Scientific Reports in Life Sciences 1 (2020): 29-37

DOI: http://dx.doi.org/10.22034/sris.2020.137097.1001

Sientific reports in life sciences

http://www.scientific-reports.com

Temporal Characteristics and Patterns of Sea Surface Temperature and Chlorophyll in the Ligurian Sea (NW Mediterranean)

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Received: 25 Sep. 2020 / Revised: 21 Oct. 2019 / Accepted: 25 Oct. 2020 / Published online: 28 Oct. 2020.

Abstract

Global warming is a well-known phenomenon, that increasing average of temperature. Oceans are affected directly from this phenomenon with changing its abiotic and biotic components. The Mediterranean Sea is known as the strongest warming sea in the world, therefore, there is big concern on understanding the pattern in change and adaptation. The Ligurian Sea is known with two main pelagic zones, which have distinctive characteristics than each other. In this study, it is aimed to understand, characterize and describe inter- and intra-annual properties of sea surface temperature and chlorophyll, as key biotic and abiotic factors of marine environments, in the marine regions of the Ligurian Sea. Remotely sensed data-sets of sea surface temperature and chlorophyll concentration between 2013 and 2019 were used for this purpose. Results showed that the regions have significantly different temperature and productivity within year. While high variation in temperature detected in onshore region, productivity was less than twice in offshore region. Inter-annual analysis showed trends showed similar patterns in the regions.

Keywords: abiotic, biotic, variation, intra- and inter-annual trends, the Mediterranean Sea

Introduction

Global warming is one of main problem in the world. Since it is the reason for increasing of acidity and temperature (Doney *et al.* 2012 and references therein), It has an important impacts by providing various stresses on marine ecosystems (Snelgrove et al. 2004). As pointed out by the changes have various impacts on biological components, which lead to alter ecosystem structure and function (Doney *et al.* 2012). It is highly advantages that monitoring biotic (Leach *et al.* 2016) and abiotic (Pearson and Dawson 2003; Mantyka-pringle *et al.* 2012) components of the ecosystem to understand current status of ecosystems. Temperature as abiotic factor of the marine ecosystem can be used an indicator of impact of climate change (GCOS 2017). Increased temperature over years effects water column by forming stronger thermal stratification. In those cases, transportation through the column becomes limited (Hordoir and Meier 2011), consequent changes are reason the some organisms can be eliminated due to lack of adaptation (Doney *et al.* 2012). Consequently, changes in transportation system and physical conditions also changes biological components and process such as productivity (van de Poll *et al.* 2013). Chlorophyll is another indicator that can be used as proxy of phytoplankton biomass. It is also considered as a tool to understand the response of marine systems (Colella et al. 2016). Additionally, both variable, temperature and chlorophyll, are available globally in time series due to having physical numerical models (for example Clementi *et al.* 2019) and retrieved data from satellite technology (for instance, Acker and Leptoukh 2007).

Trend of global warming over the last three decades were well documented for the Mediterranean Sea. A consistent warming was reported by most of the study for the entire Mediterranean Sea (Pastor *et al.* 2018, Pisano 2020) and its sub regions (Nykjaer 2009, Skiliris *et al.* 2011, Bengil 2018, Bengil and Mavruk 2019). There are also studies to evaluate inter annual pattern of chlorophyll from the Mediterranean, concluded spatial variation in trends (Colella *et al.* 2016, Bengil 2018, Bengil and Mavruk 2018). The Ligurian Sea is a branch of the Mediterranean Sea in the western part and characterizes with narrow continental shelf and steep deepening (Espesito and Manzella 1982). Additionally, its coastal region has under impact of intense rive plumes. The Ligurian Sea is the most known region in the Mediterranean Basin, especially for circulation patterns (Astraldi and Gasparini 1992, Picco *et al.* 2010), nutrient properties (Marty et al. 2002), biological components and productivity (Raick et al. 2005, Lazzara et al. 2010), and bio-optical properties (Niewiadomska *et al.* 2008, Bengil *et al.* 2016). There are distinctive three sub regions in the Ligurian Sea; offshore, onshore and transition zone with different water characteristics. Even though characteristics of the region is well known, inter- and intra-annual properties of its sub regions is not well defined. This study therefore aims to understand, characterize and describe inter- and intra-annual properties of sea surface temperature and chlorophyll, as key biotic and abiotic factors of marine environments, in the marine regions of the Ligurian Sea.

Material and methods

Two separate region that represent offshore and onshore zones of the Ligurian Sea were chosen for further analysis (Figure 1). Data set used in this study provide monthly values of sea surface temperature and chlorophyll as average of selected regions. The data sets were extracted from the Giovanni online data system; developed and maintained by the NASA GES DICS (Acker and Leptoukh 2007). The MODIS Aqua products spatial resolution was used to retrieve monthly Chlorophyll-a concentration (Chl) and sea surface temperature (SST, night time) data in a 4 X 4 km spatial resolution and a time period between 01/2003 and 12/2019. Detailed information about the algorithms of the products are presented in the OceanColor website (https//ocean-color.gsfc.nasa.gov).

The minimum, maximum, average and standard deviation (sd) of each variable was given to describe the general characteristics of the regions. To analyze difference between the descriptive of datasets in both region, Welch's two independent samples t-test and Levene's test for homogeneity of variance were performed in the different frames (annual, seasonal and monthly) of the same dataset. Additionally, a Linear Fitting with time in different frames were applied to evaluate trends of SST and Chl in time period of the study. The intercept and slope of linear trend lines with 95% confidence interval (ci) were estimated by using linear regression. Slope values and their ci were used to evaluate trends in different time period.

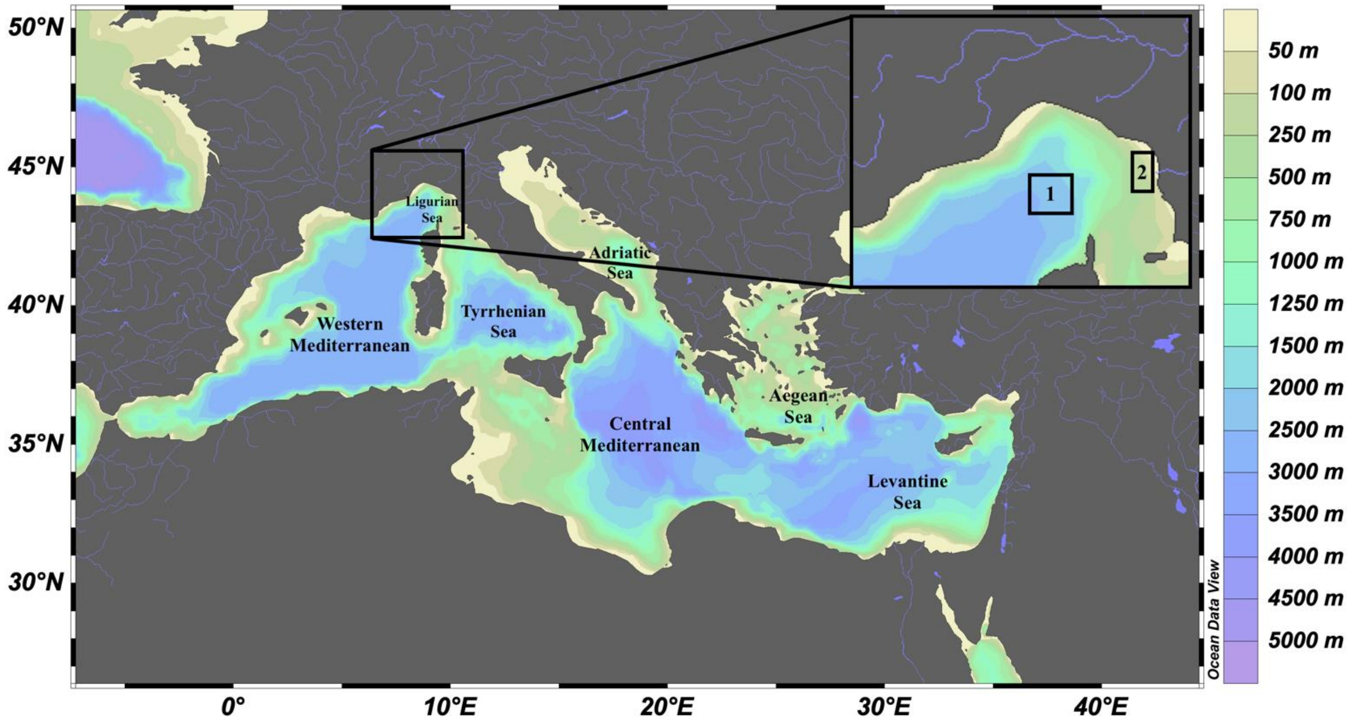

Figure 1: Study area; black boxes show selected region in offshore (1) and onshore regions (2). Figure was produced by using basemap from Ocean Data View (Schlitzer 2020)

Results

It is found that annual mean of SST was 17.83 ^oC in offshore region and 18.36 ^oC in onshore region of the Ligurian Sea. Results of seasonal descriptions showed that summer has the highest seasonal mean value of temperature with 24.54 ^oC in onshore region. The region also had the lowest seasonal mean SST as 12.65 ^oC in winter season. In additional to this, July was the hottest month (27.47 ^oC and 27.41 ^oC in offshore and offshore, respectively), as the coldest SST were measured in January (12.48 ^oC and 11.20 ^oC in offshore and offshore, respectively). Descriptions of SST for study period were presented in Table 1 for annual and seasonal time frame, and in Table 2 for monthly time frame.

Regarding to Chl in the Ligurian Sea, annual mean chlorophyll concentrations were found to be 0.37 and 1.17 mg/m^3, in offshore and onshore regions, respectively. The highest seasonal mean Chl was measured in winter (2.09 mg/m^3) from onshore region, with, while the lowest seasonal mean Chl was in summer (0.11 mg/m^3) from offshore region of the Ligurian Sea. Results of monthly descriptions indicated that the most productive month is February (max 4.35 mg/m^3) in onshore region, as the lowest Chl were measured in June, July and August, with 0.11 mg/m^3. Descriptions of Chl for study period were presented in Table 1 for annual and seasonal time frame, and in Table 2 for monthly time frame.

Comparison between regions showed there is no difference between overall annual mean SST in regions. Seasonal comparison showed that there is significant difference between mean SST value of regions in winter and summer ($p<0.001$). Additionally, months from January to October showed significant difference between monthly mean values of s SST ($p<0.05$). Regarding to Chl, it is found to be significant difference in each comparison of annual, seasonal and monthly mean Chl ($p<0.001$). Seasonal and monthly distributions of mean SST and mean Chl and their standard error were presented in Figure 2.

Linear fitting of SST with time showed no significant negative or positive trend in slope value during the study period in both region. However. Seasonal fitting showed significant of increasing trend in winter and spring and decreasing trend in summer and autumn for onshore region, while only positive trends were detected in winter and summer for offshore region ($p<0.05$). Monthly evaluation of SST indicated significant positive trends in January, February and April for offshore region, as only significant positive trend was seen in April. In order to results from linear fitting of Chl with time, showed only significant trends in seasonal time frame. While significant negative trends were found in Spring and Summer, only significant positive trend was detected in Autumn for both regions ($p<0.05$) (Table 3).

Table 1: Descriptive statistics of annual and seasonal data sets of sea surface temperature and chlorophyll in study period

		Temperature (offshore)	**Temperature (onshore)**	**Chlorophyll (offshore)**	**Chlorophyll (onshore)**
Annual	**max**	27.47	27.41	1.99	4.35
	mean	17.83	18.36	0.32	1.17
	std	4.21	4.74	0.28	0.96
	min	12.48	11.20	0.11	0.14
Autumn	**max**	21.96	21.83	0.32	3.58
	mean	17.05	17.66	0.19	0.99
	std	2.35	2.47	0.05	0.81
	min	13.22	13.61	0.12	0.21
Spring	**max**	24.78	24.37	1.99	3.43
	mean	17.60	18.61	0.58	1.34
	std	2.97	3.14	0.43	0.90
	min	13.67	13.93	0.13	0.25
Summer	**max**	27.47	27.41	0.24	0.59
	mean	23.47	24.54	0.15	0.24
	std	1.57	1.23	0.03	0.10
	min	20.80	21.80	0.11	0.14
Winter	**max**	14.73	14.77	0.61	4.35
	mean	13.19	12.65	0.37	2.09
	std	0.48	0.87	0.10	0.70
	min	12.48	11.20	0.22	0.45

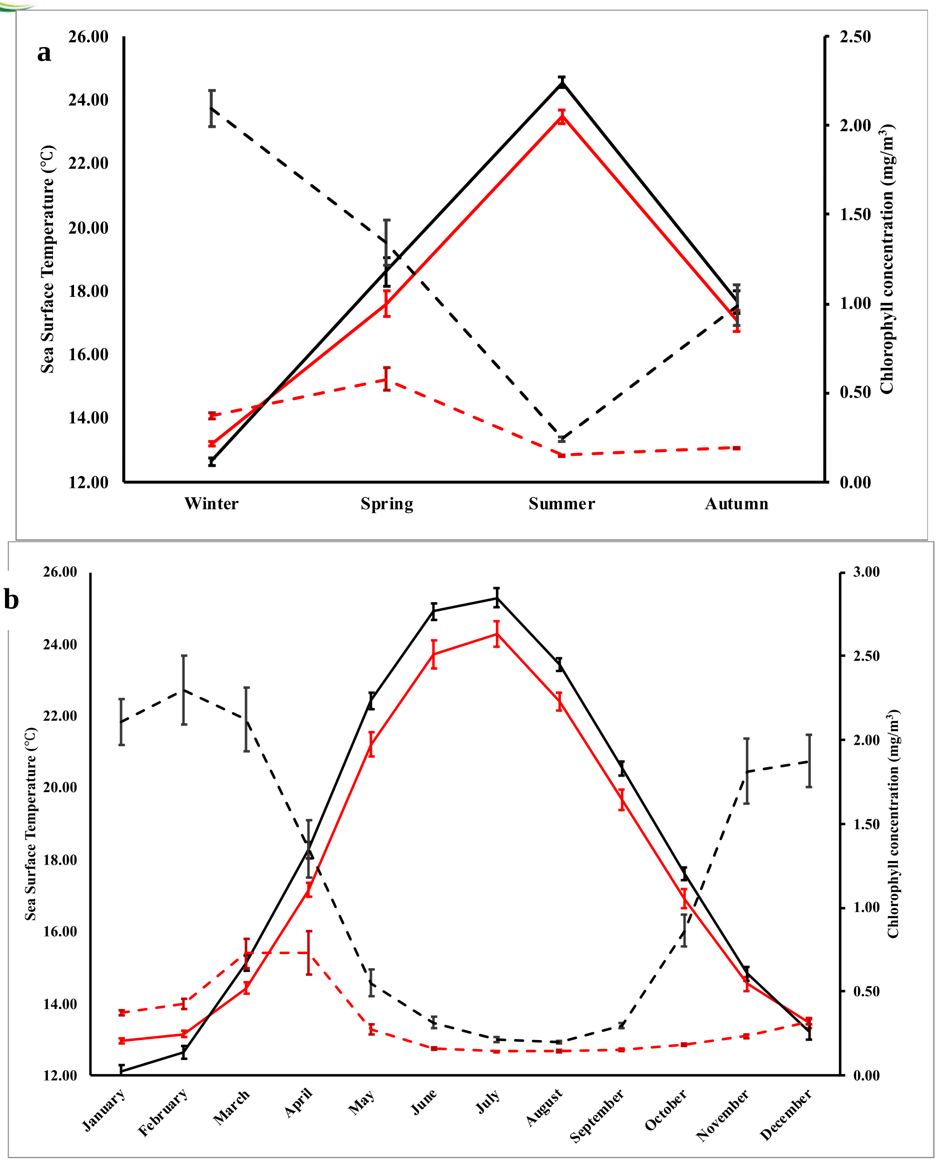

Figure 2: Seasonal (a) and monthly (b) distributions of mean values of temperature and mean chlorophyll and their standard errors; black color shows onshore region; red color shows offshore region; solid lines are SST; dashed lines are Chl; bars indicate standard error

Table 2: Descriptive statistics of monthly data sets of sea surface temperature and chlorophyll in study period.

Month		Temperature (offshore)	Temperature (onshore)	Chlorophyll (offshore)	Chlorophyll (onshore)
January	max	13.42	13.54	0.52	3.13
	mean	12.96	12.10	0.37	2.11
	std	0.30	0.70	0.06	0.56
	min	12.48	11.20	0.29	0.97
February	max	13.86	13.76	0.61	4.35
	mean	13.15	12.64	0.42	2.30
	std	0.31	0.68	0.12	0.85
	min	12.75	11.64	0.22	0.45
March	max	15.84	16.66	1.66	3.43
	mean	14.43	15.13	0.73	2.12
	std	0.62	0.85	0.36	0.77
	min	13.67	13.93	0.28	0.64
April	max	18.47	19.87	1.99	3.28
	mean	17.17	18.27	0.73	1.35
	std	0.80	0.93	0.53	0.71
	min	15.51	16.40	0.21	0.46
May	max	24.78	24.37	0.64	1.54
	mean	21.20	22.42	0.28	0.55
	std	1.38	0.91	0.12	0.33
	min	19.45	20.63	0.13	0.25
June	max	26.43	26.86	0.22	0.59
	mean	23.72	24.91	0.16	0.31
	std	1.57	1.01	0.04	0.14
	min	21.62	23.48	0.11	0.18
July	max	27.47	27.41	0.21	0.47
	mean	24.29	25.29	0.14	0.21
	std	1.49	1.06	0.03	0.07
	min	21.98	23.82	0.11	0.16
August	max	24.19	24.71	0.24	0.28
	mean	22.40	23.42	0.14	0.20
	std	0.98	0.72	0.04	0.03
	min	20.80	21.80	0.11	0.14
September	max	21.96	21.83	0.23	0.53
	mean	19.68	20.54	0.15	0.30
	std	1.21	0.77	0.03	0.08
	min	17.48	19.24	0.12	0.21
October	max	19.46	19.24	0.24	1.68
	mean	16.92	17.61	0.19	0.86
	std	1.04	0.77	0.03	0.40
	min	15.00	16.12	0.13	0.33
November	max	15.97	16.13	0.32	3.58
	mean	14.54	14.83	0.23	1.81
	std	0.86	0.74	0.05	0.79
	min	13.22	13.61	0.17	0.47
December	max	14.73	14.77	0.46	2.88
	mean	13.46	13.20	0.32	1.87
	std	0.63	0.88	0.06	0.64
	min	12.67	11.82	0.24	0.70

Table 3: Slope value and their confidence interval from linear fitting of variables with time in both regions. Bold values indicate statistically significant trends (p<0.05)

	Temperature (offshore)	Temperature (onshore)	Chlorophyll (offshore)	Chlorophyll (onshore)
Overall	0.005 ± 0.01	0.004 ± 0.011	-0.001 ± 0.001	-0.001 ± 0.002
Winter	**0.015 ± 0.008**	**0.034 ± 0.014**	-0.001 ± 0.002	-0.009 ± 0.013
Spring	0.009 ± 0.057	**0.194 ± 0.024**	**-0.014 ± 0.007**	**-0.042 ± 0.012**
Summer	**0.033 ± 0.029**	**-0.033 ± 0.022**	**-0.001 ± 0.001**	**-0.003 ± 0.002**
Autumn	0.014 ± 0.045	**-0.144 ± 0.024**	**0.002 ± 0.001**	**0.04 ± 0.011**
January	**0.032 ± 0.027**	0.038 ± 0.073	0 ± 0.007	-0.052 ± 0.054
February	**0.04 ± 0.026**	0.051 ± 0.068	0.005 ± 0.013	-0.012 ± 0.091
March	0.056 ± 0.061	0.047 ± 0.092	-0.001 ± 0.006	-0.019 ± 0.068
April	**0.048 ± 0.062**	**0.082 ± 0.08**	-0.003 ± 0.039	0.032 ± 0.082
May	-0.039 ± 0.084	-0.003 ± 0.1	-0.04 ± 0.053	-0.041 ± 0.073
June	-0.017 ± 0.15	0.021 ± 0.098	-0.004 ± 0.013	-0.012 ± 0.035
July	0.097 ± 0.162	0.052 ± 0.106	-0.001 ± 0.004	0.008 ± 0.014
August	0.125 ± 0.146	0.065 ± 0.109	-0.002 ± 0.003	0 ± 0.008
September	0.092 ± 0.094	0.048 ± 0.074	-0.003 ± 0.003	-0.002 ± 0.004
October	0.072 ± 0.126	0.057 ± 0.077	-0.002 ± 0.003	0.002 ± 0.008
November	0.066 ± 0.107	0.052 ± 0.079	-0.002 ± 0.003	-0.025 ± 0.041
December	0.063 ± 0.087	0.037 ± 0.077	0.001 ± 0.005	0.021 ± 0.085

Discussion

Two distinctive zones of the Ligurian Sea evaluated in terms of intra- and inter-annual variations. The results clearly shows that temperature and productivity properties of these zones are significantly different than each other in all months of a year in the study period. Similar to this study, biogeochemical properties of both zones were reported for relatively limited time period or specific seasons (Marty *et al.* 2002, Raick *et al.* 2005, Lazzara *et al.* 2010, Bengil *et al.* 2016). The study confirms distinctive properties for continuous temporal resolution for long time period. The study also pointed out that onshore region has higher annual variation in SST and Chl. Onshore can be characterized with warmer surface water in summer and colder in winter, while increasing productivity period from October to May. However, productivity is lower in onshore and has relatively increased pick from February to May. Since variation of month in pick, bimodal bloom structure did not observed clearly in time period of this study as reported by Raick *et al.* (2005). While strong late winter-spring bloom were consisted in offshore region, time of annual main pick varied from October to April depend on year of study period.

Study also highlighted quite higher productivity in onshore region were observed as parallel to findings of Lazarra *et. al.* (2010). It should be also noted that the region can also characterized as higher annual variance in productivity. In additional to higher river flux into the region, these distinctive productivity deference may also explain consistent difference between bio-optical properties of both zones, that is reported by Bengil *et al*. (2016). Marty and Chiaverini (2010) reported increasing productivity in the northwestern Mediterranean Sea based on their field study from offshore region of the Ligurian Sea. Similarly, time series analysis by Colella *et al.* (2016) indicated increasing trend in Chl in the most of region in the Ligurian Sea. Interestingly, it is not found annual significant trend in Chl for both region. However, results shows negative trends in spring and summer seasons and positive trend in Autumn season for both regions. These significant seasonal trends might indicate for time shift in bloom picks over time period of the study.

The Mediterranean Sea has the strongest warming rate in the world (Giorgi 2006). Parallel to this, the Liguria sea has warming trend with effect to change its biota and communities (Bianchi *et al.* 2019). Pastor *et al.* (2018) reported significantly increasing annual, seasonal and monthly trend in all over the Ligurian Sea. Significant increasing trend was also reported by many studies (Pastor *et al.* 2018 and references therein). in regarding to spatial difference in SST trend in the Liguria Sea, this study found no significant annual trends. Seasonal trends has two groups; positive trends in winter and spring and negative trends in summer and autumn for the study. Additionally, April had increasing trend in SST for both region. This difference in trends might highlight difference characteristics of SST in time period of this study, which is different that previous studies. It should be also noted that analysis methods used in trend estimation can be another reason for this difference in trends. As conclusion, onshore and offshore zone of the Ligurian Sea have different characteristics in SST and Chl between 2003 and 2019. A constant pretty higher productivity can be characterized with onshore region. However, changes in these variable over time showed similar trends in the regions. Trends indicate a possible time shift in productivity pick to Autumn.

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