SEASONAL TREND DECOMPOSITION OF MODIS CHLOROPHYLL BIOMASS TIMES SERIES IN THE ALGERIAN BASIN

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Abstract. NASA (National Aeronautics and Space Administration) has acquired to the present-day data on the temporal and spatial distribution of chlorophyll-*a* (Chl-*a*) biomass from the Moderate-Resolution Imaging Spectroradiometer (MODIS) Aqua sensor for ocean color. In our work, the daily Chl-*a* biomass was estimated from the MODIS product OC3M bio-optical standard algorithm. The Seasonal-Trend decomposition of time series based on Loess (STL) identified the temporal variability of the dynamical features in the MODIS products for Chl-*a* concentration time series in the Algerian Basin (AB) surface waters. The STL has the specificity to identify seasonal components changing over the time series composition, perfectly detects the presence of outliers, and is responsive to nonlinear trends. In the current work, this method was applied to a time series of 16 years in AB (Southwestern Mediterranean Sea) at 120 km offshore [0 to 120 km]. Decomposing the MODIS products into a trend, seasonal, and remainder components, the Chl-*a* indicated the dominance of the seasonal components with 108.7% from 2003 to 2018. Furthermore, interannual seasonal variation for Chl-*a* biomass showed the influence of the same sources of enrichment each year in the Algerian Basin.

Key words: Ocean color, Chlorophyll-*a*, MODIS, Time series, STL, Loess, interannual variability

1. INTRODUCTION

The Algerian Basin (AB) seems to be a particularly interesting study area (Harid *et al.*, 2022). This basin, which presents a specific surface circulation (Pessini *et al.*, 2020, 2018; Taupier-Letage and Millot, 1988), is characterized by an oligotrophic ecosystem in summer-autumn (D'Ortenzio and Ribera d'Alcalà, 2009; Harid *et al.*, 2018; Keraghel *et al.*, 2020; Perrot *et al.*, 2016) and by high chlorophyll-*a* (Chl-*a*) concentrations in winter-spring (D'Ortenzio and Ribera d'Alcalà, 2009), subject to anthropogenic pressure in the coastal area. Indeed, phytoplankton is the first link in the marine food chain and plays a major role in the carbon cycle at the global level and consequently in climate change. In remote sensing, the interaction of solar radiations with the ocean upper layer presents information on phytoplankton biomass (Mobley, 1994; O'Reilly *et al.*, 2000). Bio-optical algorithms allow the determination of Chl-*a* concentration in surface water, which is a proxy of phytoplankton biomass (Cullen, 1982; Huot *et al.*, 2007; Strickland, 1965).

Satellite data also provides information on the spatial and temporal dynamics of Chl-*a* in the surface seawater. Ocean Color Remote sensing is a precious help for marine environmental monitoring. Because of the availability of ocean color time series data provided by the MODIS sensor, the interannual variations of Chl-*a* biomass could be studied over various regions of the Mediterranean Sea.

In this context, this study aims to analyze the interannual variation of Chl-*a* in the AB, to get an overview of its seasonal and trend evolution using satellite measures. Furthermore, the authors use the Loess (LOcally wEighted Scatterplot Smoothing) seasonal-trend decomposition method to better describe the time series data.

2. STUDY AREA

The Algerian Basin, located in the southwestern part of the Mediterranean Sea, lies between 35°N and 40°N, from south to north, and 2°W and 8.7°E, from west to east. It is bordered in the east by the Alboran sub-basin, in the west by Sardinia, in the south by Algeria country, and in the north by the Balearic Islands (Fig. 1). The Algerian continental shelf is very narrow (Harid, 2022). Bottom depths greater than 2000 m are observed at 10 to 20 km offshore, while the average bottom depth of the basin may exceed 2600 m (Obaton, 1998).

On the other hand, the Algerian eddies propagated northwest with a mean diameter of 130 km (Cotroneo *et al.*, 2016). The vertical structure of the Algerian eddies shown the presence of recent Atlantic water in the surface and Levantine Intermediate Water in the deeper water (Cotroneo *et al.*, 2016; Millot, 1985; Millot *et al.*, 2006). The Algerian Basin is characterized by the presence of very energetic mesoscale cyclonic and anticyclonic eddies (Fig. 1), which have a large influence on the basin circulation. They also have an effect on the physical, chemical and biological component of water, phytoplankton biomass, and fishing areas (Cotroneo *et al.*, 2021).

3. METHODS

3.1. Satellite data

The signal measured by the satellite sensor represents the luminance of solar irradiance reflected by the superficial layer of the ocean (Mobley, 1994). To process, analyze, and interpret this signal in the surface layer of the AB, we used daily data of MODIS sensor (Moderate Resolution Imaging Spectroradiometer, NASA) onboard the AQUA satellite, launched in May 2002, with 1 km of spatial resolution.

The MODIS Level-2 Chl-*a* products were obtained from the NASA Goddard Space Flight Center through the Ocean Colour Web portal (http://oceancolor.gsfc.nasa.gov/). The algorithm used for the transformation of raw satellite MODIS data to Chl-*a* concentration is the NASA OC3M standard algorithm (O'Reilly *et al.*, 2000). A set of 5840 daily MODIS Chl-*a* composite maps from 2003 to 2018 have been downloaded from NASA's Ocean Color Web (2019). These data are remapped in the AB rectangle grid [35°N and 40°N, 2°W and 8.7°E] and analyzed, as described in Harid *et al.*, (2022).

3.2. STL method

There are different ways of analyzing time series data. Indeed, the authors used the method that breaks it down into different components. One way of doing this informally is using the STL (**S**easonal-**T**rend decomposition of time series based on **L**oess) function. In this work, the authors used the STL package available in R software to decompose the time series average of the Chl-*a* concentration between 2003 and 2018. The details of the STL package are available in Hafen, (2016).

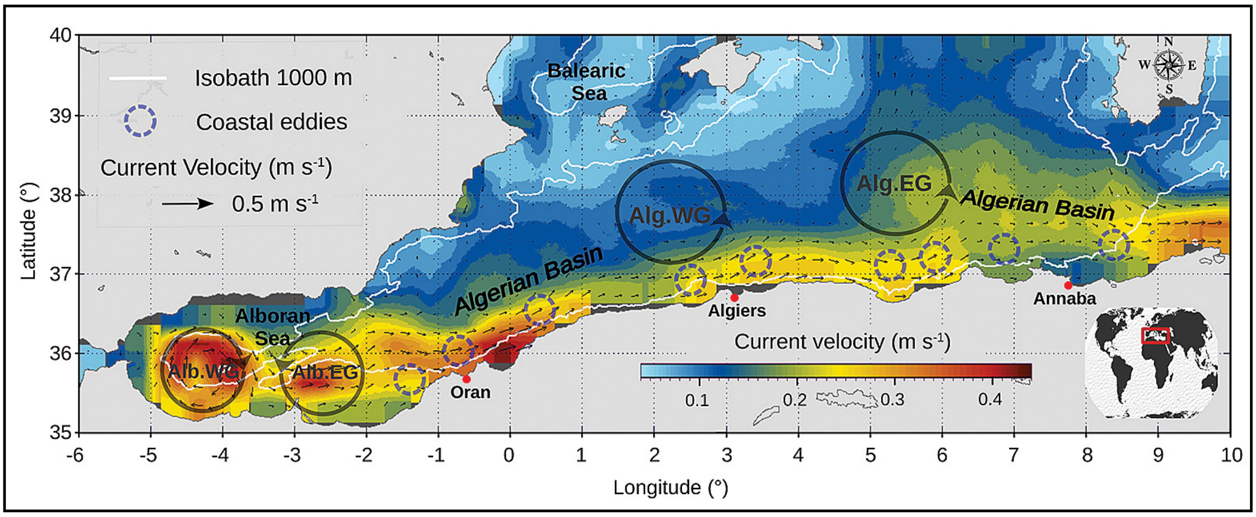

Fig. 1. Algerian Basin's geographical location (southwest of the Mediterranean Sea). Current velocity (m s^{-1}) averaged from 2003 to 2016 in the Algerian Basin, extracted from the CMEMS (Copernicus Marine Environmental Service) database of the SEA-LEVEL GLO PHY L4 REP OBSERVATIONS 008 047 altimetry data product (http://marine.copernicus.eu, last accessed February 27, 2019). The 1000 m isobath (white line) is superimposed.

The STL function decompose the time series into seasonal, trend, and remainder components using the Loess smoother (**LO**cally w**E**ighted **S**catterplot **S**moothing) as follows:

Time series = Trend + Seasonal component + Unexplained error (remainder)

Another way of analyzing the time series decomposition is to calculate the IQR (Interquartile Range). The summary function applied to the results of the STL method can identify which component is contributing the most to the observed changes over the time series. This is deducted from the percentage of the IQR for each component, which is computed from the IQR for each component relative to the IQR of the original time series.

3.3. Weather data

Meteorological data (from 2000 to 2020) such as air temperature, wind velocity, and precipitation were collected from the national meteorological office of Algiers-Algeria (ONM *"Office National Météorologique"*). Monthly and interannual averages were calculated. Also, the interannual anomalies were estimated for each parameter following this formula:

Anomalie = Annual average – Time series average

The authors used three different regions as representative of the region's climate for each part of the AB as follows: Oran represents the western climate (Western Algerian Basin), Algiers represents the central climate (Center Algerian Basin), and Annaba represents the eastern climate (Eastern Algerian Basin).

4. RESULTS

4.1. Interannual variability of Chl-a

The interannual variability of Chl-*a* in AB shows a relatively low amplitude (Fig. 2a) with a very regular summer minimum of 0.10 mg m^{-3}, while the productive season was characterized by a variable maximum, between 0.5 and 0.8 mg m^{-3}, as well as by a quasi constant duration. The 2012 productive season was an example of low Chl-*a* concentrations, while the 2017 productive season was relatively short with moderate Chl-*a* concentrations (Fig. 2).

The years 2009, 2011, 2013, and 2014 displayed relatively high temporally integrated production.

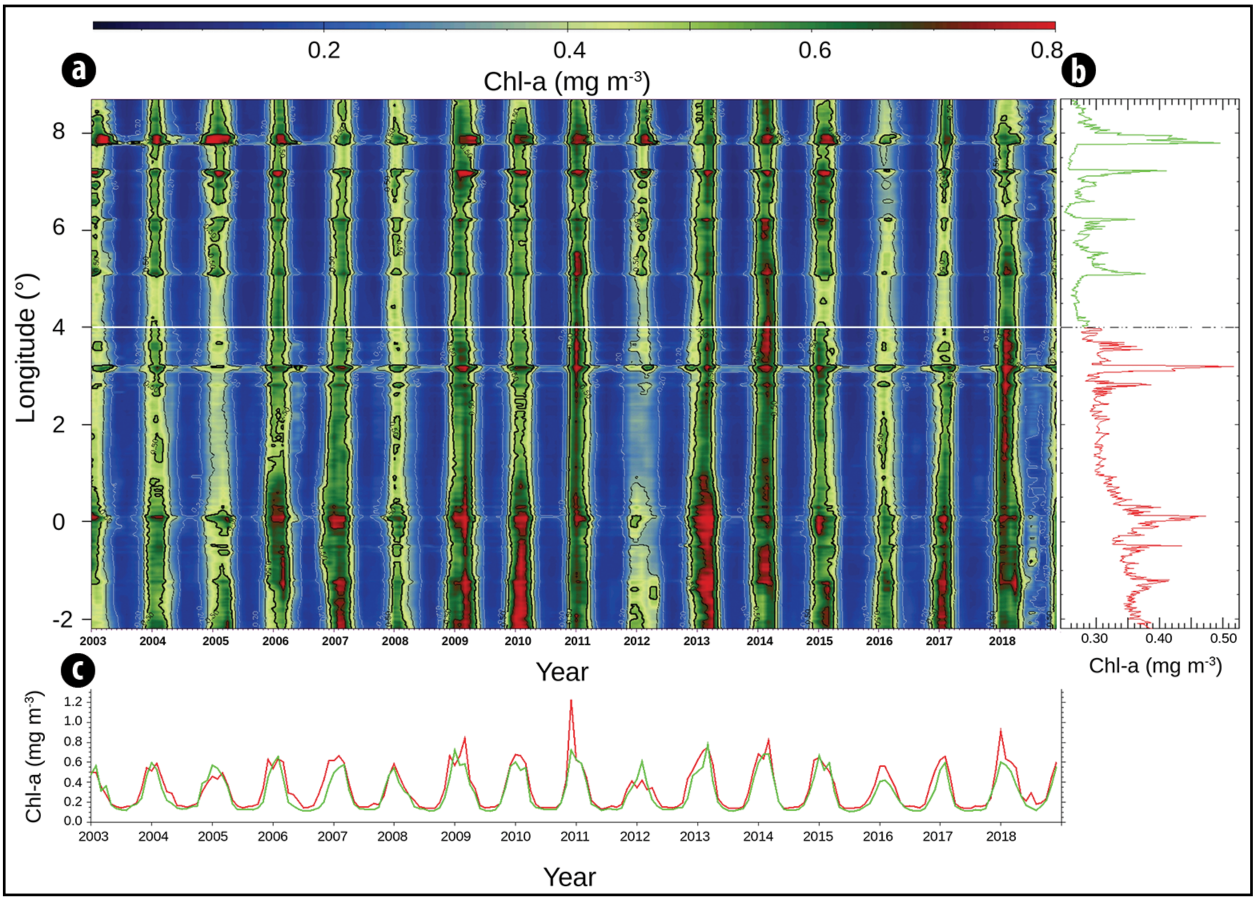

Fig. 2. Interannual variability of Chl-*a* concentration in the whole Algerian basin. (**a**) Hovmöller diagram of Chl-*a* averaged from 2003 to 2018 along a meridian transect [2.2°W to 8.7°E]. All values were averaged from the coast to a maximum distance of 120 km offshore. (**b**) Represents the average time series and (**c**) The average of longitudinal transect, for two areas from 2.2°W to 4°E (red lines) and from 4°E to 8.7°E (green lines).

Very remarkable peaks were detected in some years, during winter and/or spring blooms (Fig. 2a). The years 2009, 2011, 2013, 2014, and 2018 shown the highest values of the Chl-*a* concentrations, while the years 2005, 2008, 2012, and 2016 shown the lowest ones. Otherwise, the very low Chl-*a* concentration observed between July 2011 and July 2012 was very remarkable compared to the interannual seasonality from 2003 to 2018 (Fig. 2). The low values observed between summer and fall were less than 0.2 mg m^{-3}, except for the year 2018 when the values were slightly higher, especially in the western part of basin. In 2006, the summer started early and ended late in the eastern (Fig. 2a). In contrast, the 2006 summer was very short (Fig. 2c) in central and western parts. In 2017, the summer was longer compared to the other years and was similar for both the eastern and western regions (started early and ended late). Generally, the summer season was larger over the months in the eastern part than in the western part. On the other hand, the winter was characterized by peaks in the western part, except in 2012, the lowest year of the series, observed in the eastern part (Fig. 2b) (2012 was the lowest productive year). Also, it should be noted that in the eastern part of the basin, the Chl-*a* variability was more variable that in the western part for all years (Fig. 2b).

4.2. SEASONAL TREND DECOMPOSITION OF MODIS TIME SERIES

Figure 3 displays the decomposition of Chl-*a* concentration time series averaged between 2003 and 2018, from the coastline to 120 km offshore.

The STL decomposition of the Chl-*a* time series recorded in AB consists of four panels with different things plotted (Fig. 3):

- The first one contains the raw data, that was all of the data simply plotted over time;
- The second panel contains the remainder. This shown what was left over after the trend and seasonal components have been stripped away from the data;
- The third panel was the seasonal component, which shown a clear seasonality in the data. It can be seen as regular periodicity over seasons;
- Finally, there was the trend; it shows that there was an overall change in the mean.

The seasonal amplitude and variations were constant over time (Fig. 3), showing practically a fixed annual cycle each year. The trend component increased abruptly until 2007, then it was relatively constant between 2007 and 2013, and decreased slightly until 2015, and increased again between 2016 and 2018 (Fig. 3). As expected from this result, the remainder component has less variability.

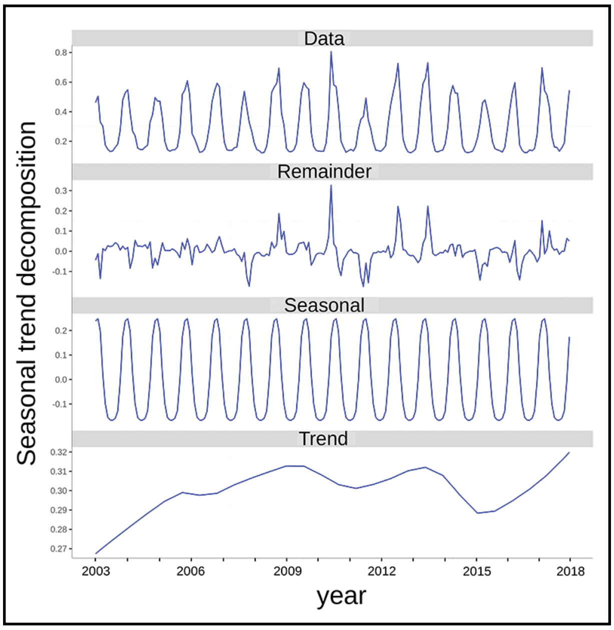

Fig. 3. Decomposition of Chl-*a* concentration time series (2003 to 2018), averaged from the coastline to 120 km offshore using the STL function.

The IQR for our time series were seasonal =108.7%, trend =15.8%, and remainder =17.4%. Indeed, the remainder component represented a non-significant percentage of data not captured by the model.

5. DISCUSSION

The western part of the AB was characterized by complex processes driven by water of Atlantic waters through the Alboran Sea (Fig. 1). This is the most dynamic part of the AB, characterized by strong vertical mixing and a permanent eddy (the AWG) trapped between the Algerian and Spanish coasts (Fig. 1). This region shows a high seasonal variability of wind velocity compared to the rest of the AB (Fig. 4c), however, the precipitation was the weakest in the whole basin (Fig. 4b). The western coast of AB was highly urbanized with more than 100,000 inhabitants per coastal city (Office of National Statistics, ONS, 2019) and a high level of tourism activity. Furthermore, as shown in Figure 2b, the high values of Chl-*a* concentration were observed in this western part of the AB.

The center part of the AB was characterized by the narrowest continental shelf of the whole Algerian coastline (Harid, 2022). Its coastal waters were influenced by the flow of Atlantic waters (Millot, 1999), and impacted by an important and increasing demography and urbanization compared to the other regions. In contrast to the western and eastern parts, the wind velocity did not exceed 15 km h^{-1} (Fig. 4f) (except the pic of 2001) and with a low variability in the last two decades (Fig. 4f). The precipitation in this region was higher than that in the west (Fig. 4e), but the Chl-*a* concentration was lower (Fig. 2b).

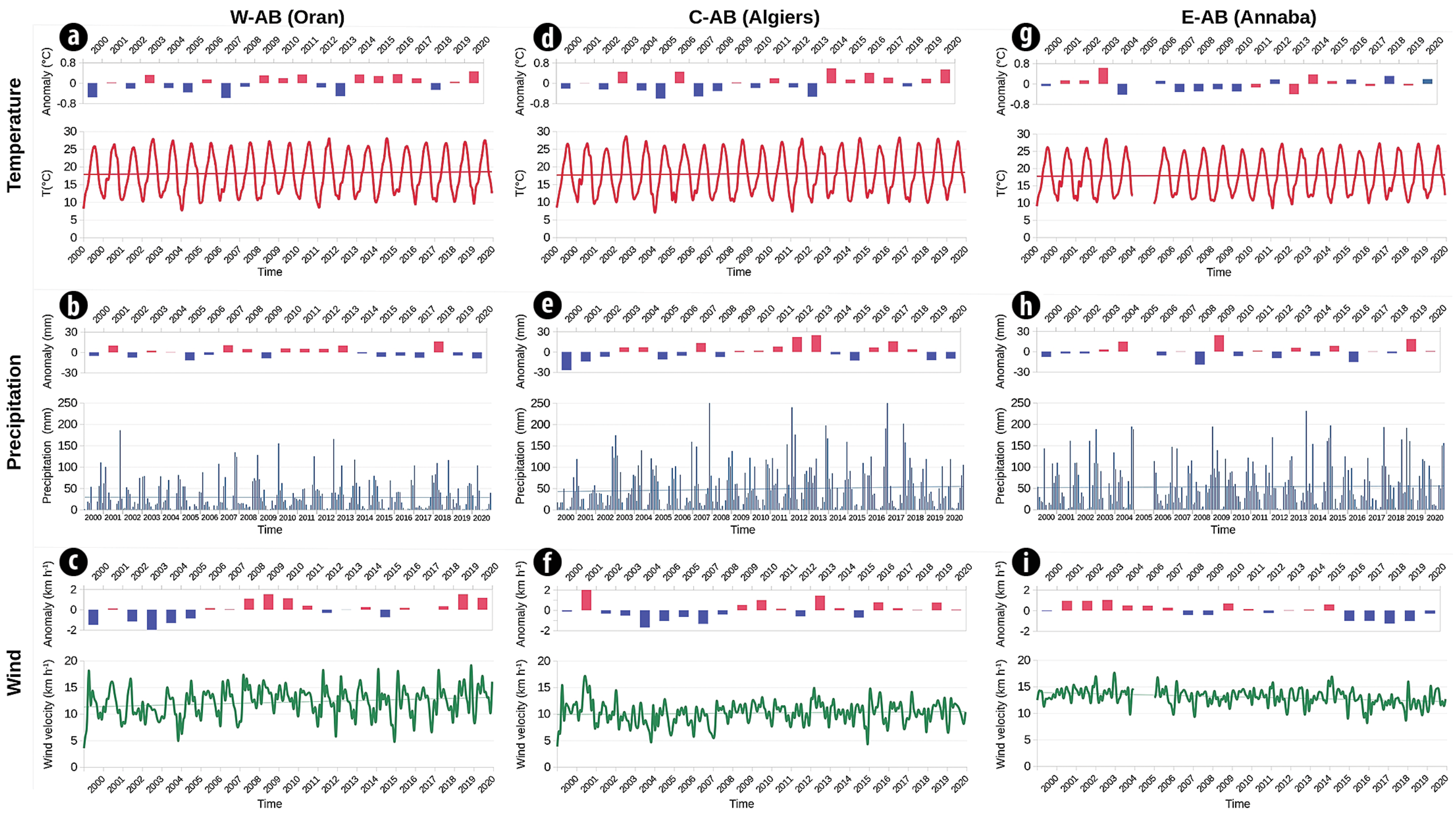

Fig. 4. Weather data trends in the Algerian Basin during the last two decades (2000 to 2020). The data were collected from National Meteorological Office of Algiers "ONM" (*Office National Météorologique*). (**a**), (**b**), and (**c**) were respectively seasonal and interannual variability of: air temperature, precipitation, and wind velocity in Oran city. (**d**), (**e**), and (**f**) in Algiers city. (**g**), (**h**), and (**i**) in Annaba city. W-AB (Western Algerian Basin), C-AB (Center Algerian Basin), and E-AB (Eastern Algerian Basin).

The eastern region of AB was characterized by the most irregular coastline of the Algerian coast. It has numerous bays, gulfs, coves, creeks, and other forms. Atlantic waters continuing on their way towards the eastern Mediterranean Sea. The eastern part of AB was the most oligotrophic region of the basin (Harid *et al.*, 2022; Mayot *et al.*, 2016; Moutin and Prieur, 2012). The wind velocity was higher than in the center part, but had the lowest seasonal variability compared to the rest of AB (Fig. 4i). The precipitation was higher than those of western and similar to the center (Fig. 4). During the years 2018, 2019, and 2020, the precipitation in the east was the highest compared to the western and the center parts (Fig. 4h). However, the Chl-*a* concentration in the east was the weakest, but characterized by several coastal peaks (Fig. 2a and 2b). These maximum values were related to the presence of gulf and bays, which were characterized by their nutrient-rich waters (Harid *et al.*, 2022).

The variability of the wind velocity in the AB followed the same pattern than those of the Chl-*a* concentrations (Fig. 2 and Fig. 4). In contrast, the precipitation do not followed the same pattern than the Chl-*a* concentrations during the last two decades (Fig. 2 and Fig. 4). On the other hand, air temperature was nearly constant throughout the basin (Fig. 4a, 4d, and 4g), which was not significant for the Chl-*a* gradient between east and west. However, the variability of Chl-*a* in the AB was related to the wind seasonality of the region, as founded by IQR which reflected the highest percentage of the seasonal component. It is important to note that the permanent mesoscale eddies were mostly generated by the wind velocity (Millot *et al.*, 1990; Millot and Taupier-Letage, 2005). The Algerian basin was submitted to intense vertical convection in winter (Raimbault *et al.*, 1993), and to less dynamic and nutrient deficient water bodies in the summer (Moutin and Prieur, 2012). However, global warming prevented the mixing of waters, reduced the increasing nutrient input and decreased productivity (Doney, 2006). In contrast, in winter, the movements and dynamics of the water bodies indicated the presence or absence of episodes of anticyclonic eddies (Olita *et al.*, 2011), which were generated by the instabilities of the Algerian current (Millot *et al.*, 1990). They nevertheless enriched oligotrophic surface waters with the nutrients necessary for phytoplankton blooms and could also induce a slight variation in annual phenology from one year to the next in the basin (Salgado-Hernanz *et al.*, 2019).

Moreover, the Algerian coastline did not contain rivers, deltas, and lagoon, it has only wadis (temporary waterways) that have a moderate flow in winter and were dry in summer (Harid *et al.*, 2022). Indeed, precipitation could not be an important factor influencing the Chl-*a* concentrations (there were no rivers with high flows that discharge nutrient directly into the sea).

6. CONCLUSION

This study has analyzed the MODIS time series for the Chl-*a* concentration at AB in the Southwestern Mediterranean Sea. The range of Chl-*a* values was practically similar during this 16 years. However, the interannual variability of Chl-*a* shown the influence of seasonal enrichment processes as well as the permanent mesoscale eddies (provides nutrients from deep water), and the stability of different sources of local enrichment each year.

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DATA AVAILABILITY STATEMENT

The MODIS data supporting figures 2 and 3 are publicly available on NASA's Ocean Color Web (2019): http://oceancolor.gsfc.nasa.gov/.

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