for analysis of periphyton biomass instead of a dry mass analysis because silt can account for a substantial portion of dry mass in some samples. Ash mass in samples can be used to infer the amount of silt or other inorganic matter in samples.
— AFDM concentrations are near the detection level in phytoplankton samples unless the sample is collected from a highly eutrophic stream or lake. However, periphyton samples can be concentrated through filtration or centrifugation for AFDM.
Analysis of POC. An alternative approach to measuring AFDM for phytoplankton samples is to obtain a measure of carbon by laboratory analysis of a subsample for POC.
— The POC fraction is derived by subtracting the particulate inorganic carbon (PIC) from the total particulate carbon (TPC): POC = TPC – PIC.
— The presence of macro-algae or aquatic plants in large amounts may necessitate accounting for this biomass (Hambrook&Canova, -2007).

Focusing in the region of the current study, e.g. the year 2010 was not a good one in the Northern Aegean Sea, neither for the Mediterranean Shag birds, nor for the fishermen. An algal bloom, which started at the end of 2009, until the end of May, had still not completed its biological cycle, when this report was published on the local press, leaving several marine areas in the region still covered with its remains. Its long duration has had devastating effects particularly on the breeding performance of the Mediterranean Shag in the Northern Aegean, where the species largest colonies in Greece are located. The breeding success was literally decimated, as some colonies produced up to 50 times less juveniles than during previous years. The extent of algal bloom was much greater than initially expected reaching as far as Limnos island, Northern Sporades and Skyros island in the central Aegean Sea. Similarly, seabird surveys at sea, indicate that areas affected by algal bloom are inhospitable to seabirds which avoid them (pub.Hellenic Ornithological Society).
The Aegean Sea displays prominent hydrodynamic features such as mesoscale eddies, hydrological fronts, strong baroclinic currents and upwelling zones. The aforementioned stand an important role in regulating primary productivity in the region. Large gradients of primary productivity have been observed in the past. The open (Oceanic) waters of the Aegean Sea have been classified as “oligotrophic”, the offshore waters as “mesotrophic” and the inshore waters as “eutrophic” (Ignatiades, L., 2005).

In the (Ghanasos et al., 2009) 8-year time series of Advanced Very High Resolution Radiometer (AVHRR) derived sea surface temperature (SST) and Sea-viewing Wide Field-of-view Sensor (SeaWiFS) derived chlorophyll data, were used to investigate the spatial and temporal variability of these parameters in the Aegean Sea and to assess their impact on the plankton ecosystem processes. Concluded in, that the key factor regulating the SST and chlorophyll distribution in the area was found to be the Black Sea cold and chlorophyll rich water entering through the Dardanelles strait. At the eastern part of the Aegean Sea, during summer, the upwelling due to Northerlies (north winds) is the most important feature affecting the SST, while from October to May there is an increasing North to South SST gradient. Surface chlorophyll concentration presents also an increasing North to South gradient during the entire climatological year, almost following the SST profile. Finally, relatively large chlorophyll concentrations are encountered in coastal regions, affected by enhanced anthropogenic and/or river nutrient inputs, such as the Thermaikos Gulf.

Further on, overall from the 1950’s until early 2000 concluded relative change in the seasonal frequencies of Southerlies-southern winds- (along with their increasing correlation to extreme weather occurrences) displaying the southern wind-wave profile in the North Aegean Sea, even more forcing, when they occur, the surface water masses towards the north, (Georgakas, K., 2012), contributing to higher concentration of chlorophyll-a towards the coasts of the North Aegean Sea, consequently may have been or currently affecting, even altering-to an extend reversing, the annual climatological N-S aforementioned increasing gradient of surface chlorophyll-a spatio-temporal distributions. This stands an account key for the selected methodology and data under examination, as this preliminary ‘conclusion’ gives credit to the estimated importance of the bioaccumulation of algae blooms and the recorded state these have been and still influence the coastal regions of northern and central-north Greece, along with the islands met, islands that can and do function as diffraction-refraction ‘fluidics’ spots for surface sea masses.
In (Kiparissis, et al., 2010) the team concluded that in the province of the Ionian sea (near Zakynthos island), allelopathic interactions induced by algae phyotoxication, caused by the factor of illegal trawling, brought caulcerpenyne (toxin from the seaweed Caulerpa taxifolia) production and deterioration of the sediment quality. Could this be a case in the North Aegean Sea? For starter, the current study introduces some extend remote sensing upon ecology-biogeochemical and physical induced phenomena, dispersed by the force of meteorological elements, can be approached.

Why though emphasizing on meteorological factors upon an issue that displays within the water mass-column? E.g: In (Papadopoulos, V.P., et al., 2012) the team investigated the sea level atmospheric pressure time series, in order of finding the factors triggering the net air-sea heat fluxes-anomalies. Heat losses were found to cause boundary intermediate and deep-sea water masses formation. Subsequently, the vertical profile of e.g. the bioaccumulation of algae, whatever the cause, is in direct correlation with the air-sea dynamics.

Indices such as the above documented, which are more and more often met, surpassing the expected natural biogeochemical recycling of the marine ecosystem, met with extended period of accumulated time of dispersion and a regional profile that extends/or inner alters the mosaic of such met as the N-S aforementioned gradient, further accompanied by relative lack of focused spatio-temporal analysis (in the present study the North Aegean Sea), indeed, do meet the standards for choosing the present thesis.

The data were chosen in respect of joining (on extend this could be achieved in the present status) the concepts of sea-air interactions, ocean climatology and physical oceanography, encompassing basic principles of satellite remote sensing.

The use of satellite remote sensing climatological approach upon the issue of algae blooms, investigating possible correlation of complex causes such as precipitation, fresh water inflow from Bosporus, surface winds, etc. is under display. The methodology in detail on the next chapter involves the combination of the aforementioned, covering a period of time, in accordance to the under use and disposal data of the latest 10 years (Dec. of 2002-Jan.2013)

Fig. 11 Chlorophyll-a Monthly composite for Feb. 2008.MODIS - Day Number 032 to 060. Notice the high-lightened red (higher concentration) areas of the Black Sea and the Dardanelles Straight and how this disperses upon the whole north coastal zone of Greece. The time of this recording is characteristic of the temporal peak for algae blooms (mainly appearing from October till May).
Fig. 12 Seasonal Chlorophyll Concentration Climatology 2002-2012, from Aqua-MODIS (4km resolution)-focus on the Aegean Basin- NW Marmaras sea. a. Autumn, b. Winter, c. Spring, d. Summer. Notice the dispersion of the higher concentrations, starting from Autumn and cascading onto the transitional of Winter to Spring and how it is increasingly distributed along the north coastal regions and the islands of the North Aegean Sea.
3. Methodology and data

3.1. Data under analysis

The derived data where mined by the Giovanni, that is a Web-based application developed by the GES DISC that provides a simple and intuitive way to visualize, analyze and access vast amounts of Earth science remote sensing data, without having to download the data. Giovanni is an acronym for the GES-DISC (Goddard Earth Sciences Data and Information Services Center) Interactive Online Visualization ANd aNalysis Infrastructure.

As merged by the analysis, data fetching, preprocessing, data masking, grid sub setter, anomaly, time averaging, dimension averaging, two dimensional plot-time series and variable products, in accordance to the variable under study, where focused covering the overall profile of the North Aegean Sea and the shoreline directly influenced by its dynamics. Coordinates selected for the overall area of the North Aegean Sea: W.22.366, N.41.155, S.37.947 and E.26.98.

"Analyses and visualizations used in this study were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC.”

In the first stage of pointing out regional seasonality and temporal periodicity, time series of the under study variable where merged, from data derived by: Ocean Color Radiometry Online Visualization and Analysis. Ocean color Giovanni facilitates visualization and analysis of several oceanographic remote sensing data sets. The current data sets include SeaWiFS data, MODIS-Aqua and MODIS-Terra data (MODIS-Terra provides sea surface temperature data only) which are processed by the Ocean Biology Processing Group (OBPG) at Goddard Space Flight Center. This interface also includes "GSM" bio-optical products derived from SeaWiFS and MODIS-Aqua data, processed by ICESS at the University of California - Santa Barbara.

Using data from MODIS-Aqua from December 2002 to January 2013, there was a first impression of the pigment peaks locked in early 2006, 2010 and 2012. In order to extend the disposable time series [(though the pigments is via different spatio-analysis (9km in SeaWiFS, 4km in MODIS-Aqua- the late selected due to the relative small area of focusing and in retrospect of not analyzing a rather global objective-)], SeaWiFS data, that covered a period from mid-1997 to 2010 (when the mission was terminated), where also under analysis.

The aforementioned pigments where the centralized idea of pointing out why the blooms occurred and with a relative high frequency in the latest years (judging from the extended period of normalized values extending from 1999-2006).

Seasonal map lat-lon-time averaged plots, per year-season where compared, in order of finding out the spatio-temporal extend of the above peaks, that where well pointed out by the produced plot displays and the further on animations.

There was also, as initiative, an annual (per month) perspective climatological lat-lon-time averaged map produced (similar methodology to the seasonal ones).

The further analysis was focused in a perspective of chl-a time series VS several selected variables such as: Precipitations rates, Euphotic Zone Depth, Colored Dissolved Organic Matter, Absorption coefficient, Sea Level Pressure, Surface Pressure and Northwards wind component. These variables where selected in chain view-resulting order, as each preserves an in to next correlation, in retrospect to the chl-a concentrations (variable that describes best the algae blooms in the North Aegean Sea).
3.2. Further Data under analysis

Following the aforementioned, the first counter-variable correlations where chosen to be with Precipitation Rate time series (derived from TRMM L-3 V6 and V7 Inter-comparison, that is tool to inter-compare TRMM Level-3 V6 and V7 monthly products), as this variable has a most immediate effect on the vertical profile of chlorophyll-a and SST (Sea Surface Temperature), SST which in memorandum has the same vertical North to South differential with chl-a (chlorophyll-a) concentrations. Rather than re-analyzing a most analyzed correlation between SST-Chl-a, some altering projective was affronted.

A most interesting impression (displaying in a way the overall water cycle) was marked out by the comparison of the time series of precipitation rate and chlorophyll-a (displayed in the results chapter). Let’s bear in mind for the time being, that precipitation has a two way effect on the enrichment of the dynamics of blooms (surfing the surface salinity profile, thus secondary pre-storing the main terra-discharges of fresh, nutrient rich masses, either riverine, or directly man-produced, but also diluting the surface accumulation of algae blooms). It functions, in this way as an enforcer and/or restrictive component.

The next counter correlation was chosen to be with Euphotic Zone Depth variable (derived from MODIS-Aqua-4km, time series product), that is the depth where photosynthetic available radiation (PAR) is 1% of its surface value. The value of z1% is a measure of water clarity, which is an important parameter regarding ecosystems. Z1% can be estimated empirically from the remotely derived concentration of chlorophyll-a (Chl), commonly retrieved by employing band ratios of remote sensing reflectance (Rrs). Found, as expected, to be vise-directly implemented by the max. values of chl-a concentration.

Further on, the Absorption Coefficient for phytoplankton (MODIS-Aqua-4km, time series product) was chosen, as the next correlation effort, in order for the peaks of chl-a to be evaluated by the relative absorbance capability of the blooms. The extent, in which why the latest peaks (except the year 2006) where not found to be followed by parallel ones in this variable, is pointed out, also in the results chapter.

Continuing, choosing the Colored Dissolved Organic Matter variable (CDOM), by MODIS- Aqua-4km time series product, came an effort of inter-comparing (descending the peaks role) as in terms of the ecosystem ‘backfire restore capability’. As displayed in the results chapter, the worst scenario of detritus in the water column was found to be the latest peak of chl-a concentration (2012), thus making the recent bloom, in ecosystem stamina description, the most incoherent and unbalanced.

Following up, the MERRA system was used, that is a NASA reanalysis for the satellite era using a major new version (V5) of the Goddard Earth Observing System (GEOS) Data Assimilation System (DAS). The MERRA focuses on historical analyses of the hydrological cycle on a broad range of weather and climate time scales. This MERRA Instance of Giovanni focuses on visualizing and analyzing the MERRA 3D monthly data from the MERRA History Collections. All data used here are at MERRA reduced resolutions of 1.25 longitude by 1.25 latitude degrees, with 42 vertical pressure levels.

The variables chosen, derived from the above analysis system, where the Sea Level Pressure (SLP), Surface Pressure (SP) and the Northward wind component, at the 1hPa level of atmospheric pressure, covering the period of 2003-2013, in order to be representative of the low-wind profile and the surface pressure profile (mean sea level) and to be compared with the time series from chl-a concentration. The current wind component was chosen, as the southerlies, outlined in the introduction chapter also, play a significant role on the drift of the surface masses towards the north Greek shoreline, area that, after all, is the spatio objective of
this study and has the most recordings of such blooms. Some rather interesting correlations, in
the form of these variables VS chl-a concentration time series where resulted, emphasizing in
this way the initiative of approaching such a phenomenon from a meteorological-
oceanographic perspective of view. These are also displayed and analyzed in the following
chapter.

3.3. Overview

The methodology under display was chosen to be as plain as possible, and in accordance also,
with the effort of this dissertation to amplify and coincide the concepts of satellite remote
sensing in terms these can have direct quantifying and quality measuring application in the
phenomenon of algae blooms in the North Aegean Sea. That is the co-use and output displays
of variables that could have the potential and the perseverance to answer, even on a primary
stage, upon why and why-then the chl-a peak concentration are met.
4. Results

4.1. Primal Results

Produced time series of Chlorophyll-a concentration. Relative quantity underestimation on SeaWiFs time series comes from the different level of resolution and by the nature of the sensor itself.

Area-Averaged Time Series (SWPMO_CHL.OCR)  
(Region: 22E-26E, 37N-41N)

![Graph](image_url)

Fig. 13. Chlorophyll-a concentration mm/m² derived from SeaWiFS (9km resolution), Jul.1997-Dec.2010 (mission terminated). The first two peaks in early 2006 and early 2010 are displayed.
Fig. 14. Chlorophyll-a concentration mm/m$^3$ derived from MODIS-Aqua (4km resolution), Dec. 2002-Jan 2013. The first two peaks in early 2006 and early 2010 are displayed and the one (the overall max.) in early 2012. The recorded from Nov. to end May period of ascending has a periodic character.

The seasonality that is clearly outputted in the aforementioned time series is displayed as follows, in terms of season per year.

**Autumn**
Spring
Fig. 15 Updated (Lat-Lon-time averaged map plots) display of the seasonality for chlorophyll-a concentration per year, extending from 2003-2012. Easily, the season pattern of November to end of May of the spatio-distribution is outlined. It is also clear the peaks of 2006, 2010 and 2012 derived also from the aforementioned time series, MODIS-Aqua, 4km res. Dec. 2002-Jan. 2013.

In order for the annual mean climatology of the phenomenon to be displayed, the following lat-lon-time averaged also map plots per month, where produced.
4.2. Further Results

1. Precipitation Rate VS CHL-A

The precipitation rate, Pr, is the average volume of water in the form of rain, snow, hail, or sleet that falls per unit of area and per unit of time at the site. It is measured in units of volume per area per time. Precipitation is one of the primary processes of the hydrologic cycle, that is, the endless movement of water through the various elements of the environment (oceans, atmosphere, land surface water bodies, and subsurface soil systems). Other processes of the hydrologic cycle include evapotranspiration, infiltration, overland flow (runoff), streamflow, deep percolation, and groundwater flow. Thorough descriptions of these processes have been presented in numerous texts in the hydrology literature.

Bearing in mind that precipitation could function as an enforcer and/or restrictive component, come the following. Descending, with a near half of the year temporal delay, are the peaks in precipitation rates time series, towards the ones in chl-a (e.g. in 2005, there was a peak in Sept-Okt. in precipitation that counter-ground bases the early Feb.-March 2006 in chl-a). In 2009, there was a peak in Okt.-Nov 2009 in precipitation, that counter-ground bases the early Jan.-Feb, 2010 in chl-a.

The overall max. peak of chl-a in early 2012 was not pre-histored by an analogue one, in late 2011 temporal peak in precipitation rate, even though the max. overall peak in precipitation rate time series is located in late 2010. Why in the descending tendency chart, in 2010, chl-a, seems to be prolonged until May-June (reminding the article of Ornithologiki, that in situ recorded the extended time of its accumulation, in the introductory)? Why the max. overall peak in time series of chl-a has a late 2010 peak in precipitation, rather than the "pattern" of 0.5 temporal aforementioned delay? Was there something that delayed the terra based water masses from out bursting in the pelagos, between 2010 and 2012? Does this explain the 1.6 max of mg/m³ in chl-a concentration in early 2012, or has a more of an immediate ecosystem response character (or both, time-delay and higher values along with the annual transition), as reasons. That is, in retrospect, that in the beginning of 2012 the precipitation time series showed over 0.04mm/hr, rather than lower level ones, as in 2006 and 2010, respectively.

Is the above a clue of a direct correlation of terra-delayed discharged masses (for whatever the reason may be, even random one), with the extent that the transitional time of the annual continuum in mm/hr precipitation rates is indicated as following? Is this, secondary, an immediate response of the ecosystem to the fresh atmospherically contributed masses, via the precipitation rates, as indicated in 2012 when there was the overall max. value of chl-a and
the annual change value showed higher value of precipitation rates, in comparison along the two peaks before this year, 2006 and 2010? Why finally, as 1999-2006 seems a normalized period of periodicity in chl-a, this one has a short period of pigments within 2010-2012? Does this give a hint upon ecosystem instability, having e.g. low temporal period of recycling in 2010 and a first time recorded short period of pigment peak, along with the decade overall in 2012? Among the following, the above will be resulted and fairly to full extend answered.

Area-Averaged Time Series (TRMM_3A12.007)  
(Region: 22E-26E, 37N-41N)

Fig. 17 Precipitation Rate (mm/hr) time series, derived from TRMM L-3 V6 and V7 Inter-comparison. Dec.2002-Jan.2013.

2. Euphotic Zone Depth VS CHL-A

The photic zone or euphotic zone (Greek for "well lit": εὖ "well" + φῶς "light") is the depth of the water in a lake or ocean that is exposed to sufficient sunlight for photosynthesis to occur. The depth of the photic zone can be affected greatly by seasonal turbidity. It extends from the atmosphere-water interface downwards to a depth where light intensity falls to one percent of that at the surface, called the euphotic depth. Accordingly, its thickness varies widely on the extent of light attenuation in the water column.

Typical euphotic depths vary from only a few centimeters in highly turbid eutrophic lakes, to around 200 meters in the open ocean. Since the photic zone is where almost all of the primary productivity occurs, the depth of the photic zone is generally proportional to the level of primary productivity that occurs in that area of the ocean. About 90% of all marine life lives in the photic zone. A small amount of primary production is generated deep in the abyssal zone around the hydrothermal vents which exist along some mid-oceanic ridges. It is used as an indirect measurement of the transparency of water masses.
In this case, one can remark the prolonged time base of chl-a concentration (until May-June) in 2010, rather than March-May, as ordinary expected, that has, as the current display shows, an 'analogue' in the mid-lower level of euphotic zone depth (over 85m-min value ever recorded, among the 2003-2013).

This low peak in EZD (Euphotic Zone Depth) time series, in this year, is in addition time-delayed, respectively, from mid-year (Summer) to late Summer-early Autumn. That's the reason why, maybe, in 2011 (although not pigmented in high values of chl-a concentration) the descending of the chart time series-time averaged in chl-a concentration, has the same temp.-delayed profile display, as the current one in 2010. That is an indication of how the aqua-marine ecosystems efforts its equilibrium, as response to these phenomena.

Maybe, these two time series indication about the prolonged time of bioaccumulation of the recycling of the phenomenon, explains and the max. overall value in early 2012, in retrospect this is also enhanced by the relative higher annual-change transitional level of precipitation rate height, in the beginning of 2012, compared with the rest two peaks, as referred to (1). The 2010 overall min. peak for EZD, in a way, projects the special character of the late two peaks in chl-a concentration. This will be enhanced and by the following correlations.

Fig. 18. Euphotic Zone Depth (m), derived from MODIS-Aqua, 4km res. Dec.2002-Jan.2013.
3. Absorption Coefficient for phytoplankton VS CHL-A

The absorption coefficient is a numeric measure of the amount of light energy that water itself and the dissolved and suspended substance within the water take up, which results in less energy or less light penetrating down into a water body. It can be measured for some or all of the wavelengths of a light ray and is reported per meter. It is an inherent optical property.

As mentioned in the chapter Ocean color Remote Sensing in complex sea systems: i) The pigmented particulate material originating from the phytoplankton (PH), ii) The non-pigmented particulate material (NP), containing organic and non-organic particles from different sources. iii) The colored dissolved organic material (CDOM), also called “yellow substances” (YS), composed of humic substances originating from phytoplankton and/or terrestrial plants, are the main divisions of “optically significant constituents”.

Note and at this point that the origin of back-scattering is still controversial and phytoplankton is probably a much less efficient back-scattering than its co-varying detrital material.

Excluding the mid-2005 peak in the variable, by sensor miss-function or by see (*) following, the 2005-2006 transitional one peak, complementing the high peak of chl-a concentration in 2006, is an indicator that the absorption was then mainly attributed due to phytoplankton blooms (as this can be considered the natural periodical phenomenon), but rather, the peaks in 2010 and 2012 are not followed by pigments in the coefficient.

The amount of back-scattering-larger (less absorption) in these cases can be, in this way, empirically explained as river outputs, bottom suspension, atmospheric deposition, etc or implicit factors scavenging the atmospheric correction process. This depicts, in this way, a meaning of a higher man-terra-atmospherically induced composed detritus for 2010, 2012, something that levels down the coefficient, counter to the peaks at chl-a concentrations or a prosthetic role between these and the (*) factor. Nevertheless, implements between these years a possible explanation of the instability of the eco-marine system in the area under study.

*Further on, different algae have pigment composition suitable for growth under their typical natural light environments. Intracellular pigment concentration is also variable with the intensity of the light field. Both pigment composition and intracellular pigment concentration influence the absorption characteristics of the phytoplankton. Pigment values can be also characteristics of a species reflects adaptation at evolutionary time scales to their environment (Photoadaptation). The response of phytoplankton to the light field may also be temporary (Photoacclimation).
4. CDOM (Colored Dissolved Organic Matter) VS CHL-A

Phytoplankton can directly contribute to the autochthonous production of colored humic-like substances in the ocean. Extrapolation of these findings to the field indicates that about 20% of the marine humic–like substances produced in the highly productive coastal upwelling system (Romera, C. C. et al, 2010) originate from growing phytoplankton. This finding comes to stand as ground base for the almost linear increasing of CDOM variable in the two late peaks of chl-a concentration in 2010, 2012.

The role of CDOM is a key for ocean biogeochemical cycles, since it can control light penetration in the water column. A high concentration of CDOM can reduce harmful UV effects on phytoplankton, acting as a photoprotector, but it can also attenuate photosynthetic usable radiation, reducing primary production in regions where light is limiting (Arrigo&Brown,-1996). On the contrary, at low concentrations of CDOM, sunlight can damage not only phytoplankton cells but also bacterioplankton physiology and deoxyribonucleic acid as well (Herndl et al.-1993). Another important role of CDOM involves its capacity for metal scavenging and the formation of complexes that can be beneficial to phytoplankton when metals present in the medium reach toxic concentrations (Midorikawa&Tanoue,-1998).

Towards the findings in Absorption Coefficient for phytoplankton VS CHL-A above, there is a rather random based fluctuation of CDOM until the late 2009. Steaming from the aforementioned, the sudden from 2010 to end 2012 alternation of the spatio-temporal profile of the variable, prolonging the fluctuation and altering the mean profile my max. and min. values, only found in this time, in retrospect with the results found in the aforementioned VS, indicate a kind of ‘ecological burst’, by either reasons of presence of more detritus (thus more
terrestrial waste load, by riverine discharges or atmospherically derived, additional, deposition, increasing bottom suspension etc.) or/and by the (*) factor, mentioned above.

Physical-chem. substances as photoadaptation or photoacclimation though, cannot explain the almost above mentioned linear follow up of this variable VS and an extent of mean-to max. min. values change. The load of detritus further on, is a multiplex factor to be identified (coming from even a temporal upwelling, with Dardanelles straight mostly contributing-terrestrial discharges), or a composition of such factors.

Nevertheless, as an important outcome that puts the late two chl-a peaks in a special concluding place, thus reinforcing the initiative for approaching the blooms phenomena in the area with satellite remote sensing, is under prove. The factors of attenuation of photosynthetic usable radiation and min. values found functioning as "dead-creating" scene in blooms, thus bio-oxidosis and altering the physio-characteristics of phytoplankton cells, with direct effect on bacterioplankton’s dissolving even capabilities, are evident proof, in accordance and to the result of (3) VS, of an ecosystem that changes (or tries to adapt, maintain the equilibrium) to a dynamic, descending (? , let’s hope not) marine scenery. Finally, what could be (as food for thought) the meaning of the lowest profile of CDOM within the 2012 recorded, for the year 2013 and the following years?

Fig.20. Colored Dissolved Organic Matter time series, as derived from MODIS-Aqua, 4km res. Dec.2002-Jan.2013.
Sea Level Pressure is the pressure value obtained by the theoretical reduction or increase of barometric pressure to sea-level. The iso-barometric level of analysis for the following, was selected to be 1 hectopascal (hPa) ≡ 100 Pa ≡ 1 mbar. For consistency, readings are adjusted to a datum of mean sea level to take account of the reduced pressure at places above sea level (1 hPa at or near sea level equals approximately 7.5 meters or 25 feet in height), thus being representative of the low profile, near sea surface, for the current and the following variables.

It worth’s mentioning, that according to Kutiel, H. et al.-2001: (a) The variability of the SLP decreases from the Balkans towards the Arabian Peninsula and is much larger in winter as compared with summer. (b) Relationship between rainfall in Turkey (where the survey was conducted) and the regional SLP is large in winter and not existing in summer. (c) Pressure patterns associated with dry conditions, show usually positive SLP departures, whereas, pressure patterns associated with wet conditions show usually negative SLP departures. (d) There is a great resemblance between pressure patterns associated with wet conditions and correlation maps of the same months. Wet condition as in means of (1) VS, enforce a possible time-delayed pattern of precipitation rates towards chl-a.

Fig. 21. Time series of Sea-Level pressure for Dec. 2002-Jan. 2013, derived from MERRA monthly history data collections.
6. SP (Surface Pressure) VS CHL-A

Surface pressure often refers to the atmospheric pressure at a location on Earth's surface. It is directly proportional to the mass of air over that location. It follows the same principles as with SLP. It was selected as being complementary and proportional to the SLP, expressed as MSLP (Mean Sea Level Pressure), by the level of hPa.

**Area-Averaged Time Series (MAIMCP-ASM.5.2.0)**

*Region: 22E-26E, 37N-41N Level: 1.0hPa*

![Surface Pressure at 1.0hPa time series derived from MERRA monthly history data collections. Dec. 2002-Jan. 2013.](image)

**7. Northward wind component VS CHL-A**

Northward winds (southerlies) play an important role into the spatio-accumulation of the surface masses, towards the north Greek shoreline. As displayed on its time series in 1hPA (isobaric layer selected to be representative of the surface Pelagos meteo-SLS-SP-current variable profile), these winds, that as expected within their periodicity, are found to be in late year or with more of a rough profile, in the beginning of the new year (Nov, Late Jan. to Febr., respectively), are found, as far as also the more rough profile emerging and descending rapidly considered, to follow:

1. The descending SP profile at mid-winter to end (as expected). With the exception of the year 2012, when the Northward components are met of along higher surface pressures, rather than descending ones, that also stand out by their overall min. value in the beginning of the year. Further, are met in this way with:

2. The descending SP profile, in the case of their reappearance in the beginning of the year, but most important as displayed, with the almost similar linear increase as in the chl-a concentration variable values in 2006 and 2010 peaks. In the case of 2012, where the overall
peak of chl-a concentration is met, there is a sudden Southward profile of wind component that up until mid-March, turns onto the Northward.

What can be outputted by the above aforementioned? There is a case of when Northward wind components are met with higher atmospheric pressure values, that the overall max. peak of chl-a concentration is met and, in addition, a tendency of when Northward components are met with descending SP levels (following the expected SP low-Northelies as wind patterns), that peaks of chl-a are met also.

The first could be logically explained, in a way, as Southerlies have a more of a relative nowadays sudden and of a more associated with extreme events profile (along with the contribution of the warm and solar radiative clarified path that a high surface pressure provides), extending in this approach and the radiative accumulation depth, in retrospect of the season that is met (ending Winter).

This sets the comparative parallelism, on this peak correlation. Further on, in the years 2006, 2007, 2008, 2010 and in 2009, 2011, with a small time delay of end winter-to beginning of the next year, for the last mentioned years, the increase in chl-a concentration is met, or vise-versa if you like, especially as far as the peak value-cases are considered, along with an increase of the southerlies (sudden change from Southward wind component to Northward). This, either with half a month time delay (a meaning that this factor stands for the ecosystem's time for the surface masses to response upon the bloom transportation towards the north, along with either cyclonic or anti-cyclonic aqua-behavior, depending further sub-regionally on the spatio-temporal. dynamics), or/and with an almost linear-temporal profile of value increase, as displayed in the years 2006, 2007, 2008, 2010 (2012 tends to follow this, but a fraction later, after the change of Southward-to Northward wind profile). This, though, as an additional note, with the time-passed SLP-SP high pressure, sets another, as pre-documented above, extend on the correlation of the current variable when high ascending or descending pressures are met, reminding that even though, there had been no absorption coefficient peaks in 2010,2012, the tendencies of the euphotic zone depth variable, along CDOM and current ones, give an overall perspective of their tendencies and possible to resulting correlation with these co-factors.

This has an extensive significance on the co-contribution of these winds towards the bioaccumulation of the algae blooms in the north Greek shoreline, where and the most resident recordings of these phenomena are me after all (e.g. Kavala bay, Thermaikos Gulf in Thessaloniki etc.). Had the time series been longer, covering an extended past period, could then this tendency, be found to be periodical-tended?

Nevertheless, the available data under disposal (max. covering this period of years), indicate, that this could not probably be the case, as being rather a form of display of an eco-system fluctuation, or to an extend reformation under forceful dynamic behavior, especially within the period of 2010-2012, when algae blooms rich in detritus and caused most likely by terra and Bosphorus water masses contribution, followed additionally by atmospherically deposited contribution and along of an increased bottom suspension-deposition, displayed relatively time delayed dispersion, and a time-base continuum rather small, thus being and marks of future study advance for a possible from tendency to periodicity.
Fig. 23. Northward wind component, as derived by MERRA monthly history data collections. Dec. 2002-Jan. 2013.
4.3. Combination of Results

From the above, there had been some rather interesting results concerning the correlation of the concentrations of chlorophyll-a (as means of expressing the extent and dynamics of the algae bloom). Chl-a is the most predominant variable for the primary productivity in the test area.

Firstly, displayed time series of MODIS-Aqua and SeaWiFs showed for the last 6 years a rather alternating era for the phenomenon. After a period of a more of a normalized fluctuation in the levels of chl-a concentrations, which extended from 1999-2006, there came the peak of 2006, 2010 and 2012. Estimating and by the residents empirical experience, displayed for example in the current study as a retrieved article concerning the Mediterranean shag, the last few years give a hint of something going on, that affects the biogeochemical natural advance of the phenomenon.

The seasonality of the algae blooms has a clear display, but in the 2010-2012, seems to be prolonged. Emerging mainly from late October until early-late May naturally, it extends its bioaccumulation state until mid-June. The year of 2010 showed the second significant peak, responding to the estimations by residents in the islands of the North Aegean Sea. The phenomenon by its self could be considered as ‘red stand light’ for the area, especially as far as this prolonged character is met.

In the precipitation variable severable (deliberate) questions emerged by its correlation with the chl-a concentration. Questions, that gave the hint of the first impression for the last few years. There is as pattern a general follow up of chl-a advance in the plots that was prescreened by few months before advance in precipitation rates. The case of not so, in the year of 2012, as mentioned and in the analysis, brings questions about the extent of this phenomenon to be always only predominately depended on the masses from Dardanelles straight of the sea of Marmara in Turkey, and/or by the riverine discharges, but mostly the extend of a new ‘and’, that is its correlation with multiple water column variables and sea-air ones, that present by definition a not so direct relationship with the documented and well respected dominant above causes. The decade min. of the next variable of the Euphotic Zone Depth gives a more clear perspective about the drifting of an ecosystem in the state of effort maintaining its natural equilibrium.

The depiction of an overall min of the EZD factor, within 2010, stands as ‘ring bell’ that for some reason this precedes by step-time the attenuation of chl-a, in retrospect that is depicted once in this decade. The bioaccumulation itself could cause such min. as the 2010 peak in chl-a concentration may prove. Along with the prolonged period of reduce by its max, this factor sets a more of a preparing character evaluation for the ecosystem, in terms of when met prolonged or and minimized, there is evident instability, that in the case of chl-a concentration is expressed as the two near peaks (2010, 2012), the late one which stands also as the overall one for the decade.

As mentioned in the analysis, the 2005-2006 transitional one peak in Absorption Coefficient, complementing the high peak of chl-a concentration in 2006, is an indicator that the absorption was then mainly attributed due to phytoplankton blooms (as this can be considered as the natural periodical phenomenon), but rather, the peaks in 2010 and 2012 are not followed by pigments in the coefficient. The back-scattering-larger (less absorption) in these cases can be, in this way, empirically explained as river outputs, bottom suspension, atmospheric deposition, etc. This depicts, in this way, a meaning of a higher man-terra-atmospheric induced composed detritus, something that levels down the coefficient. Following the findings of the EZD factor, this result emphasizes man-derived underground
for the 2012 peak in chl-a concentration. The next factor CDOM, excludes the (*) factor analyzed in this variable section.

As mentioned, phytoplankton can directly contribute to the autochthonous production of colored humic-like substances in the ocean. The role of this factor, which has a two end way of approach, depends on its tendency. The from 2010 and after random fluctuation, that turns onto a max-min. inner change, gives credit that the truth of the role of CDOM upon phytoplankton and primary production is in the middle. That is, that photoprotective character or radiative accumulating one, can be evaluated on via normalized time of fluctuations, and not when sudden peaks are met. In these cases the more, as within 2010-2012, the fluctuation, the greater the inherent and following instability.

Also, to what extend this rough advancing and descending fluctuations of this variable at that time could not have by nature created a more of a high, rather than medium ‘beneficial to phytoplankton when metals present in the medium reach toxic concentrations complexes’ was documented as reference in the analysis, of metal complexes (found also in high levels in dead fish populations), that either suffocated by lack of oxygen due to its consumption by the rapid and prolonged blooms and/or found to have high toxic metal complexes. Remember the photo of the dead fish in Kavala bay in 2010, in the introductory section? There must have been, even in the case of the (*) factor some relation to pure up on another year in the EZD factor, which did not, and was only found within the 2010 year. The matter of the ecosystem trying to maintain equilibrium, which by its self is most interesting, seems to predominate from an altered from so on year 2010 pattern. It remains to an extended, further research on the following years, to advance upon these question-results-evaluations.

The SLP and SP factors gave a dominant display of under what atmospheric pressure there is a derivative of precipitation follow up (wet condition, low temperatures, humidity and so forth characteristics of SLP-SP low level values, as in means also towards the (1) VS, enforce a possible time-delayed or a nearby pre histored pattern of precipitation rates towards chl-a.). Additionally, also gave the advance of correlating and onto maybe the most important outcome of this study that the Southerlies (Northward component winds or South winds) seem to be tended correlated with the peak-extended periods of accumulation of chl-a (algae blooms) in the North Aegean Sea. A fraction of the extend of this kind of relation, was given in the analysis of the Northward wind component (especially with implications and applications that has upon the sea-surface masses, that after all hold the first role in the primary production of the Pelagos, accepting the terra-precipitations, withholding and scattering the solar radiative components, essential for this cycle, and so on). These winds function also as an additional enforcer to bioaccumulation when drifting these surface masses towards the north Greek coastal zone, hence providing vital space for deeper masses to surface elevate (via and e.g. localized upwelling, such as summer-autumn one in along north coast of Asia Minor), even more elaborating a rich-organic re-suspension in the water column, vital for phytoplankton consumption, providing the sub ground towards spring peaks. This leading to algae blooms, that when met along dense/haline-differentially layer stabilized (reducing the suspension rates and creating hypoxic or anoxic circumstances, in terms of dissolved oxygen in sea bottom), produce greater probabilities of Harmful Algae Blooms, especially if local terra-waste loads (of e.g. especially in the latest years overburdened contribution via rivers in northern Greece such as Strymonas, Nestos, Axios) is considered.
5. Conclusion

In a nutshell, the less oligotrophic character of the North Aegean basin depicts upon:
(i) The terra discharges from mechanical derived off sedimentary profile (ii) The biologically induced production (iii) The wind transported incomes (iv) The hydrological circulation of material from the near shore basins. In the current study there has been an approach of the (ii) factor, as in accordance to its dependency upon oceanographic and meteorological constitutes. It is from the past implemented that for this area, the main contribution is derived by the riverine discharges, which are participating in advance, compared with the rest Aegean area, where more matter concentrations are met (6mg/l), but along with ephemeral currents (Lykousis et.al.-2002). This factor’s significance is moreover of critical, especially for areas not directly affected by riverine discharges, having a 65-72% cover in the first 150m of the water column. In addition the (iii) factor seems to be dominated by Sahara dust transportation, which for the overall basin of the Aegean is near 10-40g/m² (Nihlen&Olsson,-1995).

This (ii) factor component is controlled by variable and complex biogeochemical processes and can include (Aksu et. al.,1995, Lykousis et. al.,2002): (I) CaCO₃ which comes from phytoplankton, detritus of zooplankton and planktonic foraminifera, detritus of aragonites coming from pteropods, (II) Biogenic dioxide of pyrite, mainly be shells of diatoms.

The above mentioned data under analysis and display, in accordance with the as possible plain methodology selected for the current study, give an overview of how, a chain of reaction, short of speaking, upon the selection of variables, led to some rather interesting evaluations about the current state of the dynamics of the phenomenon of algae blooms in the North Aegean Sea. The SST (Sea Surface Temperature) was left out of the current study, as its correlation with chl-a concentration and its pattern of vertical North to South co-differential, is well analyzed until today. The co-display of and in situ data from e.g. the Poseidon System of the Hellenic Center for Marine Research, where not included as: 1. Several time series gaps appear for the decade under study, so as to be properly co-evaluated with the satellite derived ones and 2. Since the SST, due to the aforementioned reasons, was not included (as means of indirect perspective of chl-a), there came a more solid approach upon satellite remote sensing analysis, emphasizing on the factors mentioned in the analysis. 3. The hard majority of the citations referendum proves clear verification between satellite derived data and the in situ ones. Having been the analysis focused on an even smaller area of interest, the co-use is a must, for as the more regional the profile of the analysis (if this could be summed up as an empirical ‘general’ rule’), the more the declination between from space and local monitoring products.

Much of the current bibliography has been focusing, either on the primary biological character of its display, then the chemical, then the physical and within the last decades, on the combination of these. In past few years, there came a co-use of satellite and the in situ data, which on the most cases, proved complementary (thus, in the current study there comes an effort of evaluating-resulting with the use-as the title of this dissertation indicates-of applied satellite remote sensing).
On the other hand, there is a new era of remote sensing with user-friendly states, such as the GIOVANNI system of data-to-science interface, that proved to be efficient on evaluating the quality and to an extent the quantity correlations between dynamically inter-connected variables, such as these mentioned in the current study.

Taking into account, furthermore, that the animations, currently displayed un-stacked (as for the lat-lon. time averaged map plots, which have and the predominant spatio-temporal thesis for the analysis), are correlated with each and by deliberate descending documented order towards the selected variables (order not at all randomly displayed in the chapter of the results), shows rather how an oceanographic parameter is directly or in a mid-direct way depended on the attributes of a meteorological one (or/and vice-versa). This can be also considered to be vice-versa, as the dynamics of an ecosystem lead a multiple system of inter-connections, especially as far as ecosystems expressing phenomena as these, that extend and to the vertical profile (water column), and with rough along special characteristics upon the surface (immediate response, or with a better way to put it, along sea-air interactions). In this case a Pelagos semi-closed, as the North Aegean Sea.

Precipitations rates, Euphotic Zone Depth, Colored Dissolved Organic Matter, Absorption coefficient for phytoplankton, Sea Level Pressure, Surface Pressure and Northwards wind component are inter-connected, as means of description and derivative components of the nature’s dynamic behavior and spatio-temporal dispersion of the algae blooms in the North Aegean Sea.

The applications among satellite remote sensing are even limitless. It leans on the next years to come, for similar to advanced studies so that to enhance the possibility of such tendencies to attire periodical role, or to be more clearly correlated, as expression phases of a marine scenery in adaptation state, towards a more and more fluctuating regional and global profile of atmospheric and oceanographic display.
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