First of all, we would like to thank the associate editor Dr. Silvio Pantoja for his decision and its review about our manuscript. We have modified the manuscript according to his comments. We think that the new version of the manuscript has been accordingly improved.

5 <u>General comments:</u>

-"Thanks for providing a second version of your article. Your paper provides consistent results to identify phenology of phytoplankton in the Med Sea, evaluated for more than a decade. There are several comments from both reviewers that were responded satisfactorily but corrections were not included in version 2 (please see below)."

10 -"Several other minor changes suggested by both reviewers were not included in version 2 of article, and some of them make a more clear presentation of your work."

Author's response:

> A marked-up manuscript version (track changes in Word) is provided after the responses of the following comments, as well as a new version of the manuscript in support of this document.

15

Specific comments:

1) "Check missing reference:

Han, J., Kamber, M. and Pei, J.: Data Mining: Concepts and Techniques, third Edn., The Morgan Kaufmann Series in Data Management Systems, Morgan Kauf- mann, Boston, 2011."

20 Author's response:

> Included in the new version of the manuscript (see after), Page 17, line 10: "Han, J., Kamber, M. and Pei, J.: Data Mining: Concepts and Techniques, third Edn., The Morgan Kaufmann Series in Data Management Systems, Morgan Kaufmann, Boston, 2011.".

25 2) "Where is the following text you mentioned in response to reviewer K. Tsiaras?

The referee is right. We changed: Page 14948, line 25 -". . .whereas the dates of the minimum rate of change (i.e. the date of the lowest first derivative of the nChl time series). . ." with ". . .whereas the dates of the minimum rate of change (i.e. the date of the lowest first derivative of the nChl time series, the most negative value). . . " Author's response:

> Included in the new version of the manuscript (see after), Page 5, line 16: "whereas the dates of the minimum rate of change (i.e. the date of the lowest first derivative of the nChl time series, the most negative value)".

3) "Page 13, line 28. I agree with Reviewer K Tsiaras. Why bimodal pattern? Term "bimodal pattern" is still in v2

5 of manuscript."

Author's response:

> Modified in the new version of the manuscript (see after), Page 10, line 9: "The unimodal pattern".

4) "Considered separately is still in version 2. Interannual approach is more accurate"

10 Author's response:

> Modified in the new version of the manuscript (see after), Page 13, line 21: "...the new interannual approach demonstrates...".

5) "I agree with comment of reviewer asking for rephrasing paragraph "13) K. Tsiaras: "P14960, L2"...more than

- 15 the deep convection events, the permanent cyclonic circulation in this region was the primary factor inducing favorable conditions for phytoplankton bloom, by bringing the nitracline depths close to surface. Relatively shallow mixed layers.. "Usually deep convection sites are found in areas with cyclonic circulation due to the dome shape of the density that favours deep mixing and I think the phytoplankton bloom mechanism is mostly related to the vertical mixing. Therefore, the "relatively shallow mixed layers" might be misleading. I suggest you rephrase
- 20 this."

Version should include modified sentence (""This uplift of the nitracline by the cyclonic circulation should allow an efficient replenishment of nitrate at the surface.")."

Author's response:

> Included in the new version of the manuscript (see after), Page 12, line 8: "This uplift of the nitracline by the

25 cyclonic circulation should allow an efficient replenishment of nitrate in surface,..."

6) "I agree with comment: Page 14945, Line 20 : Replace "respectively 8 days and 9Km" with "9 Km and 8 days respectively". "

Author's response:

> Modified in the new version of the manuscript (see after), Page 3, line 16: "...at spatial and temporal resolution of 9 km and 8 days respectively...".

7) "Idem "-Page 14947, Line 12 : Replace "from of all" with "from all""

5 Author's response:

> Modified in the new version of the manuscript (see after), Page 4, line 20: "...(from all the 16 years combined)...".

8) "Idem "-Fig1: Replace "all years combined" with "all years combined""

10 Author's response:

> Modified in the new version of the manuscript (see after), Fig 1 - Page 22.

9) "Idem "-Page 14960, Line 23 : Replace "is confirmed as be strongly impacted" with ""is con- firmed to be strongly impacted""

15 Author's response:

> Modified in the new version of the manuscript (see after), Page 12, line 23: "...is confirmed to be strongly impacted...".

10) "Idem, "-Page 14962, Line 8 : Replace "have been hide" with "have been hidden" or "have been masked"."

20 Author's response:

> Modified in the new version of the manuscript (see after), Page 13, line 17: "...have been hidden...".

11) "Idem "-Page 14962, Line 8 : Replace "artifactual regime produce" with "artifactual regime produced""

Author's response:

25 > Modified in the new version of the manuscript (see after), Page 13, line 24: "...artifactual regime produced...".

12) ""> We agree with all technical corrections made by K. Tsiaras and modified the manuscript and all the figures by considering all these corrections. The manuscript was also proofread by an English native speaker. "Version 2 does not contain some of those changes"

30 Author's response:

> Modified in the new version of the manuscript. All the modifications not mentioned in the documents named "Response to K Tsiaras" and "Response to G Volpe" correspond to the corrections made to revise the English grammar (see after the marked-up manuscript version).

5 13) "You agreed with Reviewer Dr. Volpe responding "We agree with the referee. We modified the discussion (Sect. 4.2.1 and 4.2.2) by adding comments on the influence of the intracellular chlorophyll adjustments on the surface chlorophyll-a concentration. We also add some estimations of this influence when available in the literature.

We added after the line 8, Page 14957 - "However, in winter the daily Photosyntheti- cally Available Radiation

10 (PAR) at sea surface is also reduced. In response, the intra- cellular chlorophyll content in the phytoplankton cells increases (i.e. photoacclimatation process), which leads to an increase in the chlorophyll to carbon biomass ratio (e.g. Behrenfeld et al., 2005), and could in part contribute to the observed variations of the nChl in these "No Bloom" bioregions."

We re-wrote the paragraph at line 27, Page 14959 – "However recent results from profiling floats measuring the

15 [Chl] and the particle mass concentration, suggest also that in this region the photoacclimatation process could contribute to the change in the observed [Chl]surf (up to 70%, Mignot et al., 2014).""." Those new paragraphs never made it to version 2 of your article. Please check" Author's response:

> Included in the new version of the manuscript (see after),

- 20 Page 10, line 14: "However, in winter the daily Photosynthetically Available Radiation (PAR) at sea surface is also reduced. In response, the intracellular chlorophyll content in the phytoplankton cells increase (i.e. photoacclimatation process), which increase the ratio of chlorophyll to carbon biomass (e.g. Behrenfeld et al., 2005), and could in part contributes to the temporal variations of the nChl observed in these "No Bloom" bioregions.".
- 25 Page 12, line 3: "However recent results from profiling floats measuring the [Chl] and the particle mass concentration, suggest also that in this region the photoacclimatation process could contribute to the change in the [Chl]surf observed (up to 70%, Mignot et al., 2014).".

14) "New references were not added to proper section (Behrenfeld et al. and Mignot et al.)"

30 Author's response:

> Included in the new version of the manuscript (see after),

- Page 18, line 18: "Mignot, A., Claustre, H., Uitz, J., Poteau, A., D'Ortenzio, F., and Xing, X.: Understanding the seasonal dynamics of phytoplankton biomass and the deep chlorophyll maximum in oligotrophic environments: A Bio-Argo float investigation, Global Biogeochem. Cy., 28, 856-876, doi:10.1002/2013GB004781, 2014."

Page 15, line 15: "Behrenfeld, M. J., Boss, E., Siegel, D. A., and Shea, D. M.: Carbon-based ocean productivity and phytoplankton physiology from space, Global Biogeochem. Cy., 19, GB1006, doi:10.1029/2004GB002299, 2005."

15) "Fig. 1. What is "statistically pertinent"? Do you mean statistically significant? If that, please use proper statistical nomenclature"

Author's response:

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> Removed in the new version of the Fig. 1 (Page 22), and explained in detail in the manuscript, Page 4, line 23:
"Then, the stability of the resulting clusters was assessed by comparing them (using the Jaccard coefficient) with clustering results obtained after a modification (i.e. adding an artificial noise), or a subset of the dataset (Hennig,

15 2007, see also DR09). Only clusters with a Jaccard coefficient greater than 0.75 are considered stable.".

16) "I agree with reviewer Dr. Volpe regarding unclear sentence "G. Volpe: "Page 14947, line 15 - (. . .which is a criterion based on. . .) is unclear and should be rephrased""

Author's response:

20 > Modified in the new version of the manuscript (see after), Page 4, line 22: "...this index compared the within and between cluster variance...".

17) "Idem for comment "G. Volpe: "Page 14950, line 2 - substitute compare with compared"

(Author's response: Page 14950, line 2 – We replaced "...compare to the "No Bloom #2"..." with ". . . compared

to the "No Bloom #2".)

This change is not in version 2"

Author's response:

> Modified in the new version of the manuscript (see after), Page 6, line 7: "...compared to the "No Bloom #2"...".

<u>Interannual variability of the Mediterranean trophic regimes from</u> ocean color satellites

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Abstract. D'Ortenzio and Ribera d'Alcalà (2009, DR09 hereafter) divided the Mediterranean Sea into "bioregions" based on the climatological seasonality (phenology) of phytoplankton. Here we investigate the interannual variability of this bioregionalization. Using 16 years of available ocean color observations (i.e. SeaWiFS and MODIS), we analyzed the spatial distribution of the DR09 trophic regimes on an annual basis. Additionally, we identified new trophic regimes, <u>exhibiting</u> seasonal cycles of phytoplankton biomass different from the DR09 climatological description and named "Anomalous". Overall, the classification of the Mediterranean phytoplankton phenology proposed by DR09 (i.e. "No Bloom", "Intermittently", "Bloom" and "Coastal"), is confirmed to be representative of most of the Mediterranean phytoplankton phenologies. The mean spatial distribution of these trophic regimes (i.e. bioregions) over the 16 years studied is also similar to the one proposed by DR09, although some annual variations were observed at regional scale. Discrepancies with the DR09
 study were related to interannual variability in the sub-basin forcing: winter deep convection events, frontal

study were related to interannual variability in the sub-basin forcing: winter deep convection events, frontal instabilities, inflow of Atlantic or Black Sea Waters and river run-off. The large assortment of phytoplankton phenologies identified in the Mediterranean Sea is thus verified at <u>the interannual scale</u>, <u>further supporting the</u> "sentinel" role of this basin <u>for detecting the impact of climate changes on the pelagic environment.</u>

1 Introduction

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25 The Mediterranean Sea is one of the oceanic regions the most impacted by climate change (Giorgi, 2006; Giorgi and Lionello, 2008). These important environmental modifications are supposed to strongly modify the dynamics of the Mediterranean marine ecosystems (The Mermex Group, 2011), by modifying the food web structure (Coll et al., 2008), triggering regime shifts (Conversi et al., 2010) or unexpected events (e.g. jellyfish blooms, Purcell, 2005), which should have strong consequences on human activities. In the climate change context, phytoplankton plays a key role, because any perturbations on its dynamics would affect the rest of the marine food web (Edwards and Richarson, 2004). In a relatively small semicenclosed sea, such as the Mediterranean, those kind of processes should be particularly accelerated. A modification of the phytoplankton communities could impact the whole ecosystems much more rapidly than in other oceanic regions (Siokou-Frangou et al., 2010).

In the Mediterranean, as in many of the oceanic regions, the phytoplankton <u>dynamics</u> is characterized by a strong spatio-temporal variability (Estrada, 1996; Mann and Lazier, 2006), determined by the concomitant influence of

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several biotic and abiotic factors (Williams and Follows, 2003; Mann and Lazier, 2006). The link between abiotic factors and phytoplankton variability, in the Mediterranean Sea, has been mainly inferred by using satellite ocean color data (Antoine et al., 1995; Bosc et al., 2004; Mélin et al., 2011; Volpe et al., 2012). Based on band-ratio algorithms that infer surface chlorophyll-*a* concentration (considered as a proxy of phytoplankton biomass), a

general picture of the Mediterranean was revealed, confirming and reinforcing what had been derived by the relatively scarce existing in situ estimations, e.g., the presence of a widespread oligotrophy, of strong east-west and north-south gradients, the coastal influences, and the occurrence of blooming episodes in well-defined regions.

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However, despite the ecological relevance of phytoplankton seasonality (or phenology), which provides a powerful tool to identify the factors affecting ecosystem <u>functioning</u> (Edwards and Richarson, 2004), phenology has <u>received less consideration</u> in the Mediterranean. Phytoplankton phenology was generally hard to evaluate, as <u>observations were either not available</u> at the <u>required</u> temporal and/or spatial resolution (see review of Ji et al., 2010), or were restricted to coastal areas. Satellite observations provide high-frequency temporal and spatial observations and represent the only available dataset to estimate the seasonal dynamics of phytoplankton at basin-

- scale with a proper spatio-temporal resolution (Ji et al., 2010). Using satellite observations, a first attempt to characterize the Mediterranean phytoplankton phenology was recently proposed (D'Ortenzio and Ribera d'Alcalà, 2009, DR09 thereafter). Although limited to the <u>sea</u> surface, DR09 identified in the available SeaWiFS ocean color dataset, seven recurrent patterns in seasonal cycles of phytoplankton in the Mediterranean. The observed seasonal patterns (referred by DR09 as "trophic regimes") were then regrouped in four main classes on the basis of their shape characteristics: a "temperate seas-like" dynamic (referred by DR09 as "Bloom", characterized by a spring
- 20 peak), a "tropical seas-like" dynamic (referred by DR09 as "No bloom", to indicate the absence of a marked peak), an "intermittently" dynamic (considered as an intermediate regime between "Bloom" and "No Bloom" trophic regimes, and interpreted as an artifactual regime produced by averaging) and a "Coastal" dynamic (frequently observed in coastal regions, see later). Moreover, the geographical distribution of the DR09 trophic regimes followed well-defined spatial patterns, and was thus interpreted as a bioregionalization of the basin based on the
- phenological traits of the surface chlorophyll-*a* concentration. Compared to <u>other</u> existing Mediterranean bioregionalization (e.g. Nieblas et al., 2014), the DR09 approach is specifically focused on the seasonal cycles of phytoplankton and <u>is consequently</u> adapted to address issues <u>related to phytoplankton phenology</u>.

The DR09 results has <u>already</u> been used to investigate the role of the mixed layer depth (MLD) and <u>the nitrate</u> distribution on the Mediterranean phytoplankton phenology (Lavigne et al., 2013), while modeling studies have used the DR09 bioregionalization based on the seasonal dynamics of phytoplankton to ameliorate the primary production estimates from space (Uitz et al., 2012). Combining temporal (i.e. the trophic regimes) and spatial (i.e. the bioregions) analysis, the DR09 results <u>thus</u> provided <u>a</u> robust framework to identify the role of abiotic and biotic factors on the Mediterranean phytoplankton phenology.

Two main issues are, however, still unresolved. Firstly, the DR09 results were obtained <u>under a strict</u> climatological approach, providing the most relevant spatio-temporal patterns, though smoothing any interannual variability. <u>Secondly, and as a consequence of the climatogical scale, the DR09 trophic regimes and bioregions</u> could be an artifactual result of the climatological average, which, by flattening the seasonal cycle of surface chlorophyll-*a*, could have generated unrealistic seasonal cycles of phytoplankton. This point, already evoked by

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the authors, is particularly relevant for the "Intermittently" trophic regime of DR09 (see also the discussion on the "Intermittently" DR09 trophic regime in Lavigne et al., 2013).

In this paper, we reappraised the DR09 approach with the specific aim to account for the interannual variability of the Mediterranean surface chlorophyll-*a* concentration. A new method is proposed to identify the relevance of the DR09 trophic regimes on an annual basis. The method <u>also</u>_identifies the discrepancy from the DR09 climatological trophic regimes, by allowing the emergence of totally new (compared to DR09) patterns of seasonality (i.e. new trophic regimes) that could have been masked by the climatological approach of DR09. The satellite database is also expanded, by including seven additional years of ocean color data compared to the DR09 paper. The discussion is focused on the interannual variability of the DR09 trophic regimes and on the occurrence of the new trophic regimes. A step forward in the interpretation of the trophic regimes is proposed (the DR09 ones and the new ones) by considering their <u>occurrence</u> frequency at basin and regional scales, simultaneously with forcing processes.

2 Data and methods

2.1 Data

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- Surface chlorophyll-*a* concentration ([Chl]_{surf}) from Level 3 images of SeaWiFS and MODIS Aqua, at spatial and temporal resolution of <u>9 km and 8 days</u> respectively, were downloaded from the NASA's OceanColor website (http://oceandata.sci.gsfc.nasa.gov/), for the period 1998-2014. SeaWiFS data were used for the period 1998-2007, while MODIS Aqua data were used after July 2007. MODIS and SeaWiFS datasets were already shown to be consistent (Franz et al., 2005). The resulting 16-years satellite database was initially divided on a yearly basis
- 20 (from July of year T-1 to late June of year T) and a three-weeks (i.e. 24 days) moving average was applied. In the Mediterranean Sea, an overestimation of the [Chl]_{surf} retrieved from space was identified by comparison with in situ data (Gitelson et al., 1996; Claustre et al., 2002), particularly at the low values (e.g. Fig. 14 from Antoine et al., 2008). However, to <u>be consistent</u> with the DR09 analysis, the NASA standard products for SeaWiFS and MODIS (O'Reilly et al., 1998) <u>were</u> used here, instead of alternative products generated <u>through</u> regional algorithms. Consequently, as in DR09, to minimize the impact of the [Chl]_{surf} algorithms artifacts and in order to
- focus on the seasonal variations of the [Chl]_{surf} (regardless the existing difference between the Mediterranean Sea areas in the values of [Chl]_{surf}), each annual time series was normalized by its maximal value. In what follows, the time series (from July to June) of a specific year are referred as "annual" time series of normalized surface chlorophyll-*a* concentration (nChl).

30 2.2 Interrannual clustering

The method proposed here initially uses the trophic regimes identified by DR09 to classify pixels on an annual basis. The method consists in identifying, for each "annual" time series of each pixel, the DR09 trophic regime with the most similar time series. After this first classification, a number of time-series remains unclassified (i.e. "non assigned"). These "non assigned" time series are then clustered to identify new trophic regimes, which were somehow hidden in the DR09 approach.

In practice (see Fig. 1):

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Supprimé: The method proposed here refines the DR09 method on an annual basis and then identifies new trophic regimes, which were hidden in the climatological DR09 approach. The method consists in identifying, for each "annual" time series of each pixel, the closest DR09 trophic regime having the most similar seasonal cycle. When a time series is different, beyond a chosen threshold, from all DR09 trophic regimes, it is initially considered apart, in a sub-set of the initial database. All the time series of this subset are finally clustered to define new trophic regimes.

	1.	For each year and for each Mediterranean pixel, the "annual" time series of nChl and its corresponding	/	Supprimé: Chebytchev
		geographical position are extracted (Fig. 1, step 1).		Supprimé:
	<u>2.</u>	_The similarity between the "annual" time series and each of DR09 trophic regimes is evaluated using the		Mis en forme : Police :Italique
		Chebyshev distance (e.g. Han et al., 2011), with only the 8-day averages of nChl as variables (i.e. 46		Mis en forme : Police :Italique, Indice
5		variables). Between two time series $X = (x_1, x_2,, x_n)$ and $Y = (y_1, y_2,, y_n)$ the Chebyshev distance (d_{XY}) is		Mis en forme : Police :Italique
		defined as.		Mis en forme : Police :Italique
		$d_{XY} = \lim \left(\sum_{i=1}^{n} x_i - y_i ^p \right)^{\frac{1}{p}} = \max x_i - y_i $ (1)		Mis en forme : Police :Italique
		$\frac{1}{2}$ with $u = 40$. The DD00 transition begins the lawest Chebushev distance with the "engugal" times		Mis en forme : Police :Italique
		with $n = 46$. The DROS troping regime having the lowest <u>Chebysnev</u> distance with the annual times		Mis en forme : Police :Italique
10	2	series is initially selected (Fig. 1, step 2)		Mis en forme : Police :Italique
10	3.	To be definitively assigned to the selected DR09 trophic regime, the "annual" time series must be		Mis en forme : Police :Italique
		contained in the confidence interval of that DR09 trophic regime. The confidence interval is defined as		Mis en forme : Allemand (Allemagne)
		the mean Chebyshev distance between the DR09 trophic regime and all the weekly climatological time		Supprimé: (defined as the greatest difference between the
		series of nCni used by DR09 that belong to this trophic regime, plus 1.5 times the standard deviation (Fig.		time series and any DR09 trophic regimes). The DR09 trophic regime having the lowest distance with the
15	4	1, step 5). Note that the confidence interval is different for each DK09 troping regimes.		"annual" time series is
15	4.	if the annual time series fails within the confidence interval, then the annual time series and its pixel		Supprimé: initially selected (Fig. 1, step 2).
1		are assigned to the DK09 hoping regime initially selected (Fig. 1, step 4). Other wise, the annual time		Mis en forme : Gauche, Retrait : Gauche : 1.27 cm,
		series (and its associated pixel) is temporarily added to a table with an inon-assigned time series. At time		Sans numerotation ni puces
		"non assigned" or otherwise the membership of the pixels as one of the DR09 trophic regimes		(Allemagne)
20	5.	All of the "non-assigned" time series (from all the 16 years combined) were clustered by using a K-means		Mis en forme : Allemand (Allemagne)
		clustering (Hartigan and Wong, 1979) (Fig. 1, step 5). The number of clusters is decided using the		Mis en forme : Allemand (Allemagne)
		Calinski and Harabasz index (this index compared the within and between cluster variance, Calinski and		Mis en forme : Allemand (Allemagne)
I		Harabasz, 1974; Milligan and Cooper, 1985). Then, the stability of the resulting clusters was assessed by		Mis en forme : Allemand (Allemagne)
		comparing them (using the Jaccard coefficient) with clustering results obtained after a modification (i.e.		Mis en forme : Allemand (Allemagne)
25		adding an artificial noise), or a subset of the dataset (Hennig, 2007, see also DR09). Only clusters with a		Mis en forme : Allemand (Allemagne)
		Jaccard coefficient greater than 0.75 are considered stable. These new clusters include all the "annual"		Mis en forme : Allemand (Allemagne)
		time series that are statistically different from the DR09 climatological time series. In some sense, they		Mis en forme : Allemand (Allemagne)
		represent anomalies compared to the DR09 climatological analysis and, for this reason, they are referred		Mis en forme : Allemand (Allemagne)
		in the following as "Anomalous" trophic regimes.		Mis en forme : Allemand (Allemagne)
30	Four "	Anomalous" trophic regimes are obtained and all are stable (i.e. presenting Jaccard coefficients >89%)		Mis en forme : Allemand (Allemagne)
50	Overall	77.2% of the "annual" time series are classified as one of the DR09 trophic regimes and 12.8% as one of		Mis en forme : Allemand (Allemagne)
	the "Ai	nomalous" trophic regimes.		Mis en forme : Retrait : Gauche : 1.27 cm, Sans numérotation ni puces
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3 Results

35 The method described in Sect. 2.2 provides 11 time series (i.e. the seven DR09 trophic regimes and the four "Anomalous") obtained by averaging all the "annual" time series of nChl based on their membership in one of the

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11 trophic regimes (Fig. 2), as well as 16 annual maps of the spatial distribution of the 11 trophic regimes (Fig. 3). Following the interpretation of DR09, we considered the spatial distribution of the trophic regimes as a bioregionalization, and we will refer the regions having the same trophic regime as a "bioregion".

The main traits of the trophic regime time series <u>is</u> sketched in the next paragraphs (for the seven DR09 and the four "Anomalous"), whereas their associated geographical distributions <u>is</u> analyzed afterwards.

3.1 General patterns of DR09 trophic regimes

The nChl time series of the non-coastal DR09 trophic regimes (Fig. 2), <u>in spite of their common characteristics</u> (they all present minimal value in summer, Table 1), display different amplitudes of nChl and [Chl]_{surf} (i.e. defined as the difference between the mean summer value and the annual maximum values of nChl and [Chl]_{surf}, Table 1).

- 10 The "Bloom #5" and "Intermittently #4" trophic regimes show the greatest amplitudes (0.66 nChl and 0.82 mg m⁻³ for "Bloom #5", 0.63 nChl and 0.40 mg m⁻³ for the "Intermittently #4"), whereas the "No Bloom #2" trophic regime the lowest (0.48 nChl and 0.14 mg m⁻³). The timings of the main events are also different. The dates of the annual maximum values are observed in winter (February) for "No Bloom" trophic regimes (#1, #2 and #3) and in spring for the "Intermittently #4" (March) and the "Bloom #5" (April) trophic regimes. The dates of the maximal rate of change (i.e. the date of the highest first derivative of the nChl time series) are increasing from the "No Bloom", the "Intermittently #4", to the "Bloom #5", whereas the dates of the minimum rate of change (i.e. the date of the nChl time series, the most negative value) range between March ("No Bloom #3") to April ("Bloom #5).
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The "Coastal" DR09 trophic regimes show different seasonal characteristics from the rest of the DR09 trophic regimes (Table 1). The maximum value of the "Coastal #6" time series is lower (0.72 nChl) and arrives earlier (December) than for the other DR09 trophic regimes. The "Coastal #7", which shows a double peak during winter months, exhibits also a great dispersion around the mean, indicating that the resulting mean seasonal cycle is probably an artifact.

3.2 General patterns of the "Anomalous" trophic regimes

All of the "Anomalous" trophic regimes (#1, #2, #3 and #4) show minimum values of nChl in summer (0.14 nChl for the "Anomalous #1", 0.47 nChl for the "Anomalous #2", 0.28 nChl for the "Anomalous #3 and 0.17 nChl for the "Anomalous #4"). The "Anomalous #1" trophic regime shows an evident spring peak (starting in March, maximal in early April and decreasing in mid-April), whereas "Anomalous #2", "#3" and "#4" display a winter plateau, with their maximal rate of change and maximal values obtained in late fall and winter respectively (in October and February for "#2", in November and December for "#3" and in December and February for "#4").

All the above suggests that the "Anomalous" trophic regimes could be considered as modified versions of the DR09 trophic regimes. The "Bloom #5" and the "Anomalous #1" trophic regimes have similar shape, showing both a spring peak (for both the date of the maximal value in April). Although they differ slightly for the dates of the maximal and minimal rate of change (early March and Jate April for "Bloom #5", and Jate March and mid-

35 April for the "Anomalous #1"), the "Anomalous #1" trophic regime appears as a more peaked version of the

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"Bloom #5" trophic regime, with a higher amplitude in [Chl]_{surf} (0.82 mg m⁻³ for the "Bloom #5" and 1.09 mg m⁻³ for the "Anomalous #1").

Similarly, the "No Bloom #2" and the "Anomalous #2" trophic regimes could be associated. They both display weak amplitudes of nChl and of [Chl]_{surf} (0.48 nChl and 0.14 mg m⁻³ for the "No Bloom #2", 0.29 nChl and 0.09 mg m⁻³ for the "Anomalous #2", which are among the lowest of the non-coastal trophic regimes). They <u>mainly</u> differ <u>in</u> the date of the minimal rate of change, which is delayed of two month for the "Anomalous #2" (<u>in_June</u>) <u>compared</u> to the "No Bloom #2" (<u>in_April</u>). The "Anomalous #2" trophic regime appears as a smoothed version of the "No Bloom #2" trophic regime, where the winter-to-summer difference is low.

Finally, the "No Bloom #3" and the "Anomalous #3" and "#4" trophic regimes have similar shapes and spatial
repartition (see the next section). However, the "Anomalous #3" trophic regime displays differences in the timing of the maximal rate of change and of the maximal value (<u>in</u> November and December for the "Anomalous #3", and <u>in</u> December and February for the "No Bloom #3"), and the "Anomalous #4" trophic regime presents a higher maximal value of [Chl]_{gurf} (0.68 mg m⁻³) than the "No Bloom #3" trophic regime (0.35 mg m⁻³), but a lower maximal value of nChl (0.60 nChl for the "Anomalous #4" and 0.86 nChl for the "No Bloom #3"), indicating a variability in the timing of the peak between individual time-series.

The association of the "Anomalous" trophic regimes with the DR09 trophic regimes confirms the general partitions proposed by DR09 into "Bloom" and "No Bloom" trophic regimes. The low occurrence of the "Anomalous" trophic regimes indicates also that their importance in the basin behavior is low. They possibly signify an accentuation or a diminishing of the factors influencing the phytoplankton phenology, although they should be likely considered as temporary perturbations of the general "Bloom"/"No Bloom" regimes. We will discuss this later.

3.3 Geographical distribution of trophic regimes: interannual variability

The 16 annual maps, showing the spatial distribution of the 11 trophic regimes (Fig. 3), represent a first attempt to evaluate the interannual spatial variability of the bioregions (defined, in the sense of DR09, as regions having similar phytoplankton phenology or, more precisely, having the same trophic regime). In the next, the results are presented following the four main DR09 groups of trophic regimes (i.e. "No Bloom", "Bloom", "Intermittently" and "Coastal"). The "Anomalous" trophic regimes are discussed separately. The last paragraph will be dedicated to a wider analysis on the interannual spatio-temporal variability of the bioregions.

3.3.1 The "No Bloom" trophic regimes

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- Over the <u>studied</u> 16 years, "No Bloom" bioregions cover most of the Mediterranean <u>Sea</u> (67.2% on average, Fig. 4). The "No Bloom #1" is the most occurring "No Bloom" bioregion (Fig. 4). Exceptions are observed in 1999, 2001, 2004, 2012 (dominance of the "No Bloom #3") and in the 2000, 2007 (dominance of the "No Bloom #2"). The "No Bloom #1" bioregion is permanently observed in the Levantine basin, and often in the Ionian Sea (Fig. 3). Episodically, it is also observed in the <u>Western</u> basin, in particular over the Tyrrhenian Sea. During the 1999
- 35 to 2007 period, the "No Bloom #1" bioregion <u>on average</u> covered 25.6% of the Mediterranean Sea, while from 2008 to 2014, its mean percentage increases to 33.5%.

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lower maximal value of nChl (0.60 nChl) than the "No Bloom #3" trophic regime (0.86 nChl), indicating a variability in the timing of the peak between individual timeseries, but a higher amplitude of [Chl]_{surf} (0.48 mg m⁻³ for the "Anomalous #4" and 0.25 for the "No Bloom #3").

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The second most occurring bioregion is the "No Bloom #3", with a mean value of 21.5% of covered surface over the 16 years (Fig. 4). It is associated with the Algerian basin (except in 2013 and 2014), although its northern and eastern boundaries are more variable (Fig. 3). It is also observed in the North-Western Mediterranean (NWM), in the Tyrrhenian, and sometimes in a large portion of the Eastern basin (i.e. 2004 and 2012). No clear trends are observed over its interannual evolution, except in 1999, 2001, 2004 and 2012, when it was the most widespread

bioregion.

Finally, the "No Bloom #2" bioregion covers 16.7% of the Mediterranean Sea on average (Fig. 4), and it is permanently observed in the Aegean and Adriatic Seas (Fig. 3). Peaks of occurrence are observed in 2000 and 2007, when its distribution extended over the North Ionian (in 2000) and most of the Eastern Basin (in 2007). Similarly to the "No Bloom #1" bioregion, two periods could be identified in its interannual trend. Before 2008.

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Similarly to the "No Bloom #1" bioregion, two periods could be identified in its interannual trend. Before 2008, the occurrence of the "No Bloom #2" bioregion is erratic, ranging from 11.5% to 31.7%. After 2008, the surface covered is low (i.e. 10.4% on average) and constant.

3.3.2 The "Bloom" trophic regime

The "Bloom #5" bioregion covers <u>4%</u> of the Mediterranean Sea <u>on average</u> (Fig. 4), and it is observed quite exclusively in the NWM (Fig. 3). Notable exceptions are the years 1999 and 2006, when it is observed in the Southern Adriatic, and in 2003, in the Rhodes gyre area. The interannual variability of its extent (Fig. 4) ranges from very low values (i.e. in 2001, 2007 and 2014) up to 9% of the total Mediterranean surface (i.e. in 2005, which is, however, a special year due to high number of missing values). When the "Bloom #5" bioregion is weakly observed, it is generally replaced either by "Intermittently #4" (i.e. as in 2001 or in the 2007) or by the "Anomalous

20 #1" bioregion (Fig. 3). In the first case, the "Intermittently #4" bioregion extends all over the NWM with an almost total disappearance of the "Bloom #5" bioregion. In the second case, the "Bloom #5" bioregion is still present, but located in the border area of the NWM. Instead, the central area is occupied by the "Anomalous #1" bioregion (especially in 2005, 2006, 2008, 2010, 2013 and 2014).

3.3.3 The "Intermittently" trophic regime

- On average, the "Intermittently #4" bioregion occupies 12.2% of the Mediterranean Sea (Fig. 4). However, this percentage shows strong interannual variations, ranging from 7.2% to almost 24.5% of the total surface. It is permanently observed in the NWM, in the frontal area south of the large cyclonic gyre of the Ligurian Sea (Fig. 3). Its interannual variability is expressed by the high values of occurrence in 2003, 2006, 2007 and 2013, for the most in the Western basin. In the Eastern basin, it is recurrently observed in the Rhodes Gyres (2000, 2003, 2005,
- 30 2006, 2007, 2008, 2009 and 2012), in the North Ionian (1999, 2000, 2006, 2008 and 2012) and in the South Adriatic (1999, 2002, 2007, 2008, 2012 and 2014).

3.3.4 The "Coastal" trophic regimes

The "Coastal" bioregions cover 3.5% of the Mediterranean <u>Sea on average</u> (Fig. 4), with a weak interannual variability ($\pm 1.5\%$). The variability of the "Coastal" bioregions is mainly driven by the variation of the occurrence of the "Coastal #6" bioregion, which represents 95% of the "Coastal" bioregions occurrence. It is permanently

35 of the "Coastal #6" bioregion, which represents 95% of the "Coastal" bioregions occurrence. It is permanently observed in the Gulf of Gabes and, more sporadically, in the west Adriatic coast (in 2002, 2003 and 2011, Fig. 3).

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The "Coastal #7" bioregion being rarely present (less than 0.25% of the Mediterranean Sea), it will be neglected in the rest of the present study

3.3.5 The "Anomalous" trophic regimes

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(classified as "Anomalous #1").

The "Anomalous" bioregions occupy 12.8% of the surface basin on average (Fig. 4), although they are primarily concentrated in coastal zones: the "Anomalous #2" bioregion along the Adriatic and Aegean coasts, the "Anomalous #3" bioregion along the South Eastern basin coasts and the "Anomalous #4" bioregion along the Algerian coast (Fig. 3). Apart from coastal zones, the "Anomalous #1" bioregion is episodically observed in the NWM, where it occupies a region usually classified as "Bloom #5" (see Sect. 3.3.2).

3.3.6 Dominance maps

- 10 Although interannual variability in the geographical distribution of the bioregions is high, some general patterns emerge. To demonstrate this, a dominance map was calculated by evaluating, for each pixel, the most recurrent bioregion (i.e. the dominant regime), over the 16 years period (Fig. 5a). Most of the Mediterranean basin is assigned to one of the DR09 bioregions (96% of the map) and only 4% to an "Anomalous" bioregion. A second map showing the degree of membership (defined as the percent of years in which each pixel belongs to its most
- recurrent bioregion, Fig. 5b) was generated. The mean degree of membership over the whole Mediterranean area 15 is 46% (Fig. 5b), quantifying the large interannual variability of the basin. Spatial differences are, however, visible: coastal zones are generally characterized by low degree of memberships, while open ocean regions display higher values, showing less interannual variability.
- To better highlight these geographical patterns, only areas with a degree of membership greater than 50% were 20 plotted (Fig. 5c). The colored areas in Fig. 5c indicate where the bioregions are the most temporally recurrent, reflecting then the regions characterized by a weak interannual variability in the phenological traits. All the coastal areas (except in the Gulf of Gabes), as well as the regions at the frontier between bioregions, disappear. Most of the "Intermittently #4" bioregion also disappear (maintained only in a limited region of the NWM), as well as, all the "Anomalous" bioregions (except the "Anomalous #1" bioregion in the NWM) and most of the region of the 25 Alboran Sea.

Similarly, a dominance map generated by considering the four "Anomalous" bioregions only (Fig. 6a), shows their patchy distribution and irregular occurrences. However, some spatial patterns exist, and are highlighted when only the pixels having at least two occurrences of the same "Anomalous" bioregion over the 16 years period were shown (Fig. 6b). The Anomalous #2, #3 and #4 bioregions are recurrently observed, but only along coasts. As always highlighted, the only open-ocean region exhibiting a coherent and recurrent "Anomalous" pattern is the NWM

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4 Discussion

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4.1 Comparison with DR09 classification

The new method proposed here is intrinsically different from the <u>one of DR09</u> although it similarly provides trophic regimes and their spatial distributions (interpreted here as bioregions). A comparison between the two approaches is therefore required before discussing the results.

<u>To do so</u>, we verified that the algorithms used in the new method provide the same results as the DR09 methodology (i.e. generation of a weekly climatological database and then application of a K-means clustering) when the results are presented in a climatological point of view (i.e. in average over the 16 years). <u>Then, all the</u> "annual" time series of nChl were averaged according to the DR09 trophic regimes to which they belong (i.e. the DR09 trophic regimes time series in the Fig. 2), and compared to the DR09 evaluations (Fig. 7). The time series obtained with the new method are equivalent to the estimations of DR09; they are contained in the confidence

- interval and they show similar standard deviations. The only notable discrepancy is observed for the "Coastal #7" trophic regime. Our interpretation is that the seasonal signal of this trophic regime (as obtained by DR09) is too ambiguous (i.e. high standard deviation, signal relatively flat) to be retrieved with the new method used here.
- 15 Furthermore, the spatial distribution of trophic regimes obtained with the DR09 methodology (Fig. 8) applied on the new 16-years database, is close to the dominance map of the Fig. 5a (74% of <u>similarity</u>, defined as the percentage of pixels in the Fig. 5a belonging to the same DR09 trophic regime in the Fig. 8). However, some differences with the DR09 10-years map (see Fig. 4 of DR09) exist, mainly the disappearance of the "Intermittently #4" bioregion in the North Ionian. The differences observed when using the new method could be ascribed more to the natural interannual variability, <u>rather</u> than to biases introduced <u>through</u> the <u>novel</u> methodology. Note also
- that the observed differences with the DR09 10-year map could additionally be ascribed to the seven year extension of the database. In conclusion, the new method proposed here broadly supports the results of DR09 <u>obtained at the</u> climatological timescale, but there are some key differences generated by the larger extension of the database, or by the intrinsic natural interannual variability of the Mediterranean. We will address this last point in the next section.

4.2 Interannual spatial variability of trophic regimes: significance and forcing factors

The Fig. 5c clearly indicates that the interannual variability is <u>mostly</u> part concentrated <u>at</u> the boundaries between bioregions. In addition, the four "Anomalous" trophic regimes, although statistically significant (i.e. Jaccard coefficient >89%), have recurrent patterns in open-ocean only in the NWM (Fig. 6b). In the rest of the basin, they appear more as episodic fluctuations or noise than as real patterns. Although not surprising given the approach used (i.e. first finding occurrence of the DR09 trophic regimes and only second searching for anomalies), this point is not trivial. From the methodological point of view, the capability of the method to detect four anomalies demonstrates its potential application in long-term studies. However, at a more in depth analysis and in view of an oceanographic interpretation, these anomalies are not particularly relevant, as occurring only episodically and rarely indicating coherent, recurring patterns. Thus, the main climatological bioregions identified by DR09 (i.e. "No Bloom", "Bloom", "Intermittently" and "Coastal") are sufficiently comprehensive to summarize the surface

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phytoplankton phenology in the Mediterranean Sea, even at interannual level. A notable exception in this global picture is the NWM area, with the recurrent occurrence of the "Anomalous #1" trophic regime.

Finally, it is important to note that, as suggested by DR09, each bioregion (even the "Anomalous" bioregions) is directly related to a specific range of [Chl]_{surf} (see Table 1). This point suggests that the shape of the nChl time series could be related to the annual stock of phytoplankton biomass that the system could support. Based on the analysis of satellite surface data, this observation is certainly partial, although indicating a real pattern that merits further investigations.

4.2.1 The "No Bloom" trophic regimes

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bioregions.

The <u>unimodal</u> pattern of "No Bloom" regimes, with a higher biomass in fall-winter and lower biomass in springsummer, were explained in DR09 by a combined mechanism involving both the vertical redistribution of biomass in fall-winter (i.e. at the deepening of MLD) and the seasonality in the ratio consumers vs. primary producers. More recently, Lavigne et al. (2013) demonstrated the absence of light limitation in the "No Bloom" areas, confirming that the winter increase of [Chl]_{surf} is likely related to relatively small nutrient inputs, <u>as a consequence of MLD deepening. However, in winter the daily Photosynthetically Available Radiation (PAR) at sea surface is also reduced. In response, the intracellular chlorophyll content in the phytoplankton cells increase (i.e. photoacclimatation process), which increase the ratio of chlorophyll to carbon biomass (e.g. Behrenfeld et al.,
</u>

2005), and could in part contributes to the temporal variations of the nChl observed in these "No Bloom"

Among the three "No Bloom" trophic regimes, however, and considering their geographical distribution, the "No 20 Bloom #3" bioregion was interpreted by DR09 as driven by the Atlantic Water inflow <u>from Gibraltar. The</u> <u>interannual</u> variability of the Gibraltar water inflow was recently <u>assessed</u> (Boutov et al. 2014; Fenoglio-Marc et al. 2013), by combining <u>in situ</u> observations, modelling <u>experiments</u> and atmospheric estimations. Inflow at Gibraltar over the <u>1999-2008 period</u> was maximum in 2001 and minimum in 2002, 2005 and 2007, whereas it was constant around its mean value during the other years (Boutov et al., 2014). The occurrence of the "No Bloom #3"

- 25 bioregion, calculated exclusively over the Western Mediterranean (as in Fig. 4, not shown), follows a similar behavior, with an absolute maximum in 2001 and two relative minima in 2002 and 2007 (the lack of data prevents an evaluation of the "No Bloom #3" bioregion occurrence in 2005). The interannual occurrence of the "No Bloom #3" bioregion appears related to the Gibraltar water inflow. Although speculative, this correlation seems to confirm the predominant role of the Atlantic Water in shaping interannual variability of phytoplankton phenology in this
- 30 region. Interestingly, the "Anomalous #4" trophic regime, already identified as a slightly modified version of the "No Bloom #3" trophic regime, is observed mainly in the Algerian Basin (see Fig. 6). It could indicate the presence/absence of episodic anticyclonic eddies (see Olita et al., 2011), generated by instabilities of the Algerian current (Millot et al., 1990), which could induce slight variations of the annual phenology by locally modifying the surface layers.
- 35 The geographical distribution of the other two "No Bloom" trophic regimes (#1 and #2) is rather stable, with a predominance of the #2 in the Adriatic, Aegean and North Ionian and of the #1 in the Tyrrhenian, Levantine and Southern Ionian (Fig. 5a). However, in the Western Adriatic and in the Northern Aegean <u>Seas</u>, which are linked to the "No Bloom #2" bioregion, an important interannual variability is observed (Fig. 5c). In the Adriatic, the

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organic and inorganic matter run-off generated by rivers in the Italian and Balkan peninsulas is characterized by important interannual variability, which is generally related to the timing and the intensity of the run-off. This interannual variability, which controls the injection of river nutrients into oceanic surface waters (Revelante and Gilmartin, 1976; Aubry et al., 2012), could induce the phenological changes observed in the North Adriatic. In the

- 5 North Aegean Sea, the influence of the rivers and of the Black Sea Water on the phytoplankton productivity has been recently confirmed (Tsiaras et al., 2012; Tsiaras et al., 2014<u>; Petihakis et al., 2014</u>). The load of nutrients in these areas by the river and/or the Black Sea Water in late spring (in May, Balkis, 2009) could also explain the occurrence of the "Anomalous #2" trophic regime, which presents a "plateau" in May, instead of the "No Bloom #2" trophic regime. At interannual level, however, no trends or correlations have been identified.
- 10 The rest of the spatial modifications concerning both the "No Bloom #1" and the "No Bloom #2" bioregions are for the most part induced by the eastward extension of the "No Bloom #3" or by the appearance of the "Bloom #5" and/or "Intermittently #4" bioregions. The first case is likely related to the spreading of Atlantic Water, as already mentioned. The second case, discussed in the next section, could be ascribed to local, sub-basin forcing, which enables favorable blooming conditions in specific years.

15 4.2.2 The "Bloom" trophic regime

In the DR09 climatological classification, only one trophic regime exhibited a clear <u>spring</u> peak, and <u>was therefore</u> named "Bloom #5". Located exclusively in the NWM, the most productive area in the Mediterranean Sea (Morel and André, 1991; Bosc et al., 2004), it was <u>associated with</u> the winter deep convection (MEDOC Group, 1970; Marshall and Schott, 1999; D'Ortenzio et al., 2005), which induces <u>a large phytoplankton bloom</u> through intense

- 20 nutrients uptake (Marty et al., 2002). An important interannual variability on the intensity of the winter deep convection has been observed, for the most part related to the variability of atmospheric and hydrodynamic forcing (Mertens and Schott, 1998; L'Hévéder et al., 2013). In response to this oceanic and atmospheric variability, significant interannual differences in the biological response were also reported (Marty et al., 2002; Herrmann et al., 2013; Severin et al., 2014).
- 25 Our 16_year analysis confirms the recurrent presence of the "Bloom #5" bioregion in the NWM area, although it also highlights also the sporadic occurrence of the "Anomalous #1" trophic regime, considered as a modified version of the "Bloom #5" bioregion (more peaked than the "Bloom #5" regime, see Sect. 3.2). The occurrence of the "Anomalous #1" regime in the NWM temporally coincides with recorded events of <u>exceptionally</u> deep winter convection in the area (years 2005, 2006, 2008, 2010 and 2013; Smith et al., 2008; Bernardello et al., 2012;
- 30 Herrmann et al., 2010; Houpert et al., 2014). <u>Such temporal coincidence suggests that deep convection events</u> could impact the phytoplankton phenology of the region, by inducing a stronger phytoplankton bloom (i.e. a higher amplitude, 0.82 mg m⁻³ for the "Bloom #5" trophic regime and 1.09 mg m⁻³ for the "Anomalous #1" trophic regime) and a delay of the spring peak of few weeks. This stronger NWM spring bloom induced by the intense deep convection events could be the result of <u>either an increased nutrient concentration, or a modified nutrient</u>
- 35 stoichiometry, and/or of <u>an enhanced zooplankton dilution</u>, all <u>these</u> mechanisms <u>being triggered by the deep</u> convection (Herrmann et al., 2013; Severin et al., 2014). In summary, the presence of the "Anomalous #1" bioregion appears as a clear indicator of the phenological and ecological changes induced by deep convection events.

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On the other hand, the recurrent occurrence of the "Bloom #5" regime in the NWM area suggests that important phytoplankton growth occurs also when deep convection is relatively weak (as in 2001 and 2007, Houpert et al., 2014). However recent results from profiling floats measuring the [Chl] and the particle mass concentration, suggest also that in this region the photoacclimatation process could contribute to the change in the [Chl]surf

observed (up to 70%, Mignot et al., 2014). Other recent results from profiling floats measuring nitrate concentration (D'Ortenzio et al., 2014) suggest that, more than the deep convection events, the permanent cyclonic circulation in this region was the primary factor inducing favorable conditions for phytoplankton bloom, by bringing the nitracline depths close to surface. This uplift of the nitracline by the cyclonic circulation should allow an efficient replenishment of nitrate in surface." and the appearance of the "Bloom #5" bioregion even during mild 10 winters. As a matter of fact, the area is never classified as a "No Bloom" bioregion.

Unlike DR09, the "Bloom #5" regime is also observed in the South Adriatic, in the Rhodes Gyres area and in the central Tyrrhenian. In the DR09 climatological analysis, these regions were all classified as "Intermittently #4", and they are discussed in the next section.

4.2.3 "Intermittently #4" trophic regime

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- The "Intermittently" trophic regime was explained by DR09 as an effect of the interannual alternation of the 15 "Bloom" and "No Bloom" conditions. Therefore, the resulting regime should be an artifact of the climatological approach of DR09. More recently, the interannual switch between the "Bloom" and "No Bloom" regimes over the "Intermittently #4" area was partially confirmed using in situ estimations of the MLD, although the number of observations was too scarce to draw any conclusions at the basin scale (Lavigne et al., 2013). Here, the interannual
- 20 analysis over the 16-year period indicates that, among the regions classed as "Intermittently #4" by DR09, the Balearic front is permanently classified as "Intermittently #4" (Fig. 5c), while the Rhodes Gyre and the Adriatic and North Ionian Seas switch between "Bloom", "No Bloom" and "Intermittently" bioregions. In other words, the DR09 "Intermittently #4" regime is confirmed to be strongly impacted by the interannual variability. However, its permanent occurrence in the Balearic Sea and its sporadic presence in the rest of the basin suggest that it could be 25 considered a "true" regime more than an artifact of the average. The "Intermittently #4" trophic regime should be
- considered truly an intermediate regime between "No Bloom" and "Bloom" trophic regimes. Thus the name "Intermittently #4" will be replaced by "Intermediate #4".

considered as "Intermittently #4") spatial variability.

Its occurrence in the Balearic area could be then ascribed to frontal instabilities that are generated all along the Balearic front (Lévy et al., 2008; Taylor and Ferrari, 2011) during the blooming period (Olita et al., 2014). These instabilities (i.e. eddies, gyres or filaments) could also modify the local distribution of surface phytoplankton, by exporting phytoplankton rich waters in the oligotrophic waters south of the Balearic front and vice versa. The chaotic nature of these instabilities could explain the lack of clear trends in the "Intermediate #4" (before

For the Southern Adriatic, similarly to the NWM, the cyclonic circulation and the atmospheric conditions are 35 generally evoked to explain the bloom <u>onset</u>, as the deep mixing <u>recurrently</u> observed in the area is supposed to inject enough nutrients to sustain phytoplankton growth (Gacic et al., 2002; Civitarese et al., 2010; Shabrang et al., 2015). The interannual variability of the deep mixing could then influence the variability observed in the annual bioregions maps (Fig. 3). Intense deep convection events were reported in 2005, 2006, and 2012 winters

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(Civitarese et al., 2010; Bensi et al., 2013) when the area is classed as "Bloom #5". Less intense convection, reported for the winters 2000, 2008, 2009 and 2010 (Gacic et al., 2002; Bensi et al., 2013), seems to be <u>associated</u> with "Intermediate #4" or "No Bloom #5" regimes.

The alternating occurrence of "Bloom #5", "Intermediate #4" and "No Bloom" regimes in the Rhodes Gyre region cannot be explained on the basis of existing data over the study period. The Rhodes Gyre is known to be the region of formation of the Levantine Intermediate Water (LIW), which is generated under specific atmospheric forcing conditions and in a permanent cyclonic structure (Wüstz, 1961). Phytoplankton blooms are sporadically observed from space (D'Ortenzio et al., 2003; Volpe et al., 2012), although the link between LIW formation events and phytoplankton enhancement was only hypothesized (Lavigne et al., 2013). The link between bioregions and dense water formation events is not clear in the Rhodes gyre region. The episodic occurrence of "Bloom"/"Intermediate" bioregions demonstrates the specificity of this area in the Levantine basin, and it demands further investigation,

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5 Conclusions

The interannual variability of the Mediterranean Sea trophic regimes, retrieved from satellite ocean color data was presented here. Compared to DR09, a method was developed to account for the interannual variability in the spatial distribution of the DR09 trophic regimes (i.e. bioregions), and for the emergence of new trophic regimes (i.e. the "Anomalous"), which could have been hidden by the climatological approach of DR09. The satellite database was also enlarged to encompass here 16 complete years (from 1998 to 2014).

Firstly, the results from the new approach confirmed that over the studied 16 years, the DR09 bioregions (except the "Coastal #7") were the most recurrent (77.2 %), and that their mean spatial distribution was similar to the one proposed by DR09 (i.e. dominance map, Fig. 5a). In fact, the new interannual approach demonstrates that every year the patterns in the phytoplankton phenology described by DR09 (except the "Coastal #7") trophic regimes) were always recovered. Even the "Intermittently #4" trophic regime, which was interpreted by DR09 as an artifactual regime produced by their climatological averaging, was recovered, and thus confirmed to be a real
25 "Intermediate" trophic regime between the "No Bloom" and "Bloom" trophic regimes. Therefore, the DR09 trophic regimes are argued to be representative of most of the observed seasonality in the [Ch1]_{surf}, even on the annual basis.

Secondly, important regional interannual variabilities in bioregions' spatial distribution, and in the emergence of "Anomalous" trophic regimes, were also highlighted and related to environmental factors. Actually, the interannual extension of the "No Bloom #3" bioregion over the Algerian Basin was related to the inflow of Atlantic Water at Gibraltar. Though less clear, a relation was also proposed between the load of nutrients, from river runoff and the Black Sea Water, and the spatial distribution of the "No Bloom #2" and an "Anomalous" bioregion with a weaker seasonal variability (i.e. the "Anomalous #2"). In contrast, a clear link between the dense water formation events in the South Adriatic and the occurrence of the "Bloom #5" bioregion was detected. In the NWM, a clear parallel between the dense water formations, from open-ocean deep convection events, and the occurrence of an "Anomalous" bioregion with a stronger phytoplankton spring bloom (i.e. the "Anomalous #1) has been Supprimé: associated to

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identified. However, in the NWM, the permanent occurrence of the "Bloom #5" trophic regimes suggests that a sufficient replenishment of nutrients for allowing a phytoplankton spring bloom exists every year, even without a deep convection event. On the other hand, the permanent occurrence in the Balearic front of the "Intermediate #4" trophic regime (originally considered to be an artifactual regime) reveals that it is a real trophic regime, <u>supposedly</u>

- 5 related to frontal instabilities. Finally, in the Eastern Mediterranean basin (i.e. in the Rhodes gyre), the alternating occurrence between the "Intermediate #4", the "Bloom #5", and the "No Bloom" regimes was detected but cannot be explained. This highlights the need for further information over the Mediterranean basin, in order to understand the underlying mechanisms of phytoplankton phenology, and to evaluate whether future climatic changes will promote the oligotrophic status (i.e. more occurrences of "No Bloom" bioregions).
- All these results demonstrate that a bioregionalization based on the analysis of phenological patterns, as the one proposed here, provides a robust framework to identify the evolution of an oceanic area and to summarize the huge quantity of information that the satellite data offer. The limits of the approach are <u>mainly</u> related to the <u>inherent</u> errors of the ocean color data: algorithmic errors, cloud coverage and their restriction to surface layers of the ocean. These limitations are however partially attenuated by the normalization applied to the time series of the [Chl]_{surf} and by the favorable atmospheric conditions of the Mediterranean (low cloud cover).

The Mediterranean Sea is thus confirmed to be a basin showing a large variety of phenological conditions in a very narrow latitudinal range. It could be then considered as a "sentinel" <u>for</u> rapidly detecting the climate change <u>impacts</u> on the marine biomes (as suggested by Siokou-Frangou at al., 2010), <u>as it provides a place where intense</u> and long term monitoring, associated with the development of informative tools, are possible. The utilization of

20 the invaluable dataset of ocean color observations, combined with the proposed methodology, is a first step jowards this direction. The future utilization of networks of biogeochemical dedicated autonomous platforms (as gliders and Bio-Argo floats), in strong combination with remote sensing data and in the framework of bioregions (as suggested by Claustre et al., 2009 and by The Mermex Group, 2011), are likely to confirm the "sentinel" role of the Mediterranean Sea.

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Table 1: Index on the <u>trophic regimes'</u> mean time series (Fig. 2). Summer is defined from June to August include, and the date of the maximal/minimal rate of change as the date of the highest/lowest first derivative of the mean time series of nChl. Whereas the amplitude corresponds to the difference between the mean summer values and the annual maximum values of nChl or [Chl]_{surf} (see Sect. 3.2).

Supprimé: of the trophic regimes

Supprimé: The temporal resolution of the time series is 8 days. Thus the dates in the table indicate the first day of the corresponding 8 days period.

Mean summer		Date of the maximal	Maximum nChl		Date of the minimal	Amplitude		
Trophic regimes	value in nChl	rate of change	Value	Date	rate of change	in nChl	in [Chl] _{surf}	
No Bloom #1	0.31	Dec.	0.91	Feb.	Mar.	0.60	0.16	Su
No Bloom #2	0.39	Nov.	0.87	Feb.	Apr.	0.48	0.14	Su
No Bloom #3	0.24	Dec.	0.86	Feb.	Mar.	0.61	0.25	Su
Intermittently #4	0.23	Feb	0.87	Mar.	Mar.	0.63	0.40	Su Su
Bloom #5	0.16	Mar.	0.82	Apr.	Apr.	0.66	0.82	Su
Coastal #6	0.24	Oct.	0.72	Dec.	Dec.	0.48	0.54	Su
Coastal #7	0.06	Dec.	0.40	Dec.	Mar.	0.34	1.74	Su
Anomalous #1	0.14	Mar.	0.61	Apr.	Apr.	0.47	1.09	Su
Anomalous #2	0.47	Oct.	0.75	Feb.	Jun.	0.29	0.09	Su
Anomalous #3	0.28	Nov.	0.83	Dec.	Mar.	0.55	0.26	Su
Anomalous #4	0.17	Dec.	0.60	Feb.	Mar.	0.43	0.48	Su

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Figure 1: Schematic representation of the different steps of the method used in this study (see Sect. 2.2 for details).





Figure 2: Mean time series of the seven DR09 trophic regimes ("No Bloom #1", "No Bloom #2", "No Bloom #3", "Intermittently #4", "Bloom #5", "Coastal #6" and "Coastal #7") and of the four "Anomalous" trophic regimes ("Anomalous" #1, #2, #3 and #4) obtained from our method. Standard deviations are indicated as black lines.





Figure 3: Maps of the spatial distribution of the trophic regimes (i.e. bioregions), (a) for the years 1999 to 2006 and (b) for the years 2007 to 2014. Note that the year is defined from July to June, (example for the map 1999, it corresponds to the period from July 1998 to June 1999). The white pixels indicate "no data".





Figure 3.





Figure 4: (a) Time series of the area cover by the different bioregions each year (in % of the Mediterranean classified). All "No Bloom" bioregions are regrouped together, as all "Coastal" and all "Anomalous" bioregions. (b) As the Fig. 4a but only for the three "No Bloom" bioregions.





Figure 5: (a) Map of the most recurrent bioregions <u>for</u> the <u>16-year period</u> (i.e. the dominant regimes), obtained with our method. The white pixels indicate where, <u>data are mostly</u> not available. (b) Map of the percentage of presence of the dominant regimes. (c) Map of the most recurrent bioregions as in the Fig. 5a, but displaying only pixels with a percentage of presence \geq 50%. The white pixels indicate where, mostly, data are not available.





Figure 6: (a) Map of the most recurrent bioregions, calculated only <u>for</u> the "Anomalous" bioregions. (b) As in the Fig. 6a, <u>but</u> only <u>the</u> pixels that had at least their most recurrent bioregion for two years are represented.

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Figure 7: Mean time series of the DR09 trophic regimes (in color) and their standard deviations (vertical bars) obtained from our analysis. The standard deviations from the DR09 methodology (in shade area) are obtained by applying the DR09 methodology (i.e. a K-means) on a weekly climatology done with the 16-years database.





Figure 8: Spatial distribution of the climatological trophic regimes obtained from the DR09 methodology (i.e. a K-means) applied on a weekly climatology <u>calculated from</u> the 16-year, database.

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