

Referee #2

Dear Reviewer,

We want to thank you for your observations and comments. We have considered all the advices and suggestion to provide an improved version of the manuscript, in which most of sections were rewritten. The responses to each comment are structured point by point, in order to fully address to all your comments.

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Sammartino and co-authors investigated on the seasonal to inter-annual variability of the algal size community structure over the Mediterranean Sea using SeaWiFS data. The authors firstly compared, against in situ data, the performances of two existing abundance-based approaches (i.e., only based on chlorophyll concentration) developed for global scale applications. Then, they applied the best performing algorithm to the entire mission of chlorophyll concentrations retrieved from SeaWiFS data and estimated using an algorithm specifically developed for the Mediterranean Sea. Spatiotemporal variability was finally discussed and interpreted along with the physical forcing.

General Comment:

Several bio-optical algorithms have been developed for improving the knowledge on phytoplankton distribution over the world's oceans. However, determination of phytoplankton size classes by remote sensed data is still a debate as algorithms can perform with a different accuracy depending on the optical properties of the water body. The effort pursued by the authors is greatly appreciated as the Mediterranean Sea generally falls in that category where globally-validated algorithms generally need to be regionally validated and adapted. The presented exercise has a potential for studies related to biogeochemical cycles or to climate changes in the Med Sea. However, when I read this submission, many concerns regarding the validation and application of the models, the analysis of seasonal and inter-annual variability and also the grammar arose into my mind. In the present form the paper is not suitable for publication.

My major concerns:

- 1) Validation of the Hirata and Brewin models against in situ data is the weakest point of the manuscript. The authors said that the fraction of each size class was computed according to Brewin et al. (2010). Then, they used these fractions for validating both Brewin and Hirata models. But, the distribution of taxonomically significant pigments among the 3 size classes is different between these two models. Fucoxanthin is associated to microphytoplankton in the Brewin model and to both micro- and nanophytoplankton in Hirata et al (2011). Chlorophyll b is attributed to nano-phytoplankton in the Hirata model while it is associated only to pico-phytoplankton in the model by Brewin et al. (2010). This means that the validation of the Brewin model is right while the validation of the Hirata et al. model cannot be trusted. So, it is not sure that the Hirata et al (2011) model is really the best performing algorithm. A good validation of this model should be performed by computing pigment fraction in the same way of Hirata et al., which is possible from the dataset the authors have. In addition, the dataset used by authors for validation seems to include a part of data used by Hirata et al. for developing the algorithm. If it is the case, the validation is not independent.**

We agree with the reviewer that the correct validation of the Hirata model should be done using the pigment classification used by Hirata. This suggestion was taken into account and we recomputed the error associated to the two models using the HPLC-based in situ PSCs

classification used by each model. Unfortunately, when we applied the fucoxanthin adjustment and the Hirata in situ PSCs classification to Mediterranean dataset, it results that Hirata model is not suitable for the basin. In fact, the nano is strongly underestimated by the Hirata model equation and vice-versa the pico is overestimated. This means that the repartition of the chlorophyll-b adopted by Hirata is not suitable for the peculiar characteristics of the Mediterranean Sea, where the picoplankton is the dominant class of the oligotrophic and ultra-oligotrophic waters. Therefore, we decided to do not include the Hirata model in the new version of the paper and focus our analysis on the use of the Brewin method.

In the revised version of section 3 we motivated why we performed a validation of the global models on the Mediterranean Basin and we underlined that only the 15% of SeaBASS dataset were acquired in the Mediterranean Sea. So, even if the data are not completely independent it makes sense to evaluate the performance of a global model over the oligotrophic and ultra-oligotrophic condition of the Mediterranean basin. In addition, considering that, if we filter the global dataset NOMAD following the procedure described in Brewin et al. (2011) for the algorithm development, no data falls in the Mediterranean basin, the dataset used in this work can be considered fully independent from that used by Brewin.

- 2) *About the analysis of the inter-annual variability: although Sammartino et al. had a long-time series of PFT data, all the analyses referred only to 2 months (April and August). Why? There is variability in the size community structure during the other months? In addition, the authors just described the results from the maps (Figures 5 and 6) without being helped by any statistics or techniques generally used in the analysis of time-series. For instance, a good analysis could be to look at the anomalies of each year from the mean both at the basin and sub-basin scales. Such an analysis could be helpful also for studies connected to climate changes.*

Thank you for noticing this. We have decided to show only two months to minimize the number of figures to avoid boring the reader with a month by month description. In any case, the figures of the entire time series are available as additional material.

We selected April and August months, since they are representative of extreme case of the spring and summer, in which the quantitative and qualitative differences among all three classes emerge better than in the others months of the year. Indeed, April is characterized by a typical bloom period, sustained by a partial re-stratification of the water column and positive light condition. On the other hand, August represents the quietest scenario, in which the dynamic of the water masses and physical forces, modulated also by the higher irradiance, induce a higher stratification of the column; consequently, this month constitutes an extreme case with respect to April. Therefore, in the analysis of the quantitative contribution of each phytoplankton dimensional classes to the chlorophyll a , these two months are the most interesting. However, a briefly discussion of the remaining months is now provided in the paper referring to the relative maps available as supplement material. In addition, in order to support the discussion of the maps, we added in the text the monthly anomalies histograms computed over the times series (1998-2010) at basin scale (Figure 8) and sub-basin scale (Figure 10).

- 3) *In the case of the grammar, I suggest the authors to ask a English speaking person to review the manuscript before any other submission. As it is, the manuscript is difficult to follow. Some paragraphs are chaotic, others consist just in 2/3 lines.*

Thank you for your comments, before the submission to the Ocean Science Journal, we have already submitted the paper to a proofreading service. However, during this review phase we

revised the text in order to improve the quality of the writing. We have tried to change and correct some sentences following yours advices. We also used a proofreading service to check our poor English.

A list of minor comments:

Page 163 lines 7-18: *Many concepts in a few lines...this makes the paragraph chaotic. In addition, no references are used! I suggest you to refer to appropriate papers.*

Done

Page 163 lines 19-22: *what do you mean?*

We revised the sentence in order to clarify our concept.

Page 163 from line 23 to the end of the paragraph: *This is a key paragraph of your introduction, so you should develop it better. Several parts in the introduction: you introduced several concepts which have been observed in previous works. You have to cite these papers. Several times you miss to cite. Thank you for highlight this, we absolutely agree with the Referee, therefore we have tried to revise the text and to develop better the concept of cell size as a descriptive element of the community structure. We also added some references over the entire introduction.*

Page 164 line 13: *two papers commonly cited about pigment packaging effect are Morel and Bricaud (1981, Deep Sea Research, 28: 1375-1393) and Bricaud et al. (2004, Journal of Geophysical Research 109, C11010). The packaging effect depends also on pigment cellular concentration and not only on the cell size. "Dimension" is not appropriate, please use "size".*

Done

Page 165 lines 9-14. *I suggest you to split the existing methods into 2 categories (according to Brewin et al., 2011, Remote Sensing of Environment, 115, 325-339): spectral-response based approaches and abundance-based approaches. Then, I suggest you to explain more carefully why you chose to test abundance-based approaches instead of the other type.*

Done

Page 166: *you say that the Mediterranean has peculiar optical properties. This is true. However, my feelings are that you need to explain it better. 3 main hypotheses are generally assumed to be the cause of the deviation of the Med Sea optical behaviour from global bio-optical models for case 1 waters: high CDOM content (Morel and Gentili, 2009, Biogeosciences, 6, 2625-2636); Saharan dust (Claustre et al., 2002, Geophysical Research Letters, 29(10), 1469); and a higher abundance of coccolithophores with respect to other algal groups (Gitelson et al., 1996, Journal of Marine Systems, 9, 283-290). A reader who does not usually work on this area maybe could not understand.*

Thank you for this comment, which is very interesting. We discussed, in the text, the several possibilities, by you suggested, which makes unique the optical properties of Mediterranean Sea.

Page 168 line 5: *I suggest you to explain how this algorithm is specific for the Mediterranean Sea. Does it consider, for instance, the high CDOM contribution occurring in the Med Sea?*

We added some text in the introduction, giving more details about the MedOC4 algorithm, which is based on an empirical adjustment of the OC4 coefficients using a Mediterranean dataset, without any explicit dependence from CDOM concentration.

Section 2.2: *In general when you describe a data set, it is useful to add more information in the text or using a table. It is important to know for instance: number of samples, period/season, depth of sampling, location, sources. In addition a map would be also useful to display the sampled stations.*

Methods of analysis are also important. I suggest you also to write the formula you used to calculate pigment fractions.

As suggested by the reviewer, the table with in situ measurements has been added to paper (see Table 1), and also the formula for the in situ PSCs computation with the Mediterranean DP coefficients.

Section 4: *In addition to my concerns about validation, I found this section poorly written. In effect, the statistics you calculated is reported just in the table and it is not used in the text. Saying “falls well” or “fit better” is not appropriate, you have to strengthen what you are observing and persuade the reader using statistics.*

This section has been deeply revised and the results are now discussed (see Section 3).

Page 171, Lines 1-14: *why here?*

Moved in section 2.1.

Section 5: *I found very difficult to follow the results on Figure 2. It is a too busy figure.*

Maybe, a map should be better. In addition, when you describe the trends across the Med Sea you refer to the various sub-basins. However, you don't provide any indication (at least not before figure 8 and section 7) about the location of the various sub-basins across the Med Sea. I suggest indicating them at the beginning of your results, hopefully using a map. This could help the reader.

We tried to improve the old Figure 2, which is now Figure 3. The old Figure 8 is now the new Figure 1. We added in the Figure 1 the information on the location of the different Mediterranean sub-basins.

Section 5.3: *why did you focus only on the North Aegean and Adriatic Seas. There is a specific reason?*

We selected North Aegean and Adriatic Sea to highlight the impact of waters outflow in modulating PSCs variability.

Section 6: *I expected from this paragraph to understand if there was variability or not in PSCs among the years you studied. You just described the variations. Statistics could be helpful to understand if the very small variations you observed (in Figure 7) are significant or not.*

We decided to eliminate Figure 7 and to use the maps of Figure 6-7 to discuss the inter-annual variability. In fact averaging the chlorophyll *a* and PSCs fractions over the basin, some of the most interesting seasonal and inter-annual signals can be hidden. To support and better understand the phenomena observed in Figs. 6-7 we added a comment in the text of the monthly anomalies computed for the time series 1998-2010 at basin scale. However, an evaluation of the error, which affects monthly mean estimates, can be done considering the propagation of the error of each single measure over the average. If we assume that the distribution of a variable (chlorophyll *a*, for instance) in a specific grid point is Gaussian (i.e. repeated measurements over this point made in a time interval short enough to ensure stationarity in statistical sense) the average also is Gaussian (linear combination of Gaussian variables). Then we can still apply the law of propagation of the errors to compute mean error M_0 . This mean that the mean error M_0 goes as $1/\sqrt{N}$ (in our case N is the number of measurements over a grid point during a month). Then, as a consequence, the total error of the average is much more smaller than the error of each single determination. Performing this calculation (i.e. applying the law of propagation of the errors), pessimistically assuming an error of 50%, we found that in more than 99% of the grid points the error on the monthly mean is less than 0.01 mgm^{-3} . Therefore, even if the chlorophyll *a* spatial distribution cannot be considered Gaussian, the spatial average of each monthly map should not increase this error.

Page 177 line 1: “relevant processes”: which ones?

Done

Section 7: It could be useful to compare you results with those found in the same areas in other studies.

The comparison with other studies is discussed in section 7.

Page 180, lines 16-18: Not sure you can say this. To corroborate this aspect, I suggest you to adapt the model to the Med Sea and then to analyze differences with respect to the original version.

This sentence has been removed

Figure 2: it is very difficult to read.

Improved in Figure 3

Figures 5 and 6: they are too small.

The generation of the PDF made by Ocean Science reduced the resolution of the images; it should occupy A4 size. We hope that in the final version of the paper when the postscript images will be used the problem will be solved.

Figure 7: I suggest using the same scale for April and August.

We eliminated Figure 7, replacing it with the monthly anomalies computed at basin scale for the time series 1998-2010 (see Figure 8).

Figure 8: For example, which one is the Alboran Sea among the 4 red squares?

We added the information in the Figure 1.

1 Spatio-temporal variability of micro-, nano- and pico-phytoplankton in 2 the Mediterranean Sea from satellite ocean colour data of SeaWiFS

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8 Keywords: Phytoplankton Size Classes; Ocean Colour; Mediterranean Sea.

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10

11 Abstract

12 The seasonal and year-to-year variability of the [Phytoplankton Size Classes \(PSCs\)](#) spatial distribution has
13 been examined in the Mediterranean Sea [by using the entire time series of Sea-viewing Wide Field-of-view](#)
14 [Sensor \(SeaWiFS\) space observations \(1998 to 2010\)](#). PSCs daily maps have been determined using an
15 empirical model based on a synoptic relationship between surface chlorophyll *a* and diagnostic pigments
16 referred to different taxonomic groups. [The analysis of micro-, nano- and pico-phytoplankton satellite time](#)
17 [series \(1998–2010\) describes, quantitatively, the algal assemblage structure over the basin and reveals that](#)
18 [the main contribution to the chlorophyll *a* in most of the Mediterranean Sea comes from the pico-](#)
19 [phytoplankton component, above all in poor nutrient environments](#). Regions with different and peculiar
20 features are the northwestern Mediterranean Sea, the Alborán Sea and several coastal areas, such as the
21 north Adriatic Sea. In these areas, local interactions between physical and biological components modulate
22 the competition between the three phytoplankton size classes. It results that, during the spring bloom
23 season, micro-phytoplankton dominates in areas of intense vertical winter mixing and deep/intermediate
24 water formation while, in coastal areas, micro-phytoplankton dominates in all seasons, [because of the](#)
25 [nutrient](#) supply from the terrestrial inputs. In the Alborán Sea, [where](#) the Atlantic inflow modulates the
26 nutrient availability, any predominance of one class over the other two has been observed. Nano-
27 phytoplankton component instead remains widespread over the entire basin along the year, and its
28 contribution to the TChl *a* is of the order of [30–40%](#). [The largest inter-annual signal occurs in the](#)
29 [northwestern Mediterranean Sea, driven by the year-to-year variation in intensity and extension of the spring](#)
30 [bloom, followed by the Alborán Sea, in which the inter-annual variability is strongly modulated by the Atlantic](#)
31 [inflow](#).

32 In absence of sufficient in situ data of community composition, the satellite-based analysis demonstrated
33 that pico, nano and micro classes often coexist. The predominance of one group over the other ones is

34 strongly dependent on the physical-biological processes occurring at mesoscale. These processes directly
35 influence the nutrient and light availability, which are the principal forcing for the algae growth.

36

37 **1 Introduction**

38 Phytoplankton represents an important element for the survival and comprehension of the marine
39 ecosystem. Its scientific importance is owing to its ecological role in the global carbon cycle and greenhouse
40 effect (Park et al., 2015). Phytoplankton plays a key role in the biological carbon pump not only for its
41 consumption of inorganic carbon during photosynthesis but also for the transport of organic carbon from the
42 surface to deep layers of ocean. Moreover, phytoplankton contributes to the primary production, due to its
43 rapid turnover and to the great extension of the ocean on the earth's surface (Falkowski et al., 1998).

44 Phytoplankton biomass bio-geographic distribution, on global and regional scales, is directly influenced by
45 biological, chemical and physical factors such as light, nutrients availability, presence of competitors,
46 predators, as well as temperature and pH, which are all connected to the local dynamic of water masses.
47 These biotic and abiotic factors create a complex system in which the phytoplankton, in being a primary
48 producer, plays a relevant role (Reynolds, 1989) and represents the first step of the ecological pyramid as
49 well as the food web (Klauschies et al., 2012).

50 The availability of light and nutrients strongly influences the phytoplankton biomass and community
51 structure; when nutrients are reduced, the smaller component of algal biomass predominates on the bigger
52 one, but when the system shift to inverse bio-geochemical condition, the community tends to change its
53 structure, in being predominated by large cells. These types of changes could have a strong impact on the
54 marine system and on the stoichiometry, carbon storage and biogeochemistry (Marinov et al., 2010).

55 Any change of marine ecosystem state is also reflected in new morphological and physiological adjustments,
56 just like the change of size for each specific trophic stadium (Thingstad and Rassoulzadegan, 1999).

57 Thanks to the relationship between dimensions and pigmentary content, different taxa or stages of growth
58 in the same taxon, photosynthetic efficiency and bio-optical phytoplankton properties (Chisholm, 1992;
59 Organelli et al., 2007; Raven, 1998), "cell size" becomes an important descriptor of the community structure.

60 Indeed, phytoplankton cell size and pigment content are some of the physiological traits that influence the
61 rate of acquiring and processing energy and materials from the environment (Brown et al., 2004). Size and
62 biodiversity of phytoplankton community can modulate the amount of carbon fixed and exported into the
63 deep sea with respect to the nutrient availability (Finkel et al., 2010).

64 A shift in the phytoplankton size structure from a dominance of picoplankton to predominance of larger
65 nano- and micro-phytoplankton is associated with a shift in the pelagic food web (Finkel et al., 2010). The
66 dimension of cells and consequently the structure of the algal community can influence the trophic
67 organization of the marine ecosystem and the ability to produce more organic matter to be transferred across
68 the successive trophic stages (Marañón et al., 2012).

69 Given the importance of cell size in understanding the relationship between phytoplankton assemblage and
70 marine ecosystem dynamic, it is common to classify the algal community in micro-, nano- and pico-
71 phytoplankton. One of the most common Phytoplankton Size Classes (PSCs) definition identify the size ranges
72 of the phytoplankton cells as follow: micro > 20 μm , the nano from 2 to 20 μm and pico < 2 μm (Sieburth et
73 al., 1978). In oligotrophic waters the pico-phytoplankton provides a relevant contribution to the total content
74 of chlorophyll *a* (Agawin et al., 2000), being the latter defined as the sum of chlorophyll *a*, its allomers and
75 epimers, divinyl-chlorophyll *a*, chlorophyllid *a* (Hooker et al., 2005) and called TChl *a* or chlorophyll *a*
76 follow. On the contrary, in eutrophic water where cells have the opportunity to grow due to the availability
77 of nutrients and light, the larger cells prevail (Irwin et al., 2006).

78 In terms of biogeochemical function and role, size structure of phytoplankton communities provides
79 important information such as the knowledge of the community composition itself (Vidussi et al., 2001;
80 Chisholm, 1992; Raven, 1998). Indeed, in some cases, several biogeochemical functions correspond to a
81 particular taxon or size class; for instance, cyanobacteria often represents a large group of
82 picophytoplanktonic nitrogen-fixers. They are able to fix and use the forms of atmospheric nitrogen, thereby
83 having a direct impact on climate change. Yet, the principal components of the micro-phytoplankton, diatoms
84 and dinoflagellates, play a dominant role in the Carbon flux into deeper waters (Nair et al., 2008;
85 Sathyendranath, 2014). In these cases a PFTs (Phytoplankton Functional Types) classification is adopted, in
86 which each type defines a group of different species with a common ecological function.

87 Information about the composition of phytoplankton community structure can be obtained from the analysis
88 of in situ samples using different laboratory techniques such as: flow-cytometry, which provides information
89 about the number and the dimensions of the fluorescent cells in a specific water sample volume; HPLC (High
90 Pressure Liquid Chromatography), which is used to retrieve the composition and concentration of the
91 pigments content of the cells; spectrophotometry, which provides the pigment light absorption in the visible
92 spectrum, and filtration of water through filter-pads of a known size together with in vitro fluorometric
93 chlorophyll *a* extraction. As a result, there exist considerable data on in situ dimensional classes measures
94 that could be useful, also, for other applications like calibration and validation of satellite PSCs algorithms.

95 From space, the composition of the community is detected by exploiting the signature of the different species
96 and classes on the optical properties in the water column. Light absorption of a cell is affected by its pigment
97 “package effect” (Morel and Bricaud, 1981; Bricaud et al., 2004), which, in describing the chlorophyll *a*
98 efficiency in the light harvesting, is a direct function of the pigment cellular concentration and therefore of
99 the “cell size” (Chisholm, 1992; Raven, 1998; Basset et al., 2009).

100 Concentration of chlorophyll *a*, light absorption and backscattering signals, derived from remote-sensing
101 reflectance, are the main ocean colour variables that provide synoptic and multi temporal information about
102 phytoplankton distribution. Several satellite models have been developed in recent years to classify the algal
103 cells on the basis of optical variable measured from space. These are usually divided into two main classes:

104 direct models, which exploit the optical properties directly captured by the sensor; indirect models, as those
105 based on the strong relationship between the chlorophyll *a* concentration and the functional groups or taxa
106 and PSCs (Moisan et al., 2012).

107 Another classification of these methods is based on the spectral-response and abundance-based approaches
108 (Brewin et al. 2011a). The spectral-response models analyze the differences in the shape of the light
109 reflectance/absorption spectrum to provide information about different phytoplankton classes; an example
110 of this model is the Alvain's et al. (2005, 2008) one, in which different phytoplankton groups are identified
111 from the normalized *water leaving radiance* data. These authors exploit the anomalies in the spectral
112 signature of a specific taxon or a specific type of community after removing the chlorophyll *a* signal from the
113 radiance measure. The abundance-based models, instead, exploit the information coming from the
114 magnitude of chlorophyll *a* biomass or light absorption to separate one group from another (Devred et al.
115 2006; Uitz et al. 2006; Hirata et al. 2008; Brewin et al. 2010; Brewin et al, 2011b; Hirata et al. 2011). Most of
116 the satellite PSCs models are based on a specific variable: e.g. the absorption coefficient at different
117 wavelength of the cells (Sathyendranath et al., 2001), or the backscattering coefficient (Kostadinov et al.,
118 2009). Others are mixed models, just as in the case of Fujiwara et al. (2011), in which the algorithm partitions
119 between the pico + nano-phytoplankton community and the micro one, involving the absorption and
120 backscattering coefficients.

121 Most of the models described above, were developed for the global ocean and applied to infer phytoplankton
122 composition or classes from space allowing to study their seasonal and inter-annual variability at global scales
123 (Brewin et al., 2010, 2011b; Hirata et al., 2008, 2011; Uitz et al., 2006; Mouw and Youder, 2010). In this paper,
124 instead, we used a chlorophyll *a* based model to estimate phytoplankton composition in the Mediterranean
125 Sea with the aim of studying the spatial and temporal variability of phytoplankton assemblage dynamics. The
126 choice to test a chlorophyll *a*-based model rather than spectral-based ones was inspired by the possibility to
127 check the global model performances at regional scale by using available in situ observations. Indeed, in
128 Mediterranean Sea, the number of in situ data related to Diagnostic Pigments (sum of seven marker pigments
129 intended as size taxonomic pigments, DP, Vidussi et al., 2001) is much greater than the optical
130 measurements, which are very limited and not always freely available.

131 Presently, chlorophyll *a* estimates from ocean colour data were widely used to study the Mediterranean
132 phytoplankton biomass variability at basin and sub-basin scales (e.g. Antoine and Morel, 1996a, 1996b;
133 Santoleri et al., 2003; Bosc et al., 2004; Volpe et al., 2012b). Only recently, Navarro et al. (2014), adapted the
134 PHYSAT method of Alvain et al. (2005) to the Mediterranean Basin bio-optical characteristics, thereby
135 providing a regional algorithm to estimate dominant phytoplankton groups (Nanoeukaryotes,
136 *Prochlorococcus*, *Synechococcus*, diatoms and coccolithophores) from MODIS water leaving radiance
137 measures.

138 Therefore, the objective of this work is dual: i) to understand how well a simple empirical model solely based
139 on chlorophyll *a* data, as Brewin et al. (2011b) referred as BR henceforth, can describe the phytoplankton
140 biomass distribution in the Mediterranean Sea; ii) to study the spatial–temporal variability of the three
141 phytoplankton size classes (micro, nano and pico) in this basin, by applying the selected model to the ocean
142 colour products. This paper will be the first attempt to describe the seasonal and inter-annual evolution of
143 the phytoplankton size classes assemblage during the entire SeaWiFS era. In Section 2, we presented the
144 satellite and in situ data we use. In the same section we briefly describe the selected PSCs model is. In Section
145 3 we describe BR model validation over the Mediterranean Sea, using HPLC observation. Finally, the
146 variability and distribution of PSCs is analyzed at different scales of time and space (Sections 4, 5 and 6).
147 Conclusions (Section 7) summarizes the results and presents the future perspectives.

148

149 **1.1 The study area**

150 The Mediterranean Sea (Fig. 1), although relatively small, is characterized by a circulation that can be
151 compared to that of a large-scale ocean. It is among all, the most interesting of the semi-enclosed seas
152 because of the great range of processes and interactions that occur within it (Robinson and Golnaraghi,
153 1994). Most of the physical and biological processes that characterize the global ocean, many of which are
154 not well known or understood, occur analogously in the Mediterranean Sea (Siokou-Frangou et al., 2010;
155 Lacombe et al., 1981; Robinson and Golnaraghi, 1994). These biological and physical processes interact with
156 each other and influence, directly, the distribution of the phytoplankton and zooplankton community and
157 the optical properties of the seawater. Unlike the other seas and oceans, the Mediterranean Sea has unique
158 optical properties of the water column, when compared with other regions, with “oligotrophic waters less
159 blue (30 %) and greener (15%) than the global ocean” (Volpe et al., 2007). Many hypotheses were developed
160 in the past to understand and justify the reason why the Mediterranean Sea shows these properties. One of
161 them is relative to the high yellow substance content, which can be responsible of an enhancement of
162 absorbing material (Claustre and Maritorena, 2003; Morel and Gentili, 2009). Another hypothesis attributes
163 this effect to the presence of coccoliths (D’Ortenzio et al. 2002, Gitelson et al., 1996), while a third hypothesis
164 is related to the presence of submicron Saharan dust in suspension in the surface layer (Claustre et al., 2002).
165 Finally, Volpe et al. (2007) suggest that the different phytoplankton community structure, typical of the basin,
166 could alter the spectral signature and therefore be responsible of peculiar colour of the Mediterranean Sea.
167 Nowadays, it does not exist a univocal response, which can optimally justify the Mediterranean “greener”
168 than other oceans. Therefore, this peculiarity has made it necessary to develop regional bio-optical
169 algorithms in order to estimate chlorophyll *a* concentration from in situ optical measurements and satellite
170 data (D’Ortenzio et al., 2002, Volpe et al., 2007; Santoleri et al. 2008). Finally, the optical properties of the
171 Mediterranean Sea suggest verifying whether a PSCs model designed for global ocean applications can
172 perform similarly in the Mediterranean Sea.

173

174 **2 Data & Methods**

175

176 **2.1 Satellite data and processing**

177 The satellite data used in this work comes from Sea-viewing Wide Field-of-view Sensor (SeaWiFS). They are
178 daily chlorophyll *a* Level 3 (L3) data (resolution 1.1 km), from 1998 to 2010, produced by the Satellite
179 Oceanography Group (GOS) of the Institute of Atmospheric Sciences and Climate (ISAC) of the Italian National
180 Research Council (CNR), and made available to scientific community. We used the so called Mediterranean
181 Case1Case2 merged chlorophyll *a* product (GOS Chl_1-2). These daily chlorophyll *a* fields are derived from L1
182 SeaWiFS passes applying two different bio-optical regional algorithms for open and coastal waters (see Volpe
183 et al., 2012a, for the details of processing). The MedOC4 algorithm is used to retrieve chlorophyll *a* in the
184 Case 1 waters (Volpe et al., 2007) and while the Ad4, is applied for the Case 2 waters (Berthon and Zibordi,
185 2004). The identification of the optical properties of each pixel is based on the D'Alimonte's method
186 (D'Alimonte et al., 2003), which takes into account the entire spectrum from the blue band to NIR, for both
187 Case1 and Case2 waters types. For intermediate waters, a weighted average of the two algorithms based on
188 the distance between the actual reflectance spectra and the reference one for the Case 1 and 2 waters is
189 applied.

190 The choice of applying an algorithm born specifically for the Mediterranean Case 1 waters, as MedOC4,
191 provides a more realistic value of TChl *a*, as demonstrated by Volpe et al. (2007), who showed that NASA
192 SeaWiFS chlorophyll *a* fields are affected by an uncertainty of the order of 100% (Volpe et al., 2007) and
193 confirmed by several authors. The MedOC4 algorithm was developed from a readjustment of the NASA
194 algorithm OC4 (O'Reilly et al., 1998), in which the coefficients were obtained from a fourth power polynomial
195 regression fit between log-transformed in situ Mediterranean chlorophyll *a* concentration and maximum
196 band ratios at a specific wavelength obtained by in situ optical profiles (Volpe et al., 2007). Similarly, the Ad4
197 has been tuned by using the bio-optical dataset acquired by JRC in the Venice Tower located in the North
198 Adriatic Sea.

199 Besides the use of a regional algorithm, all the data distributed by GOS and those distributed by MyOcean
200 OCTAC to the end-users are quality checked. The daily TChl *a* fields, used as input in this work, were subjected
201 to quality assessment through classical matchup analysis (called offline validation in Volpe et al., 2012a).
202 Volpe et al. (2012a) demonstrates that the SeaWiFS Mediterranean regional products match up well to the
203 corresponding in situ data showing the following statistical results: the correlation coefficient (r^2) 0.815,
204 Root Mean Square Error (RMS) 0.253 mgm^{-3} , bias -0.019 mgm^{-3} , relative (RPD) 15% and absolute (ADP) 51%
205 percentage differences (see Table 4 in Volpe et al., 2012a). Given the log-normal chlorophyll *a* distribution,
206 r^2 , RMS and bias are calculated over log-transformed quantities, while RPD and APD over untransformed
207 pairs of values.

208 Here, daily chlorophyll a maps, at 4 km of resolution, were used to compute monthly maps covering the
209 SeaWiFS era (1998–2010), then the monthly means were averaged to compute monthly climatology.
210 Moreover, TChl a fields at monthly and climatological scales were then used to support the analysis of
211 phytoplankton biomass variability. In these maps, the chlorophyll a concentration is expressed as base log-
212 10 transformed considering the log-normal distribution of this pigment.

213 The BR method was then applied to compute the PSCs daily fields over the Mediterranean Sea for entire
214 SeaWiFS time series. This model expresses the TChl a concentration as the sum of pico, nano and micro-
215 phytoplankton chlorophyll a fraction, and each class is computed by using a simple function of the
216 chlorophyll a . For more details about the algorithm, see Brewin et al. (2011b). The daily PSCs fields are then
217 used to produce monthly climatological fields.

218

219 **2.2 In situ data and processing**

220 The in situ dataset used in this paper is the SeaBASS HPLC-based diagnostic pigments dataset (Werdell and
221 Bailey, 2005). All the data acquired in the Mediterranean Sea were extracted from this global dataset and
222 used for model validation purpose. The Mediterranean SeaBASS dataset (referred as “MED in situ”,
223 hereafter) consists of 1454 samples acquired in the basin since 1999 and represents the 15% of the global
224 SeaBASS data. The MED in situ data were acquired during two trans-Mediterranean cruises (Prosopé99, and
225 Boum08) covering the basin from Gibraltar to eastern Mediterranean, and near the Boussole mooring where
226 periodic measurements are carried out from 2001 to 2006. The details of the in situ observation in terms of
227 location, period of sampling, TChl a value ranges and sampling depth are reported in Table 1. Even if most of
228 the data were acquired at the Bussole sampling site, the measurements still covers the entire range values
229 of the Mediterranean chlorophyll a variability, with values ranging from less than 0.05 to more than 5 mgm^{-3} .
230

231 The Med in situ pigment dataset was quality checked and filtered by applying the same procedure used by
232 Brewin et al. (2011b). Following Aiken et al. (2009), outliers were determined from the regression of
233 accessory pigments against TChl a excluding values behind the 95% of confidence interval of the regression.
234 This reduces the number of samples from 1454 to 1085.

235 This dataset was then used to compute the in situ quantification of PSCs following the methods described in
236 the Brewin et al. (2011b), based on the previous works of Vidussi et al. (2001) and Uitz et al. (2006).

237 We point out that NOMAD dataset used by Brewin et al. (2011b) to develop their PSCs model, after filtering,
238 does not include any Mediterranean data point; therefore, our Mediterranean dataset can be considered
239 fully independent.

240

241 3 Brewin model performances over the Mediterranean Sea

242 The MED in situ is used to evaluate, for the first time, the BR model accuracy over the Mediterranean Sea
243 (Table 2 and Fig. 2). Figure 2 (left panels, a-c) shows the micro, nano and pico-phytoplankton fractions,
244 obtained by applying the Uitz et al. (2006) DP coefficients, as a function of the TChl a . A rather large scatter
245 of the data around the model curves suggests that, in the real world, the relative abundance of micro, nano
246 and pico-phytoplankton cannot be a simple function of the chlorophyll a concentration alone. In particular,
247 the BR model strongly underestimates nano plankton fraction measured in the Mediterranean basin in the
248 entire range of TChl a values, while overestimates the pico fraction for TChl a concentrations less than 0.8
249 mg/m³; only for micro plankton the curve falls in middle of the observed cloud of data points. These results
250 are quantitatively confirmed by the statistical analysis, which shows a log10 bias error of -4%, -26% and 67%
251 for micro, pico and nano fractions respectively.

252 The poor performance of the model can be due to the particular optical properties of Mediterranean waters,
253 which makes this basin unique with respect to the other oceans (see section 1). For this reason, before to
254 start performing any new adjustment of the BR coefficients, we first investigate whether if a different relation
255 between DP and chlorophyll a in the Mediterranean basin can be responsible for the observed biases. This
256 allows us also to verify the Volpe et al. (2007) hypothesis, which considers the different assemblage of the
257 phytoplankton community structure as one of the possible causes responsible of the greener colour of the
258 Mediterranean Sea. Recently, Di Cicco (2014) provided a regional DP and chlorophyll a relationship, which
259 is entirely based on Mediterranean data. She, by applying the Gieskes et al. (1988) approach to the MED in
260 situ data, performed a new multiple regression analysis to evaluate whether a different pigment ratios of the
261 phytoplankton community can occur in the basin and showed that the use of Uitz DP-TChl a relationship
262 results in an underestimation of the Mediterranean TChl a estimate overall its range values; namely the Utiz
263 line fit has a slope coefficient less than 1. The new MED DP-TChl a relationship found by Di Cicco (2014) is:

$$265 \quad TChla = 1.999[Zea] + 1.624[TChlb] + 2.088[Allo] + 0.861[19' Hex-fuco] + 0.405[19' But-Fuco] + \\ 266 \quad 1.74[Fuco] + 1.172[Peri] \quad \text{eq. (1)}$$

267
268 in which each PSCs fraction is computed as follows:

$$270 \quad f_{pico} = (1.999[Zea] + 1.624[TChlb])/TChla \quad \text{eq. (2)}$$

$$272 \quad f_{nano} = (2.088[Allo] + 0.861[19' Hex-fuco] + 0.405[19' But-fuco])/TChla \quad \text{eq. (3)}$$

$$274 \quad f_{micro} = (1.74[Fuco] + 1.172[Peri])/TChla \quad \text{eq. (4)}$$

275

276 For more details about the new coefficient retrieval, see Di Cicco (2014).
277 Consequently, we applied the new Di Cicco (2014) coefficients to obtain the new in situ PSCs classification to
278 be compared with the BR model. Effectively, the improved performances of the model with respect to the
279 in situ PSCs fractions (shown in Fig. 2, d-f) highlights how important the relation between the diagnostic
280 pigments and TChl a content is. Figure 2 summarizes the comparison between the BR satellite model and the
281 in situ PSCs fractions as obtained by using, respectively, the Uitz et al. (2006) DP coefficients (left panel of
282 Fig. 2, a-c) and Di Cicco (2014) ones (right panel of Fig. 2, d-f), while the statistical results are shown in Table
283 2. Figure 2 shows that the in situ Uitz PSCs classification is not suitable for the Mediterranean Sea and a
284 regional classification is therefore necessary. This is evident, in particular, for the nano-phytoplankton case
285 (Fig. 2 e), in which the use of MED DP relationship shifts down the cloud points and results in a better
286 performance of BR model with the log₁₀ %mean bias error falling from 67% to only 8%. By observing the
287 pico scatter plot (Fig. 2f), the dots are now distributed around the model curve for the all range of chlorophyll
288 a values, and the % log₁₀ bias decreases from -26% to 15%. Micro component represents a similar behavior,
289 both applying the global coefficients and the Mediterranean ones, as confirmed by the statistical results. The
290 statistics in Table 2, computed both in linear scale and in log-transformed scale using the reference equation
291 of Table 3, confirms that the use of Di Cicco DP relationship is a key factor to improve the in situ PSCs
292 classification. When equation (1) is used, the errors we found applying the BR model result in a MBE% range
293 from -5% to 21% which is of same order that is found by Brewin et al. (2010) by using an independent dataset
294 (from 11% to 13.3%). Consequently, we conclude that an adaptation of the BR model coefficients for the
295 Mediterranean case is not a priority considering the limited margin for improvement left after the tuning of
296 the Uitz DP-TChl a coefficients.

297

298 **4 Seasonal variability of spatial distribution of the PSCs in the Mediterranean Sea**

299 The seasonal evolution of the chlorophyll a distribution in the Mediterranean Sea is driven by the life cycle
300 of the phytoplanktonic organisms that follows the typical succession of temperate areas, with a high biomass
301 increase in late winter/early spring and a decrease in summertime, and a second smaller bloom in autumn.
302 PSCs variability follows this oscillation mostly driven by the evolution of the chlorophyll a concentration and
303 its West-East gradient (see Fig 1S (a-c) in additional material). This spatial gradient is one of the dominant
304 features of the chlorophyll a distribution in the Mediterranean Sea and reinforces the paradigm of an
305 extremely oligotrophic Eastern basin and a more productive Western side (D'Ortenzio et al., 2009). We
306 investigated the seasonal variability of this spatial gradient by computing the variation of monthly chlorophyll
307 a climatology moving from West to East along the basin (Fig. 3). In this figure, each colored line represents a
308 climatological month and the chlorophyll a value at a given longitude is obtained by averaging all the sea
309 pixels from north to south, excluding those closer than 20 km from the coast to restrict the calculus to open
310 ocean waters.

311 A decreasing trend of this surface chlorophyll *a* mean concentration, moving from West to East, is observed
312 in all the months of the year (Fig. 3). The curves highlight the occurrence of an enhanced seasonal cycle in
313 the western Mediterranean with respect to the eastern Mediterranean Sea, generally characterized by
314 oligotrophic conditions in all the months of the year. Oligotrophic conditions dominate in the western
315 Mediterranean Sea during summer, while during spring, the occurrence of the blooms is marked by two
316 distinct peaks at 4° and 9° E associated to the Gulf of Lions and Ligurian Sea respectively. The peak at 13° E,
317 instead, is the signature of the rich chlorophyll *a* area of the North Adriatic Sea.

318 The observed West to East decreasing trend is consistent with a similar trend observed in the nutrient
319 concentrations by Siokou-Frangou et al. (2010) and by Santinelli et al. (2012). These concentrations are
320 generally very low, according with the general oligotrophy of the basin, mainly linked to the lack of
321 phosphorous, which represents a limiting factor for phytoplankton community's growth (Zohary and
322 Robarts, 1998; Ribera D'Alcalà et al., 2003; Krom et al., 2004).

323 Figure 3 clearly reveals that April is the month in which the maximum excursion of chlorophyll *a* across the
324 basin occurs while August shows a minimum of the longitudinal gradient. In these two months we observed
325 the two extremes of the annual chlorophyll *a* variability all the Mediterranean sub-basin, except for the
326 Adriatic Sea. Therefore, in the next sub-sessions we focus on these contrasting months for analyzing the
327 variation of the spatial distribution of micro-, nano, and pico-phytoplankton in the Mediterranean Sea
328 resulting from the application of the BR model. However, the maps of entire climatological time series can
329 be found as supplementary materials.

330

331 **4.1 Micro-phytoplankton**

332 The seasonal spring to summer excursion of micro-phytoplankton, in the first optical depth, is shown in Fig.
333 4. In August, excluding the coastal areas, the micro-phytoplankton is uniformly distributed over the entire
334 Mediterranean and its contribution to the total chlorophyll *a* is low, with values of about 12% in the Ionian-
335 Levantine Basin and 13% in the Western basin, with relative peaks of 15–25% in the Alborán Sea. These low
336 values are associated to low chlorophyll *a* concentrations. Indeed, in summertime, the water becomes
337 warmer and the stratification of the column is more marked, thereby producing a resistant thermocline that
338 limits the transfer of nutrients to surface and consequently determines a reduced photosynthetic activity
339 (Siokou-Frangou et al., 2010). This pattern persists also in June and July (see additional material). In August,
340 high values of micro-phytoplankton contribution are observed in some coastal regions characterized by a
341 high nutrients supply due to upwelling phenomena or river runoff: the Alborán Sea, the north Adriatic Sea,
342 the Gulf of Lions and the gulf of Gabes with values ranging between 35–75 %. In the Alborán Sea, the higher
343 micro-phytoplankton contribution is highlighted by water upwelled along the Spanish coasts and entrained
344 in the west Alborán gyre (Sarhan et al., 2000).

345 In April, *instead*, the fraction of micro-phytoplankton significantly grows in the northwestern Mediterranean
346 Sea *reaching values from 30% to 57%*. This area, included by D’Ortenzio et al. (2009) in the bloom cluster, is
347 characterized by a local dynamic in which cold winter winds can induce deep mixing extending down to
348 several hundred up to thousand meters, *a value that is large when* compared to the seasonal winter overturn.
349 This deep overturning process also brings up an additional supply of nutrients complementary to that
350 furnished by seasonal convection, thus modulating the spring bloom. The bloom observed in April (Fig. 4) is
351 the result of winter upwelled nutrients and phytoplankton trapped in the euphotic zone by the spring re-
352 stratification process and *by* the increased insolation. After this high productivity’s period, micro-
353 phytoplankton contribution to the TChl *a* decreases in the whole basin, reaching its minimum in *August-*
354 *September*.

355 In April, high micro-phytoplankton values are still present in the same coastal areas *where micro*
356 *predominates in* August, with the addition of the north Aegean Sea, where the signature of the Black Sea
357 outflow is now evident *in the chlorophyll map* (Fig. 4). Differently from August, the Spanish coastal water
358 reaches also the eastern Alborán Gyre, *resulting in a widespread region characterized by micro component*.
359 In the Ionian-Levantine Basin, the contribution of the micro-phytoplankton remains low with values about of
360 *12–13%* and with higher values ranging from *15 to 21%* in the western side of the Ionian Sea and in the *area*
361 *west of Rhodes Island where the presence of the Rhodes Gyre facilitates the uplift of nutrients from the*
362 *deeper layer*.

363 *Yet, in the Western basin, an increase of micro fraction* occurs *during the entire* autumn/winter *seasons* (not
364 shown) *due to water column becoming mixed after the breakdown of the thermocline* (Bosc et al., 2004).
365 Unlike the *spring bloom*, *now the* values of chlorophyll *a* *are lower*, in agreement with previous observations
366 (Siokou-Frangou et al., 2010). This phenomenon leads to a minor percentage of micro-phytoplankton *close*
367 *to 20%* of the TChl *a*, with some peaks in the Algerian Current *that flows along* the southern *boundary* of the
368 *western Mediterranean (25–40%)*. The Eastern basin still shows low fractions of micro component during the
369 *autumn/winter months (see November to February maps in supplement material)*.

370

371 **4.2 Nano-phytoplankton**

372 The amplitude of the seasonal cycle of the nano-phytoplankton component is less pronounced than the micro
373 (Fig. 4). In summer, the contribution of the nano-phytoplankton to the total chlorophyll *a* is between *18* and
374 *24%*. In coastal areas, such as the North Adriatic Sea, its contribution to total chlorophyll *a* reaches *25–38 %*,
375 with a decrease for pixels more close to the coast where micro-phytoplankton still dominates (Fig. 5a).

376 In April, the contribution of the nano-phytoplankton remains between *20* and *25%* in most of the Ionian-
377 Levantine Basin, with the exception of the Rhodes gyre, where it reaches values of about *29%* and the
378 western Ionian Sea, where values up to *30–36%* are observed approaching the coasts of Italy (Fig. 4). In the
379 western Mediterranean Sea, the values of nano contribution to total chlorophyll *a*, vary from *25* to *38%* (Fig.

380 4). Yet, in the North Adriatic Sea, the nano fraction, in April, is always between 20 and 36 %, but with a more
381 evident decrease, with respect to August, for those pixels that are closer to the coast, where the micro-
382 phytoplankton remain predominant (Fig. 5b). The variability of nano component in the remain months of the
383 year (autumn/winter) is not so high and it still shows higher values in the Western basin (28-30%) than in the
384 Eastern (20-25%), reaching peak values of 38% in gyres of the Alborán Sea and along the Algerian current.
385 In these months as in the spring, the division, in terms of oligotrophy, of the Eastern basin with respect to
386 the Western is more evident, otherwise, the months from July to September reveal, in the open ocean, an
387 invariable pattern of nano component.

388

389 4.3 Pico-phytoplankton

390 Due to the high surface/volume ratio, pico-phytoplankton seems to be more suitable to poor nutrient
391 environments often characterized by high salinity, such as those that occur in the Levantine Basin (Le Quéré
392 et al., 2005). As suggested by Uitz et al. (2012), its capacity to survive in this type of environments justifies its
393 great abundance in the Eastern basin, thus becoming the principal producer in ultra-oligotrophic waters.

394 Indeed, Figure 4 shows that in August, the pico-phytoplankton contributes to 60–70% of the TChl *a*, in the
395 offshore waters while lower values are observed in coastal waters: about 15–30% in the western Alborán
396 Gyre, 11–24% in the North Adriatic Sea and 12–34% in the Gulf of Lions. In April, in the Ionian-Levantine
397 Basin, the pico fractions values remain high, but lower than those observed in August (64–65 %), while in the
398 northwestern Mediterranean Sea a large area of low pico TChl *a* concentration occurs with values ranging
399 between 13 and 24%. Similarly, low values are observed in coastal regions, e.g. in the north Aegean Sea,
400 where the outflow of the Black Sea influences the distribution of pico class, with values ranging from 40–45%
401 in August (see also Fig. 5c). In April, the outflow of the Black Sea waters is marked by a minimum, which
402 ranges between 13 and 20 %, which now affects all the northern part of the Aegean Sea (Fig. 5d).

403 The analysis of the January to April maps (supplementary material) shows that pico component reveals a
404 contrasting variability moving from West to Eastward, with high percentages in the latter and lower in the
405 former. With the arrival of the summer season, the pico-phytoplankton seems to cover homogeneously all the
406 basin with values of 70% and minima in correspondence of coastal areas. Later, the pico-phytoplankton
407 decreases in the most dynamic areas, such as along the Tunisian coast, in conjunction a micro and nano
408 fraction increase (see e.g. December maps of supplement). This is caused by the intrusion of new nutrients
409 from the deeper layer, due to the break of thermocline.

410

411 5 Inter-annual variability of chlorophyll *a* and PSCs in the Mediterranean Basin

412 The inter-annual variability of the surface chlorophyll *a* and PSCs distribution in the Mediterranean Sea is
413 shown in Figs. 6 and 7 for the two opposite months of April and August, respectively. In addition, the
414 chlorophyll *a*, micro, nano and pico fractions anomalies (respect to SeaWiFS climatology) have been

415 computed and then averaged at basin scale in order to identify potential inter-annual signals and changes
416 occurred during the SeaWiFS era. Figure 8 shows that, at basin scale, the inter-annual signal is very small (the
417 anomalies ranged from -0.04 to 0.06 μgL^{-1}) with positive anomalies peaks observed in winter 1999 and spring
418 2005 and 2006 as well as in March 2009, indicating that the inter-annual signal is essentially driven by the
419 intensity of the spring bloom. From the analysis of the anomalies it emerges also that pico oscillates between
420 reduced ranges of positive (maximum nearly to 0.02 μgL^{-1}) and negative anomalies (-0.01 μgL^{-1}), followed by
421 the nano component (maximum nearly to 0.03 μgL^{-1} - minimum -0.02 μgL^{-1}), while micro falls in higher
422 anomaly ranges (maximum 0.04 μgL^{-1} - minimum -0.03 μgL^{-1}).

423 The analysis of the April and August maps reveals that year-to-year variations are very small in August. In
424 April, significant variations are observed: the pico component dominates the TChl *a* concentration with
425 percentages of about 60-70%, over the entire basin, except those areas of the Western basin, characterized
426 by high and complex dynamic of the water masses. In these regions an enhanced inter-annual signal is
427 observed. In the Eastern basin these high values of pico remain constant in all years, while, in the Western
428 basin, the areas most affected by a strong decrease of pico TChl *a* contribution are located in correspondence
429 to the Gulf of Lions and in the Alborán Sea. The April time series maps (Fig. 6) reveal that the 1999, 2005 and
430 2006 are the years of highest chlorophyll *a* concentrations in the Gulf of Lions and in the coastal zones of the
431 basin. Here the contribution to TChl *a* of pico clearly decreases reaching values less than 10%, while, at the
432 same time, the micro component increases up to 60-70%, thus becoming predominant with respect to the
433 pico and also to the nano-phytoplankton fraction, which remains around to the 30-38%. This behavior results
434 into a positive peak of micro in the 2005 and 2006 anomalies time series (Fig 8). The April maps reveal that
435 nano component is not subjected to a significant year-to-year variation; however, a west to east gradient is
436 visible in all years with maximum values located offshore the Gulf of Lions, where the inter-annual variability
437 is more evident. The West to East Mediterranean oligotrophic gradient is reflected in the April micro maps
438 (Fig. 6), where the contribution to TChl *a* of the largest cells is very low, 15-19% along the entire time series,
439 highlighting the influence that poor nutrient environments, as those in the Eastern basin, have on the micro-
440 phytoplankton.

441 In August, the scenario is clearly different (Fig. 7). The chlorophyll *a* concentration is very low in most of the
442 offshore areas, although a slightly increases of TChl *a* can be observed from 2005 to 2007 in the Western
443 basin. The most evident signal of inter-annual variation is visible along the coastal zones of North Adriatic
444 Sea. The low inter-annual variability observed in August affects also the pico and nano components, but,
445 differently from micro, their contribution to TChl *a* is higher, respectively 65-70% for pico and 19-20% for
446 nano. The analysis suggests that the seasonal and inter-annual signal, observed in the TChl *a* and pico-, nano-
447 , and micro-phytoplankton time series, is driven by local processes occurring in the Mediterranean Sea, only
448 partially revealed by present basin scale analysis.

449

450 **6 Seasonal and year-to-year variability of chlorophyll a and PSCs at local scale**

451 Local processes play an important role in the ecosystem of the Mediterranean Sea interacting with the
452 physical system that contributes to drive its evolution but *that*, in turn, is affected by it (bio-feedbacks). To
453 investigate the year-to-year variability of processes that occur at local scale in the Mediterranean Sea, we
454 selected four key sub-regions: *the Northwestern Mediterranean Sea (NWMed), the Levantine Basin (LEV),*
455 *the Alborán Sea (ALB) and the North Adriatic Sea (NADR)* (see colored boxes in Fig. 1). In these regions
456 *relevant processes, such as surface currents advection, upwelling phenomena, water stratification or*
457 *nutrients and river inputs occur, modulating local ecosystem variability. Results of this analysis were*
458 *synthesized in Figure 9.*

459 In NWMed Sea (Fig. 9a) the seasonal cycle of chlorophyll a concentration shows an increase of TChl a values
460 from the initial part of the year, January–February, with *maximum* values in April and in March ranging from
461 *0.4 to 1.2 μgL^{-1} .* In summer, the chlorophyll a decreases up to *0.06 μgL^{-1} ,* and then, in autumn, it rises again.
462 The analysis of the year-to-year variability reveals an absolute spring maximum in April 2005 (Fig. 9a), with a
463 concentration of about *1.2 μgL^{-1} ,* followed by a decreasing trend from 2006 to 2007 and a new rising in 2008
464 (*0.9 μgL^{-1}). From this year onwards, the lack of some months is due to the fewer number of observations*
465 *recorded by SeaWiFS from 2007–2010. The accuracy of the TChl a variability in the NWMed sector is taken*
466 *into account computing and evaluating the anomalies over the time series from 1998 to 2010 (Fig. 10a). From*
467 *Figure 10a results that negative anomalies are more frequent and stronger than the positive ones, in the first*
468 *part of the time series. This type of oscillations still persists up 2005, when the highest positive spring*
469 *anomaly occurs (0.6 μgL^{-1}), followed by the April 2006 and 2008 positive anomalies.*

470 The mean annual value of chlorophyll a concentration for NWMed and ALB (Fig. 9a, c) are quite similar, but
471 in the latter (Fig. 9c), the seasonal cycle is less “clean” and the year-to-year variability is marked by minimal
472 values of the spring maxima from 2001 to 2004 ranging from *0.5 to 0.7 μgL^{-1}* and relative maxima in 2000,
473 2005, 2006 and 2007 ranging from *1.0 to 1.1 μgL^{-1} .* Intermediate values of the spring maximum are observed
474 in the remaining years of the series. *The “chaotic” pattern of the TChl a in the Alborán Sea is also reflected*
475 *in the corresponding anomaly (Fig. 10c). In this case, the positive and negative anomalies vary among -0.4*
476 *and +0.5 μgL^{-1} . The time series anomaly reveals that the main positive peaks occur in April 2000, March 2006*
477 *and February 2007; the same peaks highlighted in the inter-annual analysis (fig. 9c). Negative anomalies*
478 *prevail in 2002 and 2003.*

479 *Differently* from the ALB Sea, in the LEV basin (Fig. 9b) the seasonal cycle of the chlorophyll a concentration
480 is more regular. It rapidly increases from early winter months, reaching local maxima values in January–
481 February. In summer, the chlorophyll a reaches *minimum* values and then it increases again in autumn. In
482 Fig. 9b peak values appear in January 1999 and February 2004 reaching chlorophyll a concentrations of about
483 *0.08–0.10 μgL^{-1} . Among all basins, the anomaly time series of Levantine Basin (Fig. 10b) is characterized by*
484 *the smallest oscillations, ranging from -0.01 to slightly more than 0.02 μgL^{-1} . Despite these low values,*

485 positive peaks occur in 2004 and 2006, while from 1998 to 2003, the times series is dominated by negative
486 values.

487 Differently from the LEV, where chlorophyll *a* concentrations are almost one order of magnitude lower than
488 in the other sub-basins, the NADR (Fig. 9d) exhibits the highest values of chlorophyll *a* concentration. In
489 NADR, summer minima never reach values as low as those observed in other three sub-regions contributing
490 to mask the seasonal signal. The NADR inter-annual variability of the chlorophyll *a* concentration is expressed
491 by an irregular trend from 1998 to 2002, a local minimum during 2003 and then a more weakened variability
492 from the end of 2005 to 2009. In this case, main peaks occur in 2000, 2004 and 2010 while, 2003, represent
493 the year of the lowest oscillation. North Adriatic Sea anomalies (Fig. 10d) are the most intense among the
494 four sectors reaching positive values as high as $2.0 \mu\text{gL}^{-1}$ in 2000 and negative values as low as $-0.85 \mu\text{gL}^{-1}$ in
495 2003.

496 In the NWMed basin (Fig. 9a), the contribution of pico-phytoplankton to the seasonal cycle seems to be
497 constant from year-to-year, with values not higher than $0.14 \mu\text{gL}^{-1}$ and a mean concentration of $0.08 \mu\text{gL}^{-1}$.
498 Although the differences between minima and maxima of pico in each year are low, it, however, follows a
499 seasonal variability, with higher values in late winter–early spring, and lower values in summer.

500 Nano-phytoplankton shows the same seasonal cycle of pico (Fig. 9a). Both maxima and minima occur in the
501 same months of the smallest cells, but, in this case, the excursion among them, are higher with respect to
502 those of pico. The peaks occur during the early spring season, reaching an absolute maximum of $0.38 \mu\text{gL}^{-1}$
503 in April 2005 with an annual mean of $0.08 \mu\text{gL}^{-1}$. In NWMed Sea, the largest seasonal variability is due to
504 micro-phytoplankton. Maximum values occur during the spring blooms season with the highest peak of about
505 $0.7 \mu\text{gL}^{-1}$ in April 2005. During summer, micro-phytoplankton reaches very low concentrations, below 0.02
506 μgL^{-1} .

507 In contrast with the NWMed sector, pico-phytoplankton predominates in the LEV (Fig. 9b) all year around
508 with a mean concentration of $0.03 \mu\text{gL}^{-1}$ (Fig. 9b) with a seasonal cycle nearly constant from year-to-year.

509 The nano component shows a higher variability and large seasonal differences between minima and maxima.
510 The peak values, usually, occur in January–February while low concentrations are reached in summer with a
511 mean year concentration slightly higher than $0.01 \mu\text{gL}^{-1}$.

512 Furthermore, the strong and well-known oligotrophy of this basin is reflected in the fraction of micro-
513 phytoplankton, the lowest among the three PSCs, with a mean that is very close zero.

514 Among all the four sectors, the ALB (Fig. 9c) and NADR (Fig. 9d) basins show an irregular inter-annual
515 variability with a nearly absent seasonal cycle in the NADR.

516 In the ALB basin (Fig. 9c) the pico-phytoplankton concentration are relatively low and nearly constant along
517 the entire period (mean value of $0.1 \mu\text{gL}^{-1}$), with small peaks occurring during spring months.

518 Nano-phytoplankton follows the same pattern of pico, but with a higher excursion between minima and
519 maxima. The absolute peak for nano component is in March 2005, with a concentration of $0.30 \mu\text{gL}^{-1}$ respect
520 to $1.00 \mu\text{gL}^{-1}$ of TChl α .

521 For the ALB Sea, we observe a less clean seasonal cycle and a reduced year-to-year variability, above all for
522 micro-phytoplankton fraction. Micro-phytoplankton shows a seasonal oscillation with the usual increase
523 during spring blooms and a decrease in summer, as a result of a stratification of the water column. The mean
524 contribution of micro-phytoplankton to the TChl α is about of $0.15 \mu\text{gL}^{-1}$, while the maximum is $0.7 \mu\text{gL}^{-1}$ in
525 March 2006.

526 In the NADR basin (Fig. 9d) the seasonal signal is absent or, at least, not immediately visible. In contrast with
527 the other basins, the chlorophyll α content is very high, and the PSCs ratios show a different behavior with
528 respect to the other sectors. Pico-phytoplankton fraction is nearly constant along the entire time series with
529 low or absent seasonal variations. Pico mean fraction of the value the TChl α is $0.11 \mu\text{gL}^{-1}$, which is still higher
530 than the mean value ($0.03 \mu\text{gL}^{-1}$) of the LEV Sea (Fig. 9b).

531 In NADR, the highest contribution to the TChl α is provided by the micro-phytoplankton (mean value $0.7 \mu\text{gL}^{-1}$
532 ¹). It also shows inter-annual variations, but with peaks that occur in different years with respect to the other
533 three sectors. Fig. 9d reveals constant high values of micro in 2001 and 2002, two peaks in November 2000
534 ($3.1 \mu\text{gL}^{-1}$) and in May 2004 ($2.5 \mu\text{gL}^{-1}$) and the lowest values in 2003.

535

536 **7 Discussion and conclusions**

537 In this work, for the first time, we estimate the contribution of micro-, nano- and pico-phytoplankton to the
538 total chlorophyll α over the Mediterranean Sea by applying an abundance based model (Brewin et al., 2011b,
539 referred as BR) to the entire time series of the SeaWiFS mission. Since the selected model was developed by
540 using datasets from many different regions of the ocean, we started by verifying its accuracy for the
541 Mediterranean case.

542 This validation showed that the model constantly underestimates nano-phytoplankton fractions over the
543 entire range of observed TChl α concentrations while overestimates pico-phytoplankton concentration, for
544 low TChl α concentrations. These results lead to think that the specific optical properties of this basin can be
545 influenced by the phytoplankton community assemblage as suggested by Volpe et al. (2007). In fact,
546 considering that each region can be characterized by a specific pigment content, we hypothesized that the
547 different pigment ratios can represent one of the possible reason that can justify the observed deviation of
548 the model from the in situ PSCs classification. Therefore, we first investigated whether the global relation
549 between DP and chlorophyll α , used by BR model, is still valid for the Mediterranean Sea and whether the
550 use of a regionally tuned relation can contribute to reduce the observed bias between modeled and
551 measured PSCs. Our results demonstrate that the use of a regional Mediterranean DP function (Di Cicco,
552 2014) reduces the bias to values comparable with those obtained by BR at global scale and suggest that a re-

553 tuning of the empirical BR model coefficients is not a priority, with respect to the main goal of this work. We
554 concluded that, the BR model, even if developed for the global ocean, can still be used in the Mediterranean
555 Sea considering that, when applied to satellite data, the major source of uncertainty is the chlorophyll *a*
556 determination. However, the use of daily chlorophyll *a* data, reprocessed with a regional Mediterranean
557 algorithm for Case 1 and Case 2 waters, allows us to account for the unique optical properties of the
558 Mediterranean Sea, thus reducing the bias between in situ measured and satellite chlorophyll *a* estimate to
559 nearly zero (-0.02mgm^{-3}) with a relative small RMS (0.25mgm^{-3}) (see Table 4 in Volpe et al., 2012a).

560 The analysis of micro-, nano- and pico-phytoplankton satellite time series (1998–2010) allowed, for the first
561 time, to quantitatively describe the seasonal and inter-annual variability of the spatial distribution of the algal
562 assemblage structure. The results indicate that pico-phytoplankton dominates all around the year in most of
563 the Mediterranean Basin, in particular, in ultra-oligotrophic waters. Nevertheless, exceptions are: the
564 northwestern Mediterranean Sea (during the spring bloom), the Alborán Sea, and several coastal areas such
565 as the north Adriatic Sea. In the coastal areas, the contribution of micro-phytoplankton to TChl *a* is always
566 more evident, and can be explained by the high typical nutrients conditions of these regions, that favor the
567 predominance of micro-phytoplankton with respect to the other two size classes (e.g. Siokou-Frangou et al.,
568 2010). On the contrary, in the offshore waters, the contribution of nano-phytoplankton to TChl *a* is of the
569 order of 20–40% remaining mainly constant along the year (Fig. 4). This is consistent with the nano-
570 phytoplankton constant contribution to the Mediterranean primary production observed by previous
571 authors (Uitz et al., 2010, 2012).

572 In ultra-oligotrophic waters, such as those of the Levantine Basin, pico-phytoplankton prevails in the PSCs
573 climatology (section 4). This is justified by the ability of the smallest cells to exploit better the poor nutrient
574 environments, according to their high surface/volume ratio (Le Quéré et al., 2005; Timmermans et al., 2005).
575 Indeed, the summer stratification of the water column, causes a strong decrease in micro chlorophyll *a*
576 contribution, whereas, nano-phytoplankton and pico-phytoplankton survive, adapting to the warmer water
577 state (Fig. 4) (Marty and Chiaverini, 2002).

578 The typical chlorophyll *a* seasonal cycle of the temperate regions occurs in the Mediterranean Sea, with
579 maxima in spring and minima in summer. It results into a seasonal signal of the PSCs distribution,
580 characterized by an increase in the micro fraction in spring and the pico fraction in summer (Fig. 4). This mean
581 seasonal cycle can be significantly distorted in coastal regions, such as the North Adriatic Sea (Fig. 4), where
582 terrestrial inputs from rivers play an important role in modulating the nutrients supply in the upper layer of
583 the water column. In this basin, the micro class dominates all around year, in accordance with the knowledge
584 resulting from in situ measurements of the LTER (Italian Long Term Ecological Research Network) North
585 Adriatic station (Fonda Umani et al., 2005; Cataletto et al., 2012). In addition, in the Alborán Sea, in which
586 the Atlantic inflow modulates the nutrient availability, an intermediate temperate and sub-tropical seasonal
587 cycle is observed, with a chlorophyll *a* maximum in late winter–early spring (Siokou-Frangou et al., 2010). In

588 this region, our analysis reveals that, **in general**, there is not an evident predominance of one class over the
589 others all along the year (Fig. 9c). Micro, nano and pico contribution to TChl a is modulated by intermitted
590 processes, such as the variation of the Atlantic flow and **upwelling** events occurring along the Spanish coast,
591 which can cause a vertical uplift of nutrients, especially nitrates, to the surface water layer (Mercado et al.,
592 2005).

593 Inter-annual variability is observed in the entire basin, but the largest inter-annual signal occurs in the
594 northwestern Mediterranean Sea, driven by the year-to-year variation **of the** intensity and extension of the
595 spring bloom (Fig. 6). **During spring relatively high** values of chlorophyll a are observed in the whole basin
596 (Fig. 6), but above all in the Western basin **and in particular** in 1999, as reported in Volpe et al. (2012b). A
597 general decrease of **spring** chlorophyll a concentrations occur in 2001, affecting mostly the Eastern basin,
598 confirming Bosc et al. (2004) results. This decrease is reflected in a lower contribution of the micro fraction
599 on the TChl a (Fig. 6). A peak of chlorophyll a signal occurs in April 2005, accompanied by an increase of
600 micro-phytoplankton with respect to previous years (Figs. 6 and 8b). These anomalous high values of
601 averaged spring chlorophyll a field are associated with an overall increase in the concentration of chlorophyll
602 a , **which** occurs in the entire western Mediterranean Basin. They are also linked to an intensification of the
603 spring bloom in the Gulf of Lions (see Fig. 6), where an unusual and strong winter convection occurred in the
604 2005 (Volpe et al., 2012b; Font et al., 2007; Smith et al., 2008). **This phenomenon results in a local increase**
605 **of the micro-phytoplankton fraction with respect to previous years even though the nano and pico**
606 **contributions to total chlorophyll a remain dominant at basin scale** (Fig. 6). A second spring maximum is
607 observed in 2008 in both chlorophyll a and micro-phytoplankton (Fig. 6), related again to the enhancement
608 of the spring bloom in the Gulf of Lions.

609 The analysis of the year-to-year variability in the PSCs of the NWMed (Fig. 9a) confirms the occurrence of an
610 evident seasonal and inter-annual signal. The seasonal cycle of chlorophyll a and thus PSCs is **the one** typical
611 of temperate areas, with maxima in March and/or April (Fig. 9a). During these spring blooms, the micro-
612 phytoplankton exceeds the other classes, in light of the great amount of nutrients available in the water
613 column. Indeed, in this area, the winter deep and intermediated convection allows to bring up nutrients from
614 the deeper layer (Lévy et al., 1998a, b). This process modulates the year-to-year variability of intensity and
615 duration of spring bloom (Santoleri et al., 2003), which results into a strong inter-annual signal of the micro-
616 phytoplankton concentration, as revealed by our analysis (Fig. 9a).

617 The micro-phytoplankton dominates the inter-annual signal also in the NADR, while **both** nano and pico-
618 phytoplankton show slight variations (Fig. 9d). The large contribution of the biggest cells to the high values
619 of TChl a can be related to the presence of big rivers, such as Po, Brenta, Livenza, Adige and Isonzo. Every
620 year, their runoff causes the release of a large amount of organic particles and nutrients **that** support the
621 micro cell size growth and development. Our analysis shows that the peaks of micro-phytoplankton biomass,
622 usually, occur in May and November (Fig. 9d), when the river runoff **increases** due to **the** more intense rainfall

623 and snowmelt (Struglia et al., 2004; Malej et al., 1995). Anomalous events are recorded in November 2000
624 and May 2004 (Fig. 9d). In the former, the prevalence of micro-phytoplankton on the TChl a can be due to
625 the particular meteorological conditions that occurred in that year. Intense precipitations occurred in
626 November 2000 in the Po hydrographic basin (Stravisi, 2006; Russo et al., 2005), with the consequent
627 intensification of the river outflow. This intensification increased nutrients concentrations in the north
628 Adriatic Sea, contributing to the increase of micro-phytoplankton fraction, as revealed by our analysis. This
629 is also in agreement with in situ observations of the LTER station, located in the Gulf of Trieste, which shows
630 biomass peaks of micro fraction in the same year (Cataletto et al., 2012).

631 An opposite case is the Levantine Sea, where the ultra-oligotrophic regime influences the distribution and, in
632 particular, the contribution of the three PSCs to the TChl a . Fig. 9b shows that most of the TChl a is due to
633 the pico-phytoplankton class, which is predominant all along the year. This can be related to the ability of
634 the smallest cells to live and survive in extreme conditions, such as poor nutrient environments and well
635 stratified water column (Siokou-Frangou et al., 2010; Le Quéré et al., 2005). When the bloom occurs
636 (February), besides the pico class, also the nano fraction increases its contribution to TChl a .

637 In summary, in absence of sufficient in situ data of community composition, our time series analysis
638 demonstrates the potential use of ocean colour imagery for monitoring the phytoplankton assemblage in the
639 Mediterranean Basin. The possibility to identify all the components of the phytoplankton assemblage, in
640 terms of dimensional size, allowed us to provide complementary information to the present knowledge of
641 the Mediterranean phytoplankton composition, which was based so far, only on the dominant phytoplankton
642 types (Navarro et al., 2014). Our analysis demonstrated that the predominance of one group over the other
643 ones strongly depends on the physical-biological processes occurring at the mesoscale, which directly
644 influences the nutrient and light availability, i.e, the principal force for the algae growth. Our analysis
645 demonstrated that, in the evaluation of the contribution of each size class to TChl a , the ratio of diagnostic
646 pigments in relationship to chlorophyll a content is a key factor. This ratio represents one of the elements
647 that is mostly affected by the characteristics of pigment content of each specific region, which itself
648 influences all the algorithm retrieval processes. Moreover, this phenomenon can induce an eventual bias due
649 to the seasonal and inter-annual changes in the relationship between size fraction and TChl a , thus
650 representing a limit for the approaches that are based on the direct fitting of the model with in situ global or
651 regional pigment dataset.

652 Since our pioneering work does not aim to provide a specific regional product for PSCs, we are aware that
653 more efforts need to be done on this regard. As a future perspective, we would like to extend our analysis to
654 other satellite sensors in order to enlarge the PSCs time series, but we will also consider and test other
655 models, based on different variables, with the aim to track, as much as possible, the phytoplankton
656 community evolution from space. Moreover, one of our future project will be to regionalize one of this

657 approach, as well as the BR model, in order to provide a better instrument to retrieve information about the
658 PSCs variability specifically for the Mediterranean Sea.

659

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667

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Cruise	Date	Location	N° Samples	Depth (m)	TChl <i>a</i> range values (mg m ⁻³)	Sources
Prosopé99	14/09/1999 – 03/10/1999	Transmed	255	0 – 50	0.02 – 0.89	SeaBASS
Boussole Mooring	22/07/2001 – 03/12/2006	North-Western Mediterranean Sea	1143	0 - 50	0.02 – 5.52	SeaBASS
Boum08	03/07/2008 – 18/07/2008	Transmed	33	9	0.03 – 0.15	SeaBASS
Boussole03	15/07/2008 – 19/07/2008	North-Western Mediterranean Sea	23	0 - 50	0.08 – 2.20	SeaBASS

896

897 [Table 1 Information about the in situ SeaBASS sub-dataset used for the validation of the application of BR model on the Mediterranean Sea.](#)

Uitz et al. (2006) coefficients					
	MBE (mg m ⁻³)	MBE%	MBE%_log10	RMSE%_log10	R_log10
Micro	0.059	14%	-4%	29%	0.6
Nano	-0.060	-34%	67%	79%	0.5
Pico	-0.002	51%	-26%	42%	0.7
Di Cicco (2014) coefficients					
	MBE (mg m ⁻³)	MBE%	MBE%_log10	RMSE%_log10	R_log10
Micro	0.066	21%	-7%	28%	0.6
Nano	-0.013	-5%	8%	22%	0.4
Pico	-0.053	-7%	15%	50%	0.8

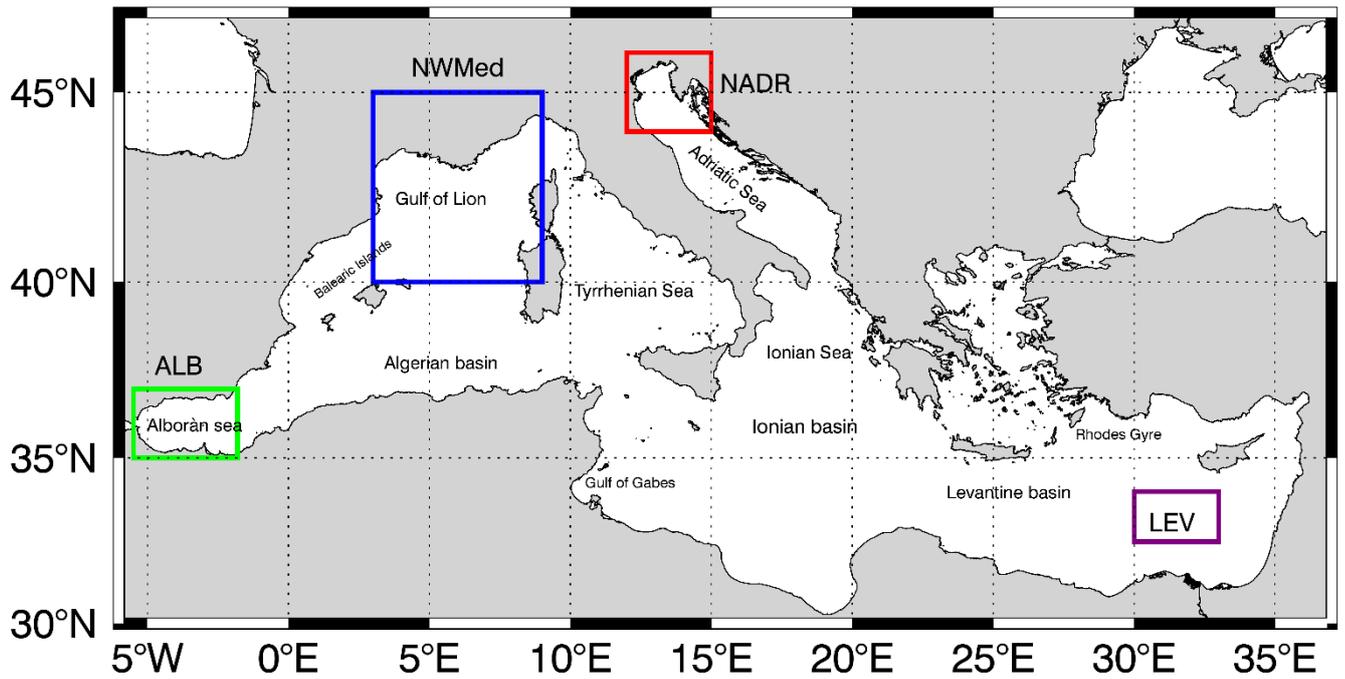
900 Table 2 Statistical results from the comparison of BR model and in situ PSCs classification obtained using, in the Diagnostic Pigments Analysis, respectively the
901 Uitz et al. (2006) and the Di Cicco (2014) coefficients. Mean Bias Error (MBE) has the same dimensions of in situ observation (x in Table 3), while Mean Bias Error
902 percentages (MBE%), Root mean square error percentages (RMSE%) and linear Pearson correlation coefficients (*r*) are dimensionless and refers to a TChl *a*
903 smoothed with a 5-points running mean. Where there is “_log10” the result refers to log-transformed units, otherwise it is expressed in linear space.

Per cent Mean Bias Error	$MBE\% = \frac{1}{N} \sum_{i=1}^N \left(\frac{Model - x_i}{x_i} \right) \times 100$
Per cent Root Mean Squared Error	$RMSE\% = \frac{1}{N} \sum_{i=1}^N \left(\frac{Model - x_i}{x_i} \right)^2 \times 100$
Pearson Correlation Coefficient	$r = \frac{\sum_i (model_i - \overline{model})(x_i - \bar{x})}{\sqrt{\sum_i (model_i - \overline{model})^2} \sqrt{\sum_i (x_i - \bar{x})^2}}$
Mean Bias Error	$MBE = \frac{1}{N} \sum_{i=1}^N (Model - x_i)$

904

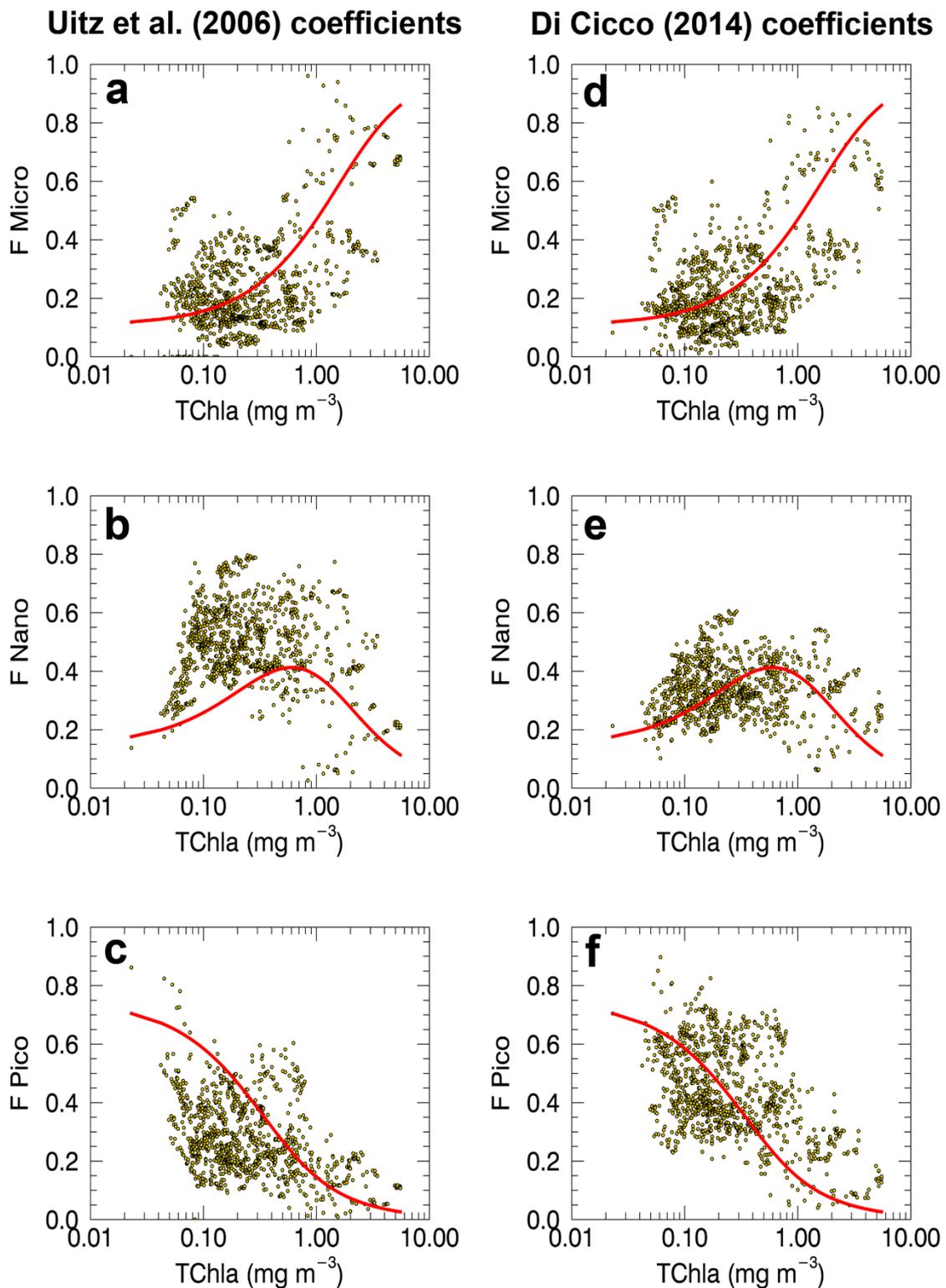
905 Table 3 Basic statistical quantities used for the assessment of the comparison of the BR model applied on the Mediterranean Sea, using the two different in situ
 906 PSCs classification approaches (Uitz et al. (2006) and Di Cicco (2014) coefficients). N is the number of observations and x is in situ measure.

907

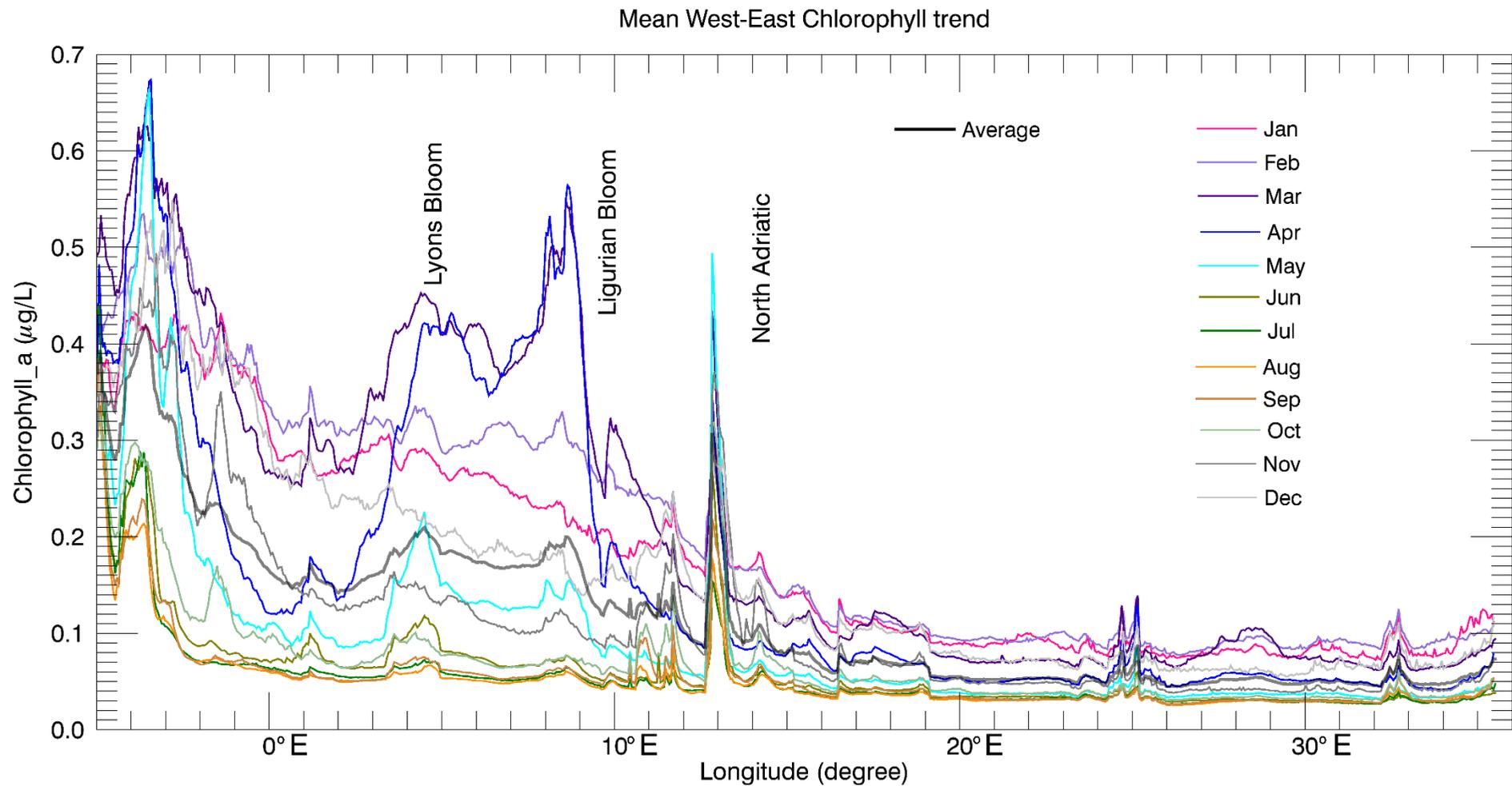


908

909 Fig. 1 Maps of the Mediterranean Sea and its most interesting basin or sub-basins. The colored box indicates
 910 the region analyzed in section 6 for the seasonal and inter-annual variability of TChl α and PSCs at local scales.
 911 The green box refers to the Alborán Sea (ALB), the blue box to the Northwestern Mediterranean Sea
 912 (NWMED), the red one indicates the North Adriatic Sea (NADR) and the purple box refers to the Levantine
 913 Sea (LEV).



914
 915 Fig. 2 BR model (red line) plotted against in situ PSCs classification (yellow dots) obtained using the Uitz et al.
 916 (2006) coefficients (a-c, on the left panel) and Di Cicco (2014) coefficients (d-f, on the right panel). The yellow
 917 dots refer to the in situ size class fractions resulting from the use of the diagnostic pigments (DP) of the
 918 SeaBASS Mediterranean subset.



919

920 Fig.3 West-Eastward climatological monthly mean chlorophyll a concentration (mgm^{-3}) over the basin, for the time series 1998-2010. The colored lines are build
 921 up averaging all pixels from North to South for each longitude degree of the basin, moving from West to East. The high chlorophyll a values of Gulf of Lions,
 922 Ligurian Sea and North Adriatic Sea are highlighted in the figure (see also the map of Mediterranean Sea, Fig. 1).

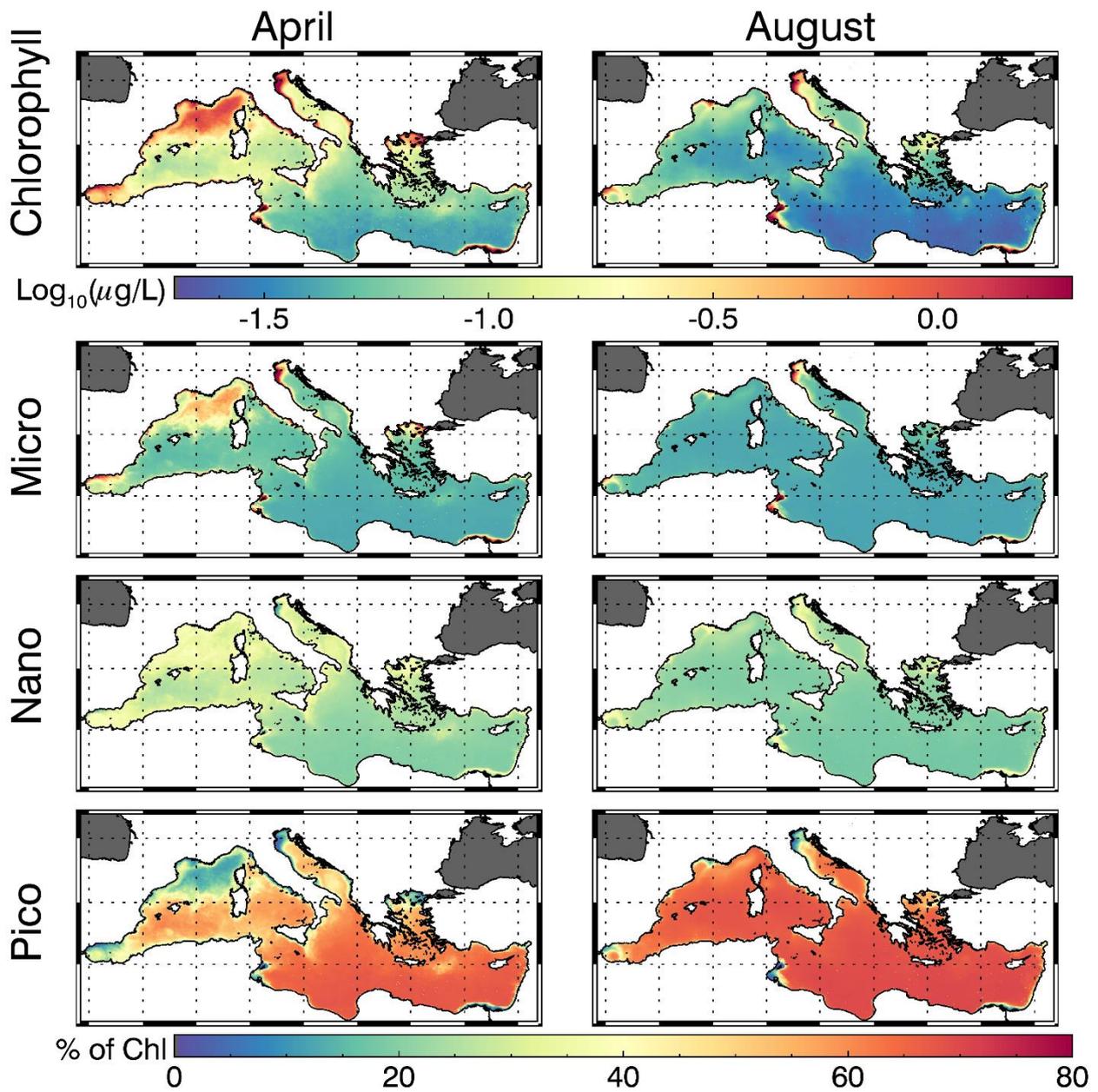


Fig. 4 Seasonal spring to summer excursion in the Mediterranean Sea of TChl *a* and PSCs. On the left panel, the April climatology (1998-2010) maps of TChl *a* (μgL^{-1}) and PSCs (%). On the right panel, the August climatology (1998-2010) maps of TChl *a* (μgL^{-1}) and PSCs (%).

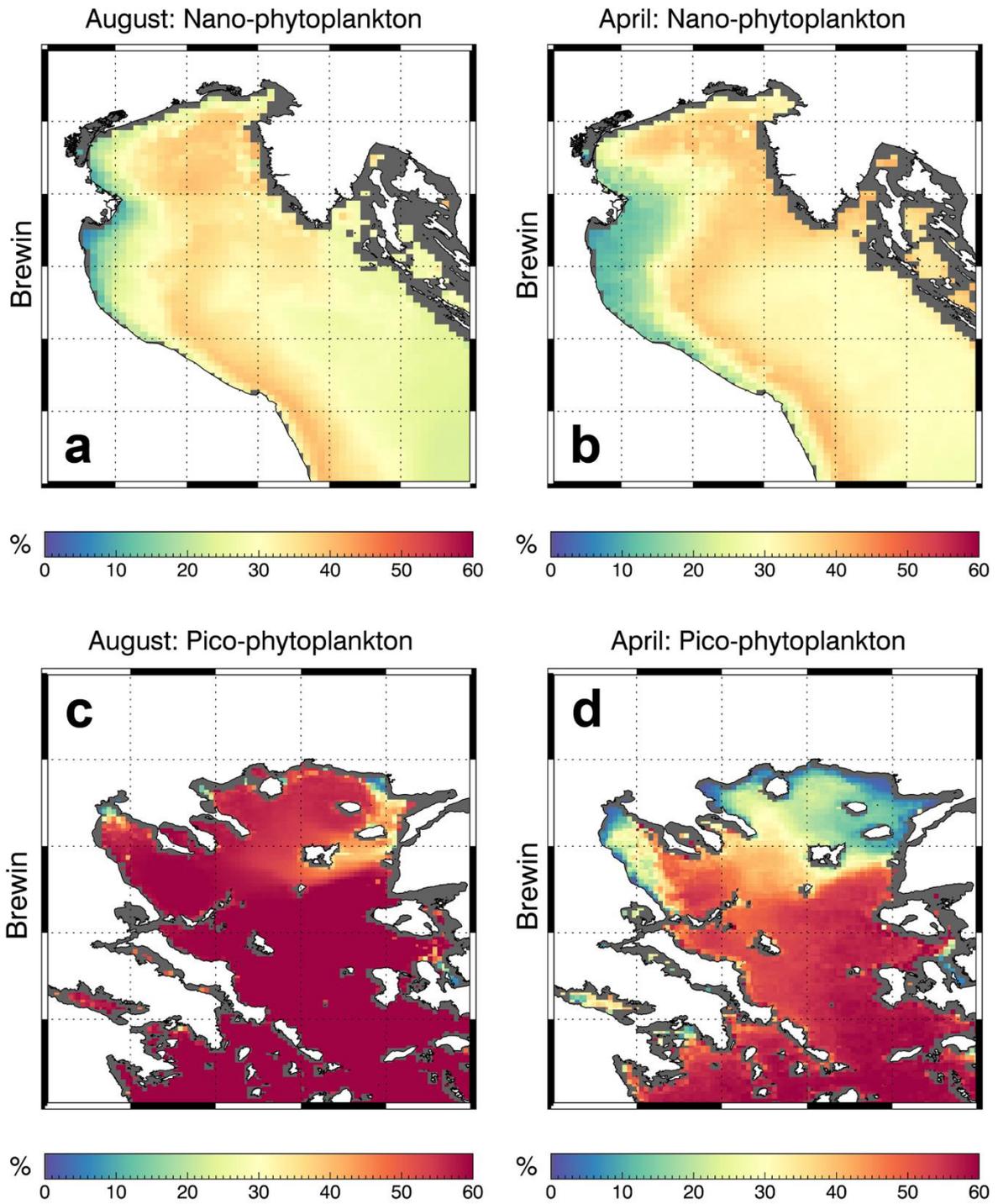


Fig. 5 Seasonal spring to summer excursion of nano- and pico-phytoplankton fractions (%) of TChl *a* in two sectors. Nano percentages (%) in the North Adriatic Sea for August (a) and April (b) climatology (1998-2010). Pico percentages (%) in the Aegean Sea for August (c) and April (d) climatology (1998-2010).

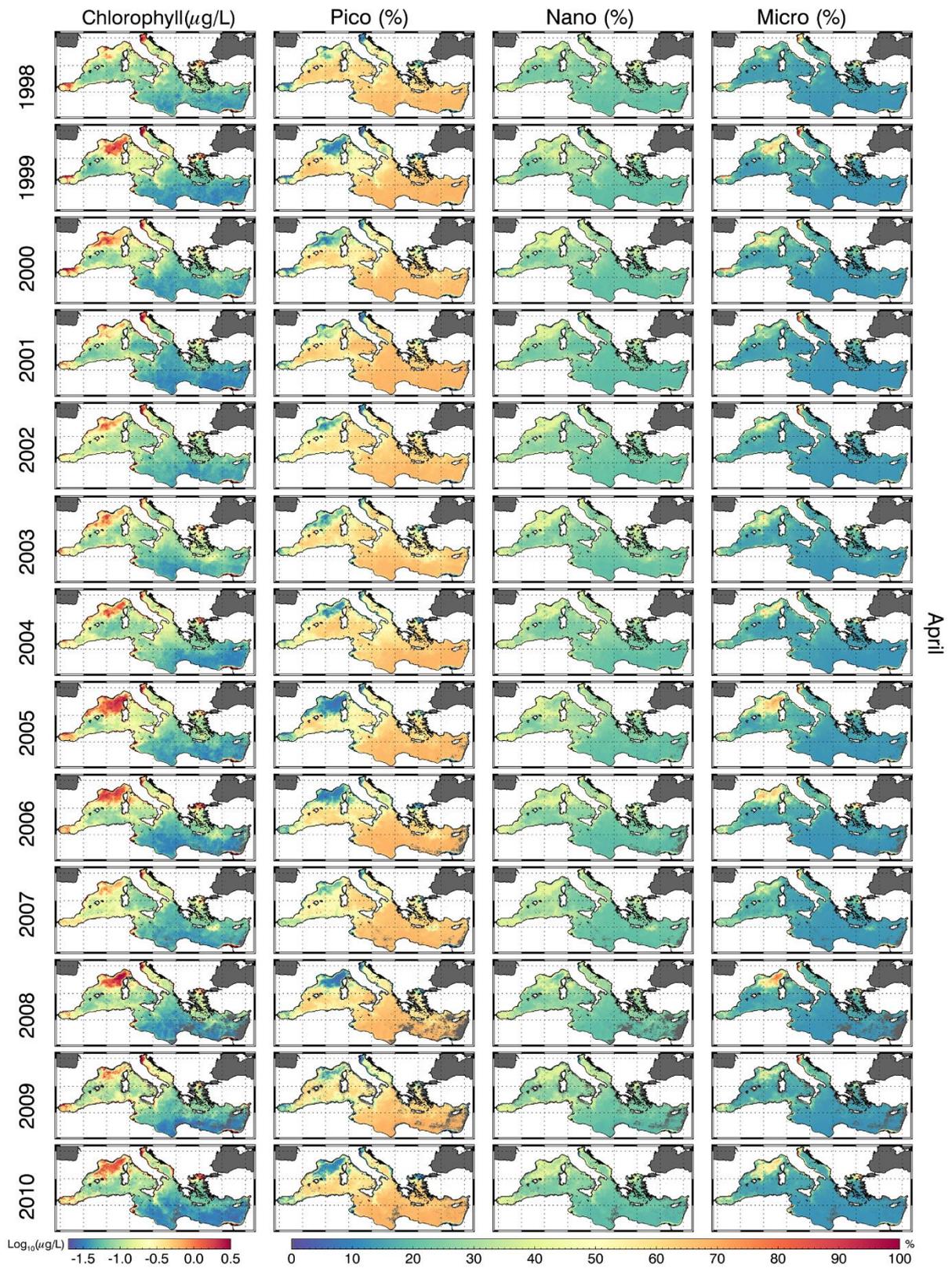


Fig. 6 Monthly maps of inter-annual variability (1998-2010) of TChl *a* and PSCs over the entire basin for April. The first panel refers to TChl *a* (μgL^{-1}), the second to Pico fraction on TChl *a* (%), the third and the fourth respectively referred to Nano and Micro fractions (%).

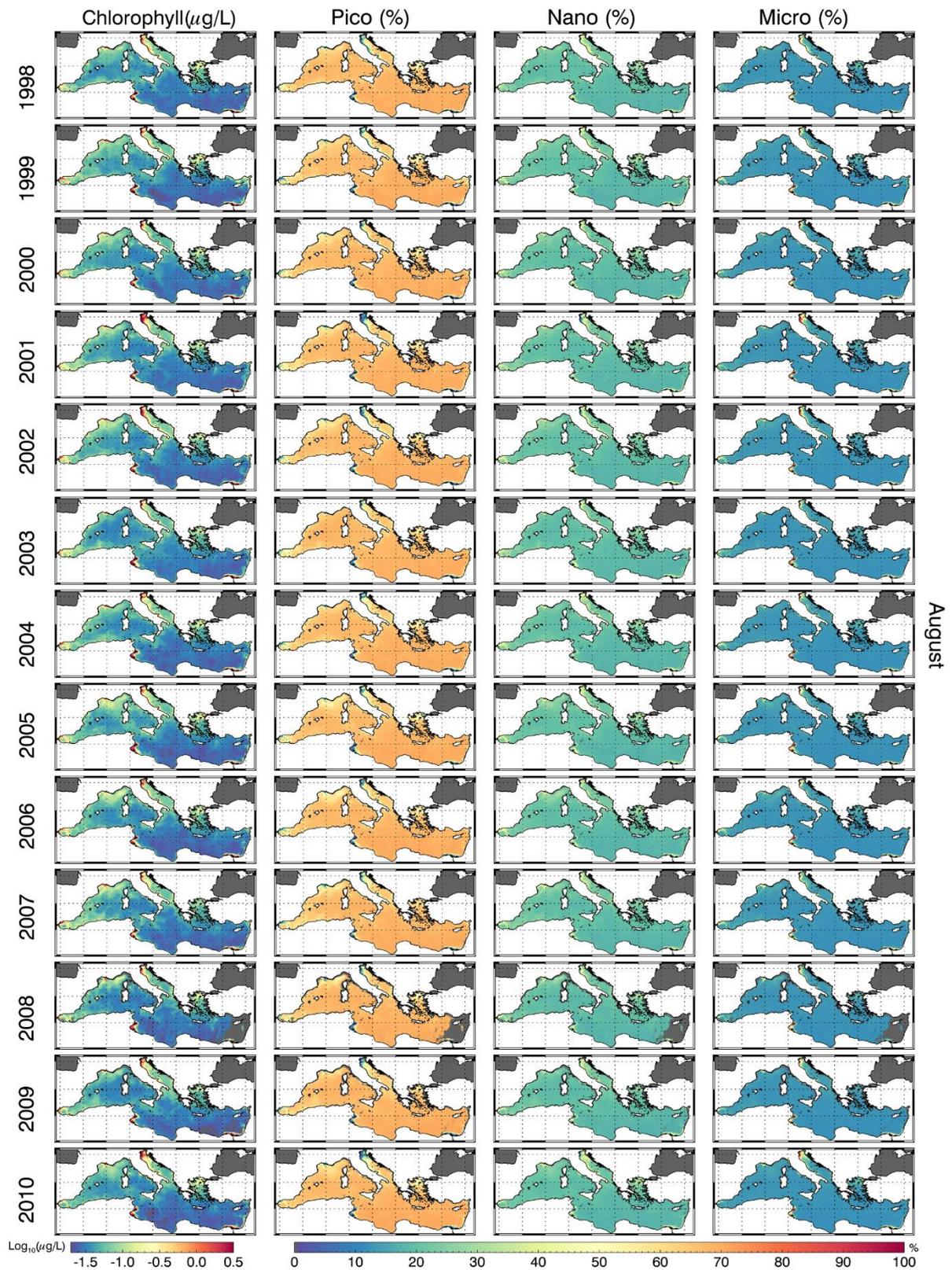


Fig. 7 Monthly maps of inter-annual variability (1998-2010) of Tchl *a* and PSCs over the entire basin for August. The first panel refers to Tchl *a* (μgL^{-1}), the second to Pico fraction on Tchl *a* (%), the third and the fourth respectively referred to Nano and Micro fraction (%).

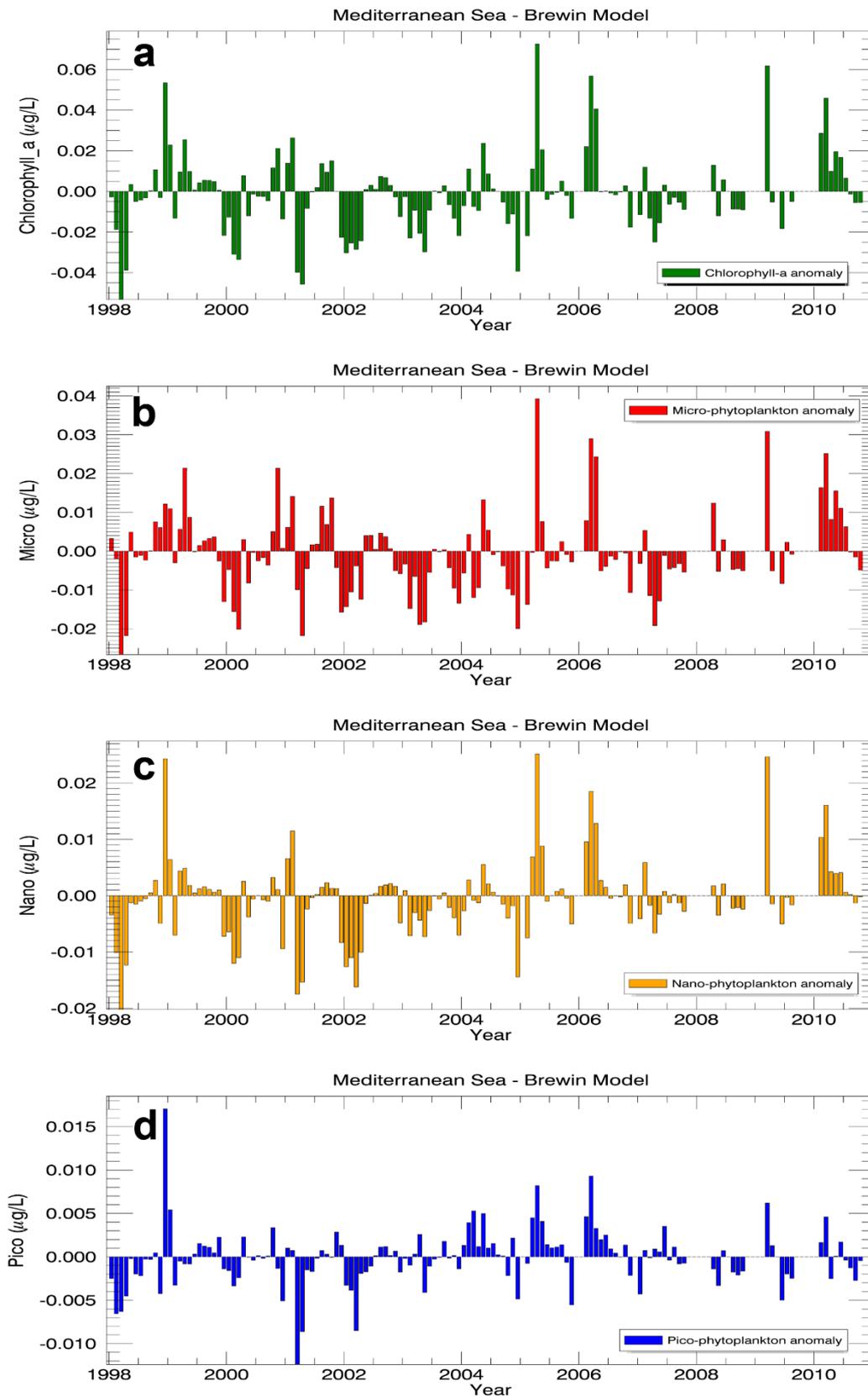


Fig. 8 Monthly anomalies computed for the entire time series (1998-2010) over the Mediterranean basin. Gaps in the time series correspond to months where less than 90% of observations were recorded in the basin. From top to bottom, there are the anomalies of TChl a , micro contribution to TChl a , nano contribution to TChl a , pico contribution to TChl a .

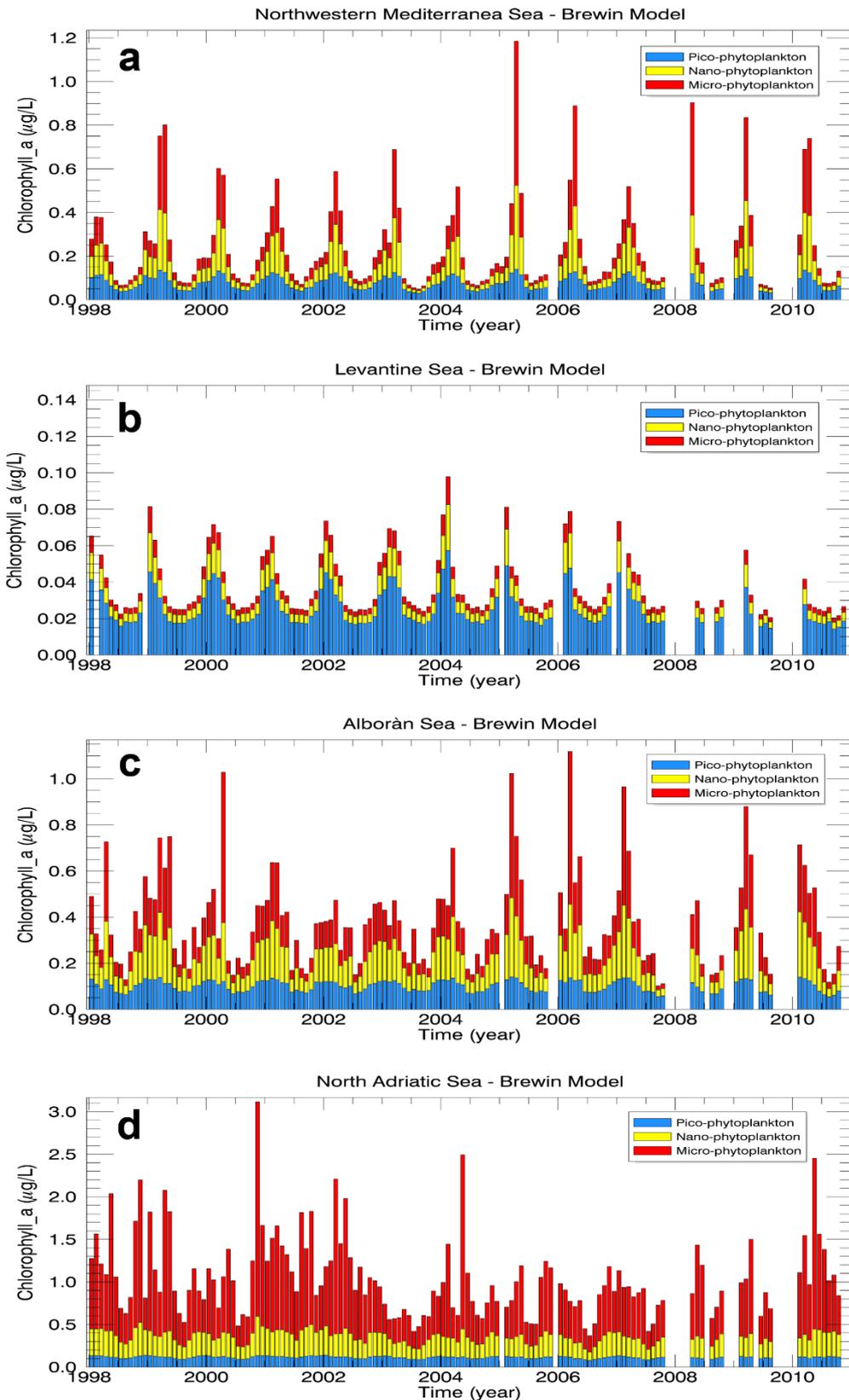


Fig. 9 Inter-annual variability of the contribution of micro-, nano- and pico-phytoplankton to the TChl a ($\mu\text{g/L}^{-1}$) from 1998 to 2010 in the four sectors: Northwestern Mediterranean Sea (a), Levantine Sea (b), Alborán Sea (c), North Adriatic Sea (d). Gaps in the time series correspond to months where less than 90% of observations were recorded in the region.

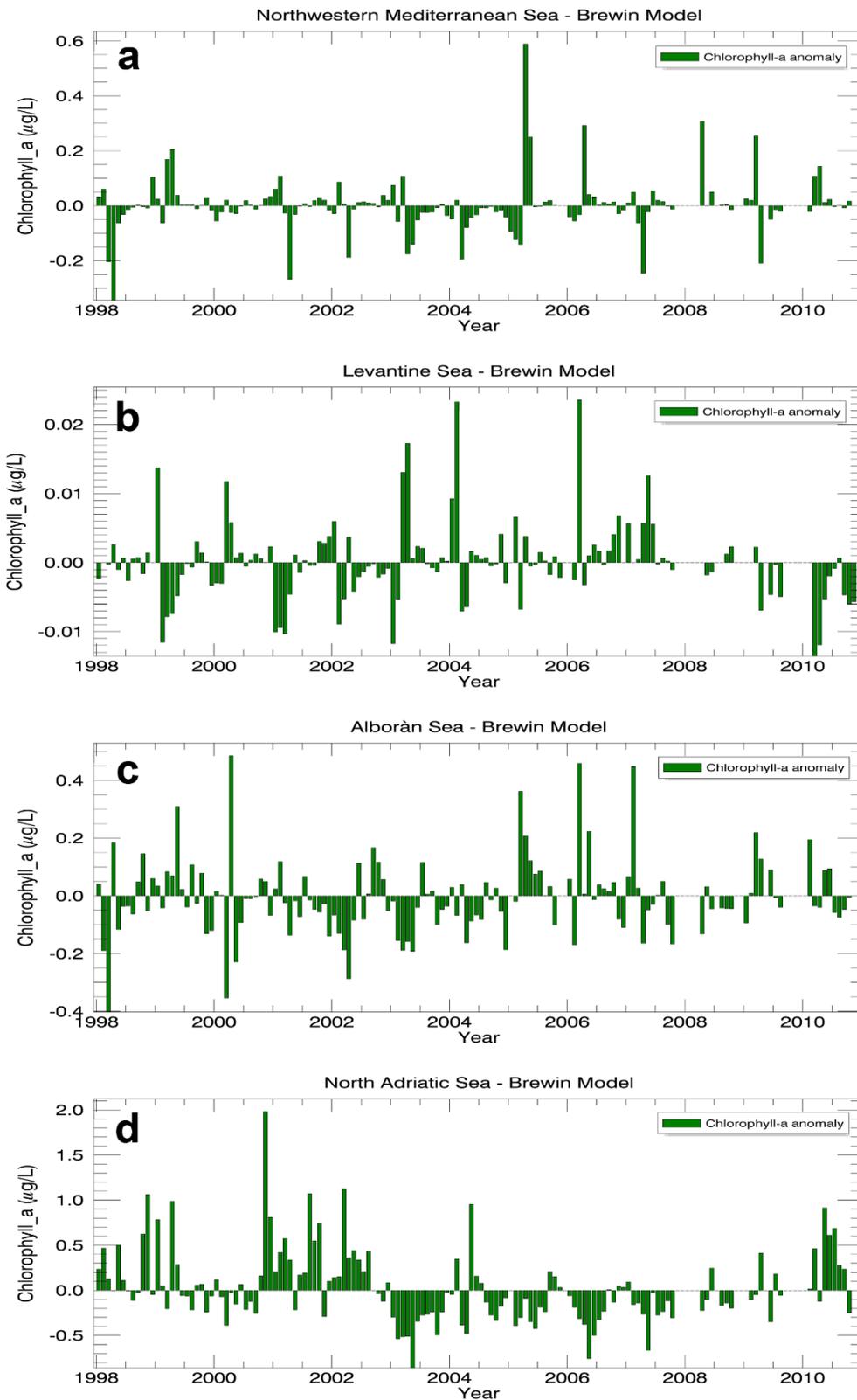


Fig. 10 Monthly anomalies of TChl a computed for the entire time series (1998-2010) over each of the four sectors. Gaps in the time series correspond to months where less than 90% of observations were recorded in the region. From top to bottom there are the anomalies of TChl a in the Northwestern Mediterranean Sea (NWMed), Levantine Sea (LEV), Alborán Sea (ALB) and North Adriatic Sea (NADR).