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## Spatio-temporal variability of a chlorophyll-a based biomass index and influence of coastal sources of enrichment in the Algerian Basin

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1           **Spatio-Temporal variability of a Chlorophyll-*a* based biomass index and**  
2           **influence of coastal sources of enrichment in the Algerian Basin**

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## 23 **Highlights**

- 24 • A specific fortnightly climatology of 1-km resolution Chlorophyll-*a* has been generated  
25 over the Algerian basin from MODIS data to explore the coastal domain.
- 26 • The Algerian Basin is characterised by two extreme seasons of high and low biomass,  
27 separated by sharp transitions, while the coastal area reveals a separated dynamic.
- 28 • Discontinuous and intense coastal cross-shore gradients reveal specific coastal sources of  
29 enrichments.
- 30 • A Chl-*a* based integrated index was defined to determine the importance of coastal  
31 enrichments.
- 32 • The Chl-*a* biomass in Algerian coastal waters is mainly associated with enrichments from  
33 wadis and cities with a pronounced seasonal effect.

34 **Abstract.** This study investigates the spatial distribution and temporal variability of chlorophyll-  
35 *a* (Chl-*a*) biomass in the Algerian Basin (AB) along its meridional and cross-shore dimensions,  
36 focusing on coastal enrichments. After correcting most atmospheric disturbances in the daily  
37 MODIS Level-2 data series between 2003 and 2018, a fortnightly climatology of 1-km  
38 resolution Chl-*a* has been generated to account for specific coastal features previously poorly  
39 evidenced from 4-km level-3 data. The AB is characterised by two extreme seasons of high and  
40 low biomass, separated by sharp transitions, that characterise the offshore domain. The coastal  
41 area (<10 km) reveals an intense and distinct dynamic associated with highly productive local  
42 hotspots rather than seasonal variability. A biomass index is proposed as the horizontally  
43 integrated Chl-*a* concentration from the coastline to the most offshore extension of the 0.5 mg m<sup>-3</sup>  
44 Chl-*a* isopleth. This index separately quantifies the cumulative biomass of both offshore and  
45 coastal domains with large alongshore variability. Low values (<5 g m<sup>-2</sup>) were observed in the  
46 offshore area during summer and high values during the spring blooms (up to 40 g m<sup>-2</sup>), while

47 maximum values ( $>50 \text{ g m}^{-2}$ ) were locally observed in the coastal domain. The narrow coastal  
48 area alone represents 44% of the total biomass, with coastal hotspots where the enrichment is up  
49 to 5 times higher than offshore. Multivariate modelling of the potential factors favouring coastal  
50 enrichments shows that the phytoplanktonic biomass in coastal waters is mainly associated with  
51 enrichments from wadis and seasonally from city sewage as well as by the presence of a bay. A  
52 separate source of enrichment is undoubtedly associated with the presence of aquaculture cages.

53 **Keywords:** Ocean colour; alongshore variability; wadi; anthropic enrichment; MODIS.

## 54 1. Introduction

55 Chlorophyll-*a* (Chl-*a*) biomass is associated with the net primary production in marine  
56 ecosystems, and marine physical and biochemical processes strongly influence its variability. A  
57 precise description of the spatio-temporal variability of Chl-*a* biomass is necessary to  
58 understand coastal marine systems functioning. The Chl-*a* concentration in the southwestern  
59 Mediterranean Sea (Med) is closely related to winter mixing and summer stratification. The Med  
60 ecosystem is increasingly threatened by human activities in coastal areas, as well as by a  
61 continuing warming trend (Vargas-Yáñez et al., 2010). A recent study conducted by Keraghel et  
62 al. (2020) highlights that the southwestern Med is a net sink of carbon dioxide, even compared to  
63 the Med as a whole, which is a significant contributor at the global level (Khaliwala et al., 2013).  
64 Scientists are still trying to understand the evolution of the Med ecosystem to better assess  
65 current and future changes and consider solutions to mitigate some impacts of global warming.

66 The Algerian Basin (AB) is classified as mesotrophic (D'Ortenzio and Ribera d'Alcalà, 2009;  
67 Harid et al., 2018; O'Reilly and Werdell, 2019). Water exchange across Gibraltar has a  
68 significant influence on its general circulation (Béranger et al., 2005; Millot, 1989; Peliz et al.,  
69 2009) and controls its nutrient content (Bethoux et al., 2002; Crispi and Pacciaroni, 2009; Elbaz-  
70 Poulichet et al., 2001; Huertas et al., 2009), with a direct influence on the Chl-*a* based

71 phytoplanktonic biomass. In winter, the presence of distinct water bodies indicates the eastward  
72 movements of anticyclonic eddies (Olita et al., 2011), generated by instabilities in the Algerian  
73 current (Millot et al., 1990), which enrich the surface water and increase its primary production.  
74 The Atlantic water flow is characterised by a transit time of two to four months between  
75 Gibraltar and the Algerian coasts (Millot, 1999), strongly influencing the seasonal Chl-*a* signal  
76 (Salgado-Hernanz et al., 2019). In summer, the stability of water masses limits the nutrient input  
77 (Moutin and Prieur, 2012), leading to a decrease in phytoplankton production.

78 The continental shelf of the AB is very narrow (15 km on average) and is neglected in most  
79 studies. Nonetheless, the shelf is the richest domain of the AB and shelter more complex  
80 interactions than in the offshore domain. Ocean colour remote sensing has provided high-quality  
81 observations in this respect for over twenty years on the abundance and distribution of Chl-*a*  
82 concentration, which is considered a proxy for phytoplankton biomass (Cullen, 1982; Strickland,  
83 1965). Turbid waters in the Med are rare compared to other seas (Morel et Prieur, 1977).  
84 According to Antoine et al. (1995), the coastal case-2 waters (where other constituents as  
85 mineral particles are also present) in the whole Med are estimated to be 5%. Currently, ocean  
86 colour analysis coupled with in-situ data could be used to characterise and monitor  
87 phytoplankton blooms (Barale et al., 2008; Cerino et al., 2019; Groom et al., 2019; Lavigne et  
88 al., 2015; Mayot et al., 2016; Palmiéri et al., 2018). In previous studies, a significant limitation  
89 was related to the poor representation of coastal patterns due to Level-3 data at 4-km resolution  
90 (as in Lavigne et al., (2015), Marañón et al., (2020), Mayot et al., (2016), Volpe, (2012), Volpe et  
91 al., (2018)).

92 To this end, our study proposes a practical approach to improve the quality of the standard  
93 MODIS-Aqua Level-2 1-km resolution (swatch) Chl-*a* product, specifically in coastal  
94 environments, where the higher data resolution provides more detailed information. A  
95 comparison between simultaneous in-situ and satellite Chl-*a* was performed to assess the

96 accuracy of MODIS Chl-*a* data in AB. In addition, a cumulative Chl-*a* biomass index ( $I_B$ ) was  
97 developed to synthesise the spatial patterns and variability of Chl-*a*. This paper describes the  
98 seasonal climatology of  $I_B$  in AB from 16 years of data (2003-2018), focusing on offshore and  
99 coastal areas separately. Finally, a discussion on the influence of different sources of coastal  
100 enrichment on the Chl-*a* biomass in the AB is presented.

## 101 **2. Methods**

### 102 **2.1 Study area**

103 The Algerian Basin (Fig. 1) is a major energetic area for mesoscale activity throughout the Med  
104 (Amores et al., 2013; Pessini et al., 2018). Millot and Taupier-Letage (2005) described the East  
105 flowing Algerian current, which carries Atlantic surface water, is 50-100 km wide and 100-200  
106 m thick with a speed of some 10s  $\text{cm s}^{-1}$  (El-Geziry and Bryden, 2010). It generally follows the  
107 continental slope and generates small eddies of 10-100 km diameter, lasting a few weeks or  
108 months. Periodically, this current forms a growing meander of 50-100 km; it can detach to form  
109 an anticyclonic eddy of 100-200 km diameter that encompasses the entire thickness of the Med  
110 water (El-Geziry and Bryden, 2010; Fani et al., 2014; Millot, 1989). Some oceanic eddies persist  
111 for up to three years, circulating in the AB in a cyclonic circuit (Millot and Taupier-Letage,  
112 2005). Thus, the AB acts as a reservoir where Atlantic waters accumulate before flowing either  
113 eastwards (surface waters) or northwards (deep waters) of the Med (Millot, 1999). Indeed, this  
114 buffer zone decouples the inflow and outflow of Med surface waters.

### 115 **2.2 Satellite data sources**

116 We used daily Level-2 Chl-*a* concentration data from the MODIS-Aqua sensor from 2003 to  
117 2018 at 1-km nominal resolution. The data set consists of 5844 daily observations from 15020  
118 individual orbits acquired from NASA's Ocean Color website (NASA's Ocean Color Web, 2019).  
119 Each daily data field was remapped over the AB, between 35°N-40°N and 6°W-10°E (Fig. 1), at

120 a spatial resolution of 96 pixels per degree of latitude and longitude. The equivalent daily  
121 MODIS Level-3 mapped data set at 4-km spatial resolution was obtained from the NASA Ocean  
122 Data Processing System. This data set was compared to the MODIS Level-2 data set to  
123 demonstrate permanent coastal Chl-*a* patterns. The climatological period from 1 to 15 January  
124 2003-2018 (Fig. 2) illustrates the differences between both spatial resolutions of 1-km and 4-km.  
125 In this work, a corrected version of the MODIS Level-2 data at 1-km was used to adequately  
126 describe the AB Chl-*a* variability in the coastal and offshore areas.

### 127 **2.3 Cloud masking improvement of MODIS Level-2 Chl-*a* data**

128 This section describes the specific processing steps applied for the first time to the standard  
129 cloud-corrected Level-2 Chl-*a* fields to detect and remove spurious patterns that affect data  
130 quality, even in fortnightly averages (Fig. 2b). Specifically, we noticed the presence of (i)  
131 partially cloudy pixels at the edge of the cloud mask, resulting in spurious high Chl-*a* values and  
132 (ii) noisy pixels. Three criteria were used to discriminate these contaminated pixels: 1) a  
133 maximum allowable value associated with a realistic Local Chl-*a* Gradient (LG), 2) a maximum  
134 value of daily Chl-*a* change during 3-day periods (Temporal Variation, “TV”), and 3) their  
135 position as Isolated Pixels (IP) inside the cloud mask. The pixel values corresponding to any of  
136 these criteria cited here are selected and replaced by the missing value.

#### 137 *2.3.1 Local Gradient (LG) criteria*

138 First, we applied a 3x3 Gaussian filter (Eq. 1) followed by a Sobel Gradient filter (Sobel, 1990)  
139 as follows:

$$140 \quad k(x, y) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2+y^2}{2\sigma^2}\right) \quad (1)$$

141 where,  $k(x,y)$  is the matrix of the kernel used to convolute the original image;  $x$  and  $y$  are the  
142 pixel’s position along the abscissa and ordinate axes respectively.  $\sigma^2$  is the variance of the 3x3  
143 pixel matrix.

144 The horizontal and vertical components of the Sobel gradient (Eq. 2 and Eq. 3, respectively)  
 145 were separately computed and combined into the final gradient (Eq. 4):

$$146 \quad G_h[x][y] = k(x, y) * \begin{Bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{Bmatrix} \quad (2)$$

$$147 \quad G_v[x][y] = k(x, y) * \begin{Bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{Bmatrix} \quad (3)$$

$$148 \quad Sobel_G [x][y] = \sqrt{G_h^2[x][y] + G_v^2[x][y]} \quad (4)$$

149 As spurious gradients are mainly associated with atmospheric perturbations in the vicinity of  
 150 clouds, a maximum threshold value of the local Sobel gradient of Chl-*a* was considered to detect  
 151 outlier pixels (Fig. 3a), at a maximum distance of 5 km from cloud borders (black areas in Fig.  
 152 3b). After several tests, two thresholds were defined: 0.4 mg m<sup>-3</sup> km<sup>-1</sup> and 1 mg m<sup>-3</sup> km<sup>-1</sup>  
 153 respectively for the coastal zone (distance from the coast <5 km) (Fig. 3c) and the offshore area.

### 154 2.3.2 Temporal Variability (TV) criteria

155 Each daily individual Chl-*a* pixel value of a given day (Day<sub>0</sub>) was compared to the average value  
 156 of the previous day (Day<sub>-1</sub>) and the following day (Day<sub>+1</sub>) when one or both values are available  
 157 to detect anomalous Chl-*a* variations through time, as given by Eq. 5:

$$158 \quad TV = Day_0 - \left( \frac{Day_{-1} + Day_{+1}}{2} \right) \quad (5)$$

159 This difference was then compared with the maximum threshold of temporal variability set at 2  
 160 mg m<sup>-3</sup>. Furthermore, this test was applied in the offshore domain only (distance from coast >20  
 161 km) to consider the higher spatio-temporal variability of the coastal environment (Fig. 3e).

### 162 2.3.3 Isolated Pixel (IP) removal

163 This criterion is used to eliminate pixels closely associated with a cloud structure. We considered  
 164 that Chl-*a* pixels bordered by more than five cloudy pixels (including those isolated in a cloud)



165 belong to the same atmospheric structure and should be eliminated (Fig. 3f).

#### 166 2.3.4 *Combination of criteria*

167 The three criteria mentioned above were cumulated, and the pixels marked by at least one  
168 criterion were removed. The resulting daily data are significantly less noisy, as shown in Fig. 3h.

169 A fortnightly climatology of Chl-*a* at 1-km resolution is then computed for the whole AB.

### 170 **2.4 Comparison between in-situ and satellite Chl-*a* data**

171 We compared the resulting 1-km satellite Chl-*a* data with an initial set of 70 high-performance  
172 liquid chromatography (HPLC) measurements of surface Chl-*a* concentration obtained during  
173 the SOMBA (*Système d'Observation à la Mer dans le Bassin Algérien*) cruise in the AB between  
174 August 13 and September 10, 2014 (Mortier et al., 2014). Further details about the cruise are  
175 available at <https://doi.org/10.17600/14007500>. Calibration precision was estimated to be 0.4%  
176 from the HPLC 1200 instrument used for the Chl-*a* measurements. A total of 34 measurements  
177 were retained according to their correspondence with satellite passes within  $\pm 6$  hours. The  
178 nearest pixel at 1-km resolution was considered. A representativity error (RE) was also  
179 considered, based on the proximity of a high Chl-*a* gradient, which we defined at a value of 0.01  
180  $\text{mg m}^{-3} \text{ km}^{-1}$ , compared with the effective Chl-*a* gradient measured in a 5x5 pixel matrix (Error  
181 bars in Fig. 4). In contrast, this spatial variability is generally low for pixels far from eddies (Fig.  
182 4b and 4e). We also checked the proximity of the HPLC measurements to the clouds (less than 5  
183 km); only two measurements deviate from this criterion (Fig. 4c and 4d).

### 184 **2.5 Biomass index**

185 A modified version of the coastal Chl-*a*-based index developed by Demarcq et al., (2007) was  
186 applied. Based on the Chl-*a* concentrations, a threshold ( $\beta$ ) of Chl-*a* concentration was set to  
187 compute the proposed integrated Chl-*a* biomass index ( $I_B$ ) in AB. This threshold was chosen as a  
188 value observed during all seasons (Fig. 7b). A value of  $0.5 \text{ mg m}^{-3}$  was selected according to this

189 criterion for the present study. The integrated Chl-*a* biomass index was calculated at each coastal  
190 point with the following formula:

$$191 \quad I_B = \left( \sum_{dist=Dist_{min}}^{Dist(\beta, max)} \overline{Chla} \right) \times Dist_{(\beta, max)} \quad (6)$$

192 where, the average Chl-*a* is calculated by the formula:

$$193 \quad \overline{Chla} = \left( \sum_{i=1}^{n(\beta, max)} Chla \right) / n_{(\beta, max)} \quad (7)$$

194 where,  $n_{(\beta, max)}$  is the position of the most distant pixel of the cross-shore transect.

195 The cross-shore distance associated with the index  $Dist_{(\beta, max)}$  is the most distant position where  
196  $Chl-a \geq \beta$  with the constraint  $Dist_{(\beta, max)} \leq max$ , is the maximum allowable distance. When this  
197 distance is determined, all pixel values from  $Dist_{min}$  to  $Dist_{(\beta, max)}$  are considered, regardless of  
198 their value; sometimes slightly  $< \beta$ . If no data  $\geq \beta$  was found within a profile, the computation of  
199  $I_B$  was performed only for the first valid pixel at the only  $Dist_{min}$  position, regardless of its value.  
200 The maximum distance for  $Dist_{(\beta, max)}$  in km was chosen at 10 km for the coastal area and 80 km  
201 for the next offshore area, according to the average structure of the cross-profiles (Fig. 6b). It is  
202 important to note that for continuity reasons, the first (inner) pixel of the offshore area was  
203 considered the pixel immediately offshore of the last of the coastal areas. The integrated coastal  
204 and offshore biomass indices were then calculated for the entire Algerian coastline or part of it  
205 (Table 1).

206 To estimate the relationships between Chl-*a* biomass (Chl-*a* or  $I_B$ ) classes and factor variables  
207 representative of the different sources of coastal enrichment, we applied the Generalized Linear  
208 Model (GLM) approach. All data analysis was done using the “stats” package version 3.4.4 of  
209 the R software.

## 210 **2.6 Physical oceanographic data**

### 211 *2.6.1 Altimetry data*

212 Geostrophic ocean currents and total kinetic energy (TKE) were extracted from the CMEMS

213 (Copernicus Marine Environmental Service) database of the *SEA-LEVEL GLO PHY L4 REP*  
214 *OBSERVATIONS 008 047* altimetry data product (<http://marine.copernicus.eu>, last accessed  
215 February 27, 2019), for the same period, and remapped in the AB at a spatial resolution of 0.25°  
216 (Fig. 1 for geostrophic currents and Fig. S2b for TKE).

### 217 2.6.2 *Mixed Layer Depth*

218 The mixed layer depth (MLD) has been defined in previous studies (as Lavigne et al., (2015) and  
219 Volpe, (2012)) using in-situ data in the Med (AB included). In this study, the monthly  
220 climatology (1969 to 2013) of the MLD was used as defined by Houpert et al. (2015) (data from  
221 <https://www.seanoe.org/data/00354/46532/>).

### 222 2.6.3 *Wadis outflows*

223 Outflow data measured by the Algerian National Agency for Hydraulic Resources (*Agence*  
224 *Nationale des Ressources Hydrauliques*, ANRH, <http://www.anrh.dz/>) were used to evaluate the  
225 possible influence of wadis (temporary rivers) on the Chl-*a* variability along the Algerian shelf.

## 226 3. Results

227 We show that a high-resolution fortnightly climatology very significantly improves the  
228 description of the spatio-temporal variability of Chl-*a* (including abrupt seasonal changes) and a  
229 spatio-temporal view of the enrichment sources. We explore here the coastal and offshore  
230 domains along meridional and cross-shore transects, focusing on the coastal domain, to  
231 understand the main seasonal dynamics of these enrichments.

### 232 3.1 Impact of data resolution on the description of seasonal patterns

233 Firstly, we compared the standard (original) MODIS data (1-km) to the corrected (this work)  
234 MODIS data (1-km). The improvement is particularly high during winter (characterised by a  
235 large cloud cover) with better detection of atmospherically contaminated pixels (Fig. 5). An  
236 example of the impact of Chl-*a* outlier values in the spatial distribution of the time series  
237 averages is represented in Fig. 5a and Fig. 5b for a fortnightly, and in Fig. 5c and Fig. 5d for a  
238 monthly climatological average. This correction produces a moderate decrease in Chl-*a* mainly

239 during the productive season, reinforcing the describing cross-shore profile. The resulting  
240 fortnightly climatology of MODIS Level-2 Chl-*a* data (at 1-km resolution) in the AB can be  
241 found online at <https://doi.org/10.5281/zenodo.5390383>.

242 The new fortnightly climatology at 1-km resolution was compared to the 4-km resolution used in  
243 all previous studies. Seasonal variability of Chl-*a* from the corrected MODIS 1-km Level 2 data  
244 (Fig. 6b) was explored along average cross-shore transects and compared to the MODIS 4-km  
245 Level-3 data (Fig. 6a). A closer look at the shorter distances (0-10 km) (Fig. 6c and 6d) shows  
246 that, as expected, the improvement is very significant and highlights much stronger cross-shore  
247 patterns (Fig. 6e and 6f for the most contrasted months of March and August), both in terms of  
248 Chl-*a* concentration average and seasonal patterns. The coastal Chl-*a* (0-10 km) from the 1-km  
249 data is 37% higher than that from 4-km data (49% and 46% respectively at distances of 2 and 4-  
250 km from the coast). The 4-km product cannot detect a significant part of the coastal enrichment,  
251 representing 44% of the production of the AB from 1-km data, while only 25% are detected from  
252 4-km data. Consequently, the spatial resolution impacts the scale of the description and more  
253 importantly the high contribution of the coastal area in the regional marine productivity.

### 254 **3.2 MODIS Level-2 data validation in the AB**

255 The in-situ Chl-*a* data range between 0.062 and 0.307 mg m<sup>-3</sup> (Fig. 4). These values are typical  
256 for the AB offshore area during the oligotrophic season in the surface layer. Both sources of Chl-  
257 *a* data span nearly the same magnitude. The HPLC data have a slightly lower mean and median  
258 (respectively 0.100 mg m<sup>-3</sup> and 0.094 mg m<sup>-3</sup>) than the satellite data (0.105 mg m<sup>-3</sup> and 0.104 mg  
259 m<sup>-3</sup>). It should be noted that the satellite has a vertically integrating effect (exponentially  
260 decreasing) on the estimated Chl-*a* value. In contrast, the in-situ measurements represent  
261 exclusively punctual surface values at 1 m depth and the remaining ones at 2 m depth. The final  
262 error associated with the Chl-*a* satellite data was estimated at 0.025 (8% of the average) by the  
263 RMSD (Root Mean Square Deviation) between Chl-*a* HPLC and MODIS Level-2 data.

264 No in-situ measurements were available in the coastal areas of the AB. Nevertheless, Pieri et al.,  
265 (2015) have found that the OC3M standard algorithm (used in our work) gives valid results in  
266 the Western Mediterranean Sea when the Chl-*a* concentration does not exceed 1 mg m<sup>-3</sup>. In our  
267 case, the Chl-*a* exceeds 1 mg m<sup>-3</sup> generally in the three first kilometers from coast (i.e. the 3 first  
268 pixels) and only during the high production season (December to March, as shown in Fig. 6 and  
269 7). To estimate the importance of the likely overestimation of the values >1 mg m<sup>-3</sup>, we apply an  
270 empirical correction model with two levels of intensity, by reducing the values >1 mg m<sup>-3</sup> by a  
271 factor of two and by a factor of three. The results show a relatively modest overestimation of  
272 respectively 6% and 9% of the Chl-*a* in these two extreme cases. This allows us to assume that a  
273 likely overestimation of the Chl-*a* values in the very coastal area does not significantly impact  
274 our conclusions.

### 275 **3.3 Cross-shore and seasonal variability of Chl-*a***

276 Chl-*a* cross-shore sections (Fig. 6b) indicate that the lowest Chl-*a* concentrations are observed  
277 from May to October at all locations, both in coastal and offshore areas. The highest Chl-*a*  
278 concentrations, representing the productive season, are observed from November to April. In the  
279 coastal area, the maximum Chl-*a* can exceed 2 mg m<sup>-3</sup> in winter (Fig. 7a) and 0.5 mg m<sup>-3</sup> in  
280 summer (Fig. 7a). However, in the offshore area, beyond 10 km from the coast, the average  
281 minimum reach 0.5 mg m<sup>-3</sup> in winter and 0.2 mg m<sup>-3</sup> in summer (Fig. 6b and Fig. 7b). Beyond 10  
282 km, the Chl-*a* concentration becomes stable during all seasons (Fig. 6b and Fig. 7a). Indeed, we  
283 chose the distance of 10 km from the coast as the shortest distance at which Chl-*a* seasonality  
284 becomes weak and stops increasing towards the offshore (Fig. 6b and 7b).

285 The cross-shore gradient is well pronounced throughout the year and increases exponentially  
286 towards the coast (Fig. 6b). The intensity of this gradient is maximum during the productive  
287 season and is always maximal at the coast and regularly decreases with increasing distance from  
288 the coast (Fig. 6b), ranging from 0.2 to 2 mg m<sup>-3</sup> onshore (Fig. 6b) and 0.1 to 0.5 mg m<sup>-3</sup> offshore

289 (Fig. 6b).

### 290 **3.4 Meridian variability and seasonality of Chl-*a* biomass index**

291 The integrated cross-shore biomass index (Section 2.6) was computed from each coastal point  
292 northwards to integrate the Chl-*a* concentration up to a variable distance (Fig. 8b) where Chl-*a*  
293 drops below the predefined value of  $0.5 \text{ mg m}^{-3}$  (see methods). The aim was to explore and  
294 quantify the integrated coastal Chl-*a* biomass along the Algerian coastline (Fig. 8d). The value  
295 was carefully chosen as the best threshold  $\beta = 0.5 \text{ mg m}^{-3}$  that intersects the different average  
296 cross-shore climatological profiles over the year (Fig. 7b). The red line in Fig. 8a represents the  
297 maximum distance effectively reached during the productive season (we considered Chl-*a*  $< 0.5$   
298  $\text{mg m}^{-3}$  as oligotrophic and does not represent an enrichment). The resulting distance (Fig. 8b)  
299 shows that the productive area varies over time from a few kilometres in summer (cyan area in  
300 Fig. 8b) with a minimum of 1 km (when only one sea pixel is considered) to a maximum of 80  
301 km in winter, mainly reached near the Alboran Sea in the west. The longitudinal gradient along  
302 the coastline shows an apparent decrease of this distance eastward, which is well in line with the  
303 decreasing influence of the enrichment of Atlantic waters entering the Alboran Sea and moving  
304 eastwards.

305 The average Chl-*a* along the same transect (Fig. 8c) shows extreme variability between regions,  
306 from values  $< 0.5 \text{ mg m}^{-3}$  in summer (this is possible when a minimum of one sea pixel is  
307 considered) to values  $> 2 \text{ mg m}^{-3}$  between April and November, i.e., during low-biomass season.  
308 The resulting biomass index  $I_B$  (Fig. 8d) is defined as the product of the previous distance by the  
309 average Chl-*a* concentration along the same transect (Eq. 6). This index represents the spatial  
310 integration of the most elevated Chl-*a* values along the cross-shore transect, while the vertical  
311 dimension is partially considered by the attenuation depth of the satellite measurement.  
312 Nevertheless, this depth represents a variable fraction of the euphotic layer, according to the  
313 shape of the vertical Chl-*a* profile.

314 The Chl-*a* (Fig. 8c) represents a proxy of the average phytoplankton biomass over the cross-  
315 shore profile, while the spatially integrated index ( $I_B$ , Fig. 8d) is predominantly determined by  
316 the length of the profile (Fig 8b). The  $I_B$  index is expressed in  $\text{g m}^{-2}$  and varies between 20 and  
317  $50 \text{ g m}^{-2}$  during the productive season (Fig. 8d) with a regular eastward decrease. Several peaks  
318 in phytoplanktonic biomass are observed ( $I_B$  is  $>45 \text{ g m}^{-2}$ ; between  $2.2^\circ\text{W}$  and  $0.5^\circ\text{E}$  from  
319 January to March, between  $5.1^\circ\text{E}$  to  $5.5^\circ\text{E}$  in January and February, and at  $7.7^\circ\text{E}$  from January to  
320 March-April). These peaks correspond to pronounced extensions of  $\text{Dist}_{0.5\text{mg}}$  (Fig. 8b) as near the  
321 Alboran region or mostly to higher Chl-*a* values in the central and eastern parts of the AB (Fig.  
322 8c).  $I_B$  is  $<10 \text{ g m}^{-2}$  everywhere during the low-biomass season, except in the Algiers and Annaba  
323 bays (Fig. 8d).  $I_B$  is, in fact, practically zero from June to September in many locations where the  
324 Chl-*a* concentration barely exceeds  $0.5 \text{ mg m}^{-3}$  (Fig. 8c).

## 325 **4. Discussion**

326 The construction of a data set at 1-km spatial resolution allows investigating and extracting the  
327 specific enrichments of coastal origin, distinguishable from the large-scale seasonal cycle.  
328 Previous descriptions of the climatological cycle in the AB were based on monthly averages  
329 (instead of fortnightly in this study) and at a much higher spatial resolution. Therefore, our  
330 description of the cross-shore gradient of Chl-*a* and its variability along a longitudinal gradient  
331 becomes much more realistic and highlights the high importance of the coastal domain ( $<10 \text{ km}$ )  
332 in the whole basin.

### 333 **4.1 Processes governing Chl-*a* variability in AB**

#### 334 *4.1.1 Seasonal variability*

335 AB is characterised by two contrasting seasons (Fig. 7a): an early 3.5-month high-biomass  
336 season (mid-December to March) and a 4.5-month low-biomass season (June to mid-October),  
337 characterised by intense stratification. The two seasons are separated by quasi symmetrical and  
338 sharp 2-month transition periods in spring and autumn (Fig. 7a). The extreme precocity of the

339 productive period (between October and November), i.e. during a low sun elevation, clearly  
340 shows that light is not the main limiting factor in the occurrence of winter blooms. The  
341 seasonality of Chl-*a* is closely related to the dynamics of the Mixed Layer Depth (MLD, Fig. 7a,  
342 brown line and Fig. S1 in supplementary material), which is maximum (40 m to 60 m) in winter  
343 between December and February and very low (15 m) in summer from June to September.

344 It is well known that winter and spring blooms in the region are almost exclusively driven by the  
345 nutrient input following autumn and winter vertical mixing (Fani et al., 2014; Huertas et al.,  
346 2012; Lazzari et al., 2012; Millot et al., 1990; Pasqueron de Fommervault et al., 2015), as  
347 reflected by our biomass index (Fig. 8d). Moreover, the results show that high Chl-*a* values  
348 dominate several well-defined coastal areas outside the productive season, from April to  
349 November (Fig. 8c). On a large scale, the variability of Chl-*a* concentration in the AB is known  
350 to be driven by the inflow of nutrient-rich Atlantic waters that enter the Alboran Sea through the  
351 Gibraltar strait (Taupier-Letage and Millot, 1988) and progress eastwards along the AB. The  
352 same conclusions have also been drawn more recently by several authors (Fani et al., 2014;  
353 Huertas et al., 2012; Lazzari et al., 2012; Pasqueron de Fommervault et al., 2015). Consequently,  
354 the eastward propagating eddies modulate the circulation of water masses beyond the continental  
355 shelf (Pessini et al., 2020), generating intense vertical mixing (Millot et al., 1990). Its positive  
356 influence on productivity is perceptible up to the eastern part of the country and is reinforced by  
357 nutrient enrichments from the bottom (Millot et al., 1990). The offshore vertical mixing is  
358 considered to be the main factor influencing winter-spring enrichments before the summer-  
359 autumn stratification period.

360 In addition to these two well-known potential sources of enrichment, we identified a third coastal  
361 source: the presence of nutrients of coastal origin, generally associated with bays or gulfs, which  
362 enhance local phytoplankton growth. The integrated Chl-*a* biomass index ( $I_B$ , Fig. 8d) is used in  
363 this study as a proxy for the primary production dynamic in the AB. Better than local Chl-*a*



364 averages, it adequately describes the longitudinal variability of spring blooms due to its cross-  
365 shore integrative capability. In other words, the Chl-*a* averages (Fig. 8c) gives a clear view of the  
366 origin of the enrichment effects without considering their spatial importance. In contrast, the  $I_B$   
367 (Fig. 8d) integrates both components.

368 However, this index in Fig. 8d (and the associated average Chl-*a*) does not distinguish between  
369 coastal and offshore sources of enrichment. We, therefore, divided it into an inshore and an  
370 offshore component, as detailed in Section 2.6. The coastal area is defined as the distance  
371 between the coast and the  $0.5 \text{ mg m}^{-3}$  isopleth position, with a maximum distance of 10 km (Fig.  
372 6b). The offshore component is then defined as the area beyond this variable spatial limit up to a  
373 maximum distance of 80 km. The maximum 10 km limit was chosen to best separate the coastal  
374 and offshore signals, from the Chl-*a* signature (Fig. 9a-b) and the corresponding integrated  
375 biomass index (Fig. 9c-d).

#### 376 4.1.2 Coastal enrichment

377 Beyond the spatially averaged seasonal signal computed in both domains (Fig. 7a), the results  
378 give precise insights about their regional alongshore variability, which is well distinguished by  
379 the biomass index (Fig. 9c-d). The coastal biomass index ( $I_B$ , Fig. 9c) highlights the increase in  
380 the duration of the productive season varies, that from 4 to 6 months from East to West and from  
381 4 to 8 months (and more) in the coastal areas in the form of spatially distinct peaks of values  $>20$   
382  $\text{g m}^{-2}$ . Some locations, such as the Algiers Bay ( $3.2^\circ\text{E}$ ) and the Annaba Bay ( $7.9^\circ\text{E}$ ), show high  
383 index values almost yearly. In contrast, no Chl-*a* peaks are visible in the offshore area (Fig. 9d),  
384 even in the locations where the highest coastal peaks are observed (Fig. 9c). The offshore area  
385 exhibits a much more homogeneous spatial pattern with high cumulated biomass during the  
386 central part of the productive season, with a maximum between January and February, except  
387 near the Alboran Sea, where the maximum occurs one month later. The duration of the  
388 productive season considering the  $I_B$  at  $10 \text{ g m}^{-2}$  limit, varies from 5 months (December to April)

389 west of 1°E with maximum values constantly between 30 g m<sup>-2</sup> and 40 g m<sup>-2</sup>, then is 4 months in  
390 most of the area up to 7°E, to a minimum duration <2 months (mid-January to February) with  
391 maximum values <25 g m<sup>-2</sup>. Between 5°E and 6°E longitude, a distinct offshore maximum in the  
392 biomass index (Fig. 9d and Fig. 11, blue curve) is observed during the productive season. This  
393 feature probably corresponds to the relative permanence of the mesoscale cyclonic EAG (Eastern  
394 Algerian Gyre, Fig. 1) as described by Testor et al., (2005) and where high Chl-*a* concentrations  
395 are regularly found (Taupier-Letage, 2003).

396 The same processing was applied to compare these results with the equivalent information from  
397 the 4-km Level 3 data and presented in Supplementary Fig. S2. As previously shown, the coastal  
398 fraction of the enrichment is here only 25% (44% from 1-km data), and only two areas with Chl-  
399 *a* peaks would be partially detected, regardless of the season. This clearly shows that 1-km data  
400 are a minimum requirement to adequately explore the relative importance of the different sources  
401 of enrichment in the coastal regions.

402 Coastal and offshore averages of the biomass index were calculated for all areas where high  
403 biomass index values were observed, hereafter referred to as **High-Biomass Coastal Zones** (or  
404 **HBC**), and outside these zones referred to as **Low-Biomass Coastal Zones** (or **LBC**). The aim is  
405 to separate the specific effects of local (coastal) enrichments from the large-scale enrichments  
406 (Table 1, left-hand side). Compared to LBC, HBC logically dominate the total biomass by a 4-  
407 fold ratio (+300%) in summer, and almost double by +80% in winter (Table 1, and Fig. S3a). The  
408 importance of HBC is still high in the offshore domain in summer (+97%), while almost no  
409 difference is observed (+7%) in winter during the productive season (see Fig. S3b for more  
410 details). The annual cumulative biomass index associated with the HBC represents 88% of the  
411 coastal domain, despite a corresponding coastline fraction of 42%. Because of the relative  
412 importance of the winter period (December to March) in the productive season, we summarised  
413 the overall significance of the coastal sector by its ratio to the offshore sector (Table 1, right-

414 hand side). This ratio shows that the coastal domain slightly dominates from January to February  
415 in both LBC and HBC (respective values of 0.64 and 0.73). Nevertheless, this ratio strongly  
416 increases in the adjacent months (December and March), with values of 2.57 and 4.14 for LBC  
417 and HBC respectively, highlighting the importance of HBC in coastal areas.

#### 418 *4.1.3 Large scale longitudinal variability*

419 We specifically examined three profiles of the average biomass index and the MLD and TKE  
420 (Fig. 10), both averaged from the coast to 80 km offshore, to explore the longitudinal variability  
421 of the phytoplankton biomass over the year. Three cross-shore transects from the coastline to 80  
422 km offshore were examined at three longitudes (1°W, 4.5°E and 7.5°E, blue dashed line in Fig.  
423 8a). They were chosen because of their independence from the observed enrichments in the  
424 coastal domain (Fig. 8c).

425 Firstly, the results show a substantial eastward decrease in the intensity of the productive season,  
426 as shown by the biomass index (Fig. 10, orange bars), with annual cumulative values of 285, 152  
427 and 86 g m<sup>-2</sup> from West to East. This quantifies well the observations of a progressive decrease  
428 in the influence of the rich Atlantic waters eastward, following its progressive nutrient depletion.  
429 The shape of the productive season is stable at 1°W and 4.5°E, with a variable maximum centred  
430 at the first fortnight of February. A precise computation of this chronology along the entire  
431 Algerian coast (data not shown) shows that this central position is relatively stable from 1°W to  
432 8.7°E (with minor variability <1 fortnight). In contrast, there is a positive shift of almost a  
433 fortnight (first fortnight of March) between 3°W and 1°W near the Alboran Sea, where a  
434 maximum shift of two fortnights is observed (data not shown). The productive season is more  
435 extended, due to the higher nutrient content of Atlantic waters.

436 We know that winter mixing due to wind and currents is the main cause of nutrient availability in  
437 the euphotic layer of the region (Conan et al., 2018; Fernandez et al., 2006; Kessouri et al., 2018;  
438 Millot, 1989). A close relationship was effectively observed between the seasonality of the MLD

439 and, to a lesser extent, the TKE (see Fig. S1 for spatial mapping of these two parameters) and the  
440 dynamics of the productive season captured by the biomass index. The MLD deepens eastwards  
441 with a simultaneous winter maximum (45 m to 60 m, see Fig. S1a) from January to February  
442 while the Modified Atlantic Waters (MAW) are drifted eastwards (Font et al., 1998). The  
443 productive season follows the winter mixing (average MLD >20 m, blue line) by about one  
444 month in the western and central part of the region (Fig. 10a-b). At the same time, a relative  
445 synchrony is progressively reached further East (Fig. 10c). The TKE (computed from  
446 geostrophic currents, i.e., including eddy energy and permanent currents) is almost permanently  
447 high at 1°W near the Alboran Sea (Fig. 10a) and not in phase with the biomass index.

448 It is very likely that, along with the significant enrichment effect of the MAW, water mixing is an  
449 important factor in the initiation of surface productivity but is probably not a limiting factor near  
450 the Alboran Sea with high-energy levels related to both Alboran gyres. Lower energy levels are  
451 observed further East at 4.5°E (Fig. 10b) with a slight relationship to the biomass index, while a  
452 higher association is observed at 7.5°E (Fig. 10c). This well-defined seasonal pattern explains  
453 that the higher MLD (50 to 60 m) observed in January-February, induces a rapid mixing of  
454 surface waters and a rapid increase in planktonic biomass during the second half of February.  
455 Average wind speed (data not shown) do not show any relationship with the surface water  
456 mixing, with low winter wind values from October to February. The MAW trajectory determines  
457 the large-scale variability of planktonic biomass in the AB. It is strongly constrained by nutrient  
458 availability, while the different sources of coastal enrichment represent a significant contribution  
459 throughout the year and unexpected relative importance of about two-thirds during the central  
460 part of the productive season and progressively higher during the rest of the year.

#### 461 **4.2 Sources of coastal enrichment**

462 Previous studies using Chl-*a* variability as a proxy of the phytoplankton biomass variability  
463 along the Algerian basin have focused on large spatial scales, mainly over the continental shelf

464 (Mayot et al., 2016; Pieri et al., 2015; Salgado-Hernanz et al., 2019). They have generally  
465 ignored small scales and coastal waters, except locally for sanitary purposes or risk assessment.  
466 The annual average of the  $I_B$  averaged spatially from all seasons was calculated in the coastal  
467 domain (0-10 km, green curve in Fig. 11) and in the offshore domain (beyond 10 km, blue curve  
468 in Fig.11). The ratio ( $I_B$  Coastal/ $I_B$  Offshore) is considered a relative indicator of the local coastal  
469 enrichment (red curve in Fig. 11). The  $I_B$  coastal peaks are variable in space and time (Fig. 11)  
470 and indicate many distinct anomalies. In the Arzew, Bou-Ismaïl, Algiers and Annaba bays, the  $I_B$   
471 average is  $>20 \text{ g m}^{-2}$  throughout the seasons (Fig. 11). These anomalies correspond mainly to  
472 sandy coasts (orange bars in Fig. 11). It is important to note that many microphytobenthos  
473 species (some diatoms, cyanobacteria, chlorophyceae and/or flagellates) prefer shallow sandy  
474 coastal environments for their development (Cook and Røy, 2006; Hassan et al., 2006).  
475 Nevertheless, the origin of these high production areas remains unclear.

476 Several bays are associated with wadis (temporary rivers) in many locations along the coast (in  
477 blue in Fig. 11). These wadis are characterised by shallow flows (Fig. 12), generally  $<15 \text{ m}^3 \text{ s}^{-1}$   
478 during all year seasons. For example, in the Bou-Ismaïl Bay (Fig. 12a), the Mazafran flow varies  
479 from  $<4 \text{ m}^3 \text{ s}^{-1}$  in summer (June to October) and from 4 to  $13 \text{ m}^3 \text{ s}^{-1}$  in winter. In Algiers Bay  
480 (Fig. 12b), the El-Harrach flow presents a very similar pattern. The Algiers city is affected by  
481 intensive urbanisation (~70% of the coastline up to 800 m inland is urbanised), which has caused  
482 significant environmental degradation of the coastal area and impacted the coastal morphology  
483 (Rabehi et al., 2019). In Annaba Bay, the Seybouse wadi (Fig. 11, wadi 1) input is highly  
484 concentrated in  $\text{PO}_4$  and  $\text{NH}_4$  compared to Mediterranean rivers (Ounissi et al., 2014), and  
485 presents a potential risk of eutrophication (Ziouch et al., 2020). The observed peaks of *Chl-a*  
486 (and  $I_B$ ) are associated with different contributions (Table 2): the type of coast (sandy and rocky),  
487 the presence of wadis and large cities, and the presence of bays.

488 In many cases, coastal enrichments are not the result of a single factor: for example, a biomass

489 peak is observed at 7.3°E associated with a wadi (wadi 2). The peak disappears shortly at 7.5°E,  
490 despite the presence of sandy coast. In Oran Bay, a coastal peak is observed despite the absence  
491 of a sandy coast and wadis (Fig. 11). However, Oran is a large city (>100,000 inhabitants) (Fig.  
492 11), that induces a significant marine pollution due to wastewater discharged into the sea,  
493 increasing nutrients in coastal waters. Another enrichment is observed at approximately 1.3°W,  
494 where floating aquaculture cages are installed (Fig. 11). These aquaculture facilities are  
495 considered a significant source of local enrichment (Cao et al., 2007). The low flows of the  
496 wadis on the Algerian coast suggest that suspended matter (SM) from terrestrial inputs is weak in  
497 coastal waters. In contrast, a significant source of SM may originate from local sediment  
498 resuspension, especially on sandy coasts, where sediment resuspension generates a considerable  
499 flux of nutrients (Robinson and Hill, 2005).

500 It is also known that the inner part of gulfs and bays trap nutrients from territorial inputs by  
501 modifying local hydrodynamics that limit nutrient dispersal, thus maintaining high coastal  
502 production with little influence on offshore production. It is important to note that, all previous  
503 studies (Colella et al., 2016; Okubo, 1973; Pingree and Maddock, 1979; Signell and Geyer,  
504 1991; Taillandier et al., 2020; Wolanski and Hamner, 1988) never considered potential coastal  
505 influences. In winter and early spring, the richer coastal waters are often mixed with the offshore  
506 waters and therefore contribute to the production beyond the continental shelf up to 10 km from  
507 the coast, as shown by our biomass index.

### 508 **4.3 Modelling approach**

509 As previously mentioned, the Algerian coastal waters were divided into two classes: HBC (High-  
510 Biomass Coastal Zones) and LBC (Low-Biomass Coastal Zones) (Fig. 11). The HBCs  
511 consequently refer to the highest values of Chl-*a* and I<sub>B</sub>, and the LBCs to the lowest values.  
512 Their separation into two classes was visually optimised by defining specific thresholds for Chl-  
513 *a* and I<sub>B</sub> variables, summarised in Table 3 (response variables). We defined three qualitative

514 variables: the presence of wadis, the type of coast (sandy/rocky), and the existence of a Bay. The  
515 City is defined as a quantitative variable with four levels: 0 (no-city), 25 k, 75 k, and 200 k  
516 inhabitants.

517 Table 2 summarises the respective characteristics of LBC (numbered 1-16) and HBC (numbered  
518 1-15) as manually selected in Fig. 11. The presence of Cities, Wadis and Bays are positively  
519 related to the detection of High-biomass coastal areas. At the same time, the type of coast  
520 appears to be irrelevant, mainly compared to the presence of a Bay.

521 Linear qualitative models (General Linear Models) were performed to evaluate the interactions  
522 between either the coastal Chl-*a* concentration or the biomass index ( $I_B$ ) and the four explanatory  
523 variables, as shown in Table 3. The two specific areas HBC-1 and HBC-8 were excluded from  
524 the modelling because these two areas are specifically influenced by aquaculture floating cages  
525 that are not associated with the explanatory variables. A general model (m1 in Tab. 3) is first  
526 tested by combining all seasons to test the separation between HBC and LBC, as presented in  
527 Fig. 11. This model explains 67% of the variability, with a unique City effect. The Wadi effect is  
528 absent, probably because of its association with City. On the opposite, in winter, the Chl-*a*  
529 response variable (m2 model, 79%) is primarily associated with the presence of a Wadi, then to  
530 City. In contrast, the  $I_B$  response variable (m3 model) is mainly related to a Bay and City  
531 presence. The winter  $I_B$  model (m3) is very similar in explaining the biomass variability (77%),  
532 with a dominance of City presence (as previously with Chl-*a*) as well as to a significant Bay  
533 effect. In these winter models, the Wadi effect is only evidenced by the Chl-*a* variable that most  
534 reflects the influence of local enrichments rather than their spatial extension, associated with the  
535 biomass index ( $I_B$ ), highlighting the Bay effect.

536 During summer (low-biomass season), the Chl-*a* based model (m4 in Tab. 3) shows only 57% of  
537 explanation, with a unique Wadi effect despite the generally low flow of wadis in winter (Fig.  
538 12). The equivalent model for the biomass index (m5) explains 78% of the variability, with a

539 dominance of Bay presence, while the Wadi effect is still present. The lower biomass variability  
540 in summer (not shown) is better explained by the spatially integrated biomass index ( $I_B$ ). The  
541 later highlights a Bay effect, even if the main variability of the coastal enrichments is probably  
542 dominated by wadis and underneath by the influence of cities sewage.

543 Therefore, we can argue that anthropic effects (presence of a City and a Wadi) dominate the  
544 biomass variability in the coastal areas along the Algerian coast, much more than “natural”  
545 effects such as the coast type and the presence of a bay. However, the presence of Bay is also of  
546 primary importance for trapping enriched water within the coastal domain. Another significant  
547 point is undoubtedly the strong positive effect of aquaculture cages in two specific country  
548 locations (Fig. 11). It is noteworthy that marine aquaculture has developed considerably over the  
549 last decade, with a national initiative plan whose objective was to produce 100,000 tonnes of fish  
550 and shellfish by 2020 horizon (FAO, 2019).

## 551 **5. Conclusion**

552 Satellite-based *Chl-a* is an important proxy of phytoplanktonic biomass that allows us to  
553 disentangle very different dynamics between the coastal and offshore domains of the Algerian  
554 Basin (AB), characterised by a very narrow continental shelf. We show that a specific fortnightly  
555 climatology of 1-km resolution *Chl-a* generated from MODIS data makes possible this  
556 identification. The AB is characterised by two extreme high and low biomass seasons, separated  
557 by short 2-month transition periods. The offshore variability is closely related to large-scale  
558 processes governed by the influence of Atlantic waters and a progressive eastward decrease in  
559 biomass. The coastal domain reveals a very distinct dynamic associated with highly productive  
560 hotspots rather than a well-defined seasonality. The irregular morphology and nature of the  
561 Algerian coast (bays, gulfs, rocky or sandy coasts) is shaped by numerous terrestrial and  
562 temporary inputs that affect its local productivity. A *Chl-a* based spatially integrated index allows



563 us to quantify the importance of these coastal enrichments. At the same time, a modelling  
564 approach shows that seasonal wadis and city sewages, along with the presence of a bay, explain  
565 up to 79% of the presence of these productive hotspots. A separate source of enrichment is  
566 undoubtedly associated with the recent presence of aquaculture cages. Finally, considering  
567 phytoplanktonic communities and the in-situ determination of water quality would be beneficial  
568 to understand the biological consequences of these enrichments.

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## 578 **Figure captions**

579 **Figure 1.** March climatological average of the Chl-*a* concentration ( $\text{mg m}^{-3}$ ) between 2003 and  
 580 2018 in the Algerian Basin (Mediterranean Sea). The average current velocity ( $\text{m s}^{-1}$ ) for the  
 581 same period (black arrows), the 800 m isobath (red line), and the  $0.5 \text{ mg m}^{-3}$  isopleth (dark green  
 582 line) is superimposed. The stations of the SOMBA-2014 cruise are also superimposed (white  
 583 dots). The large eddies in black (Alg. WG and Alg. EG) are deduced from the average sea level  
 584 anomaly between 2003 and 2018. The average position of the Alboran eddies (Alb. WG and Alb.  
 585 EG) are added.

586 **Figure 2.** Comparison of Chl-*a* concentration for the first fortnight of January (2003-2018  
587 climatology) from (a) MODIS Level-3 data at 4-km resolution and (b) MODIS Level-2  
588 (uncorrected data) at 1-km resolution.

589 **Figure 3.** Definition of the outlier pixels criteria for improving the cloud masking (example of  
590 07 January 2014). (a) Local (3x3 matrix) Sobel gradient ( $\text{mg m}^{-3} \text{ km}^{-1}$ ). (b) Distance (D1) from  
591 the cloud borders, in km (clouds are in white). (c) Distance (D2) from the shoreline, in km. (d to  
592 f): Pixels identified as cloudy from, (d) the gradient criteria, (e) the temporal variation (TV)  
593 criteria, (f) from isolated pixels within cloud (IP) criteria. The result of the combination of all  
594 three criteria is shown in (h) versus the original MODIS Level-2 data (g).

595 **Figure 4.** Linear relationship (red line) (a) between MODIS satellite corrected data (Y axis) and  
596 in-situ Chl-*a* data (X axis) during the SOMBA cruise (14 August to 10 September 2014) in the  
597 Algerian Basin. (b), (c), (d), and (e): spatial variability of the daily Chl-*a* field associated with  
598 four selected stations. The stations represented with a grey cross in (c) and (d) were removed  
599 from the comparison on the basis of a gradient threshold criteria or because their proximity to  
600 clouds.

601 **Figure 5.** Results of the elimination of outlier pixels from the original uncorrected MODIS  
602 Level-2 data (left column), respectively for a fortnightly average (example of 1-15/01/2014) (a  
603 and b), and for a monthly climatological average (example of January 2003-2018) (c and d).

604 **Figure 6.** Hovmöller diagrams of the cross-shore seasonality (from the coast line to 120 km  
605 offshore) of the Chl-*a* concentration in the Algerian Basin averaged between 2.2°W and 8.7°E,  
606 from fortnightly climatologies (2003-2018) computed from (a) MODIS Level-3 data at 4-km  
607 resolution, (b) MODIS Level-2 corrected data at 1-km resolution. The black line separates the 10  
608 km distance from the coast. (c) and (d) highlight the data for this coastal area. The average cross-  
609 shore profiles in March (green line) and August (blue line) are shown in (e) and (f).

610 **Figure 7.** Average seasonality of the Chl-*a* concentration from 2003 to 2018 in the Algerian  
611 Basin from fortnightly Chl-*a* averages (a) in the 0-10 km coastal sector (green plain line) and  
612 offshore (blue plain line). The corresponding 4-km resolution Chl-*a* MODIS data (dotted lines)  
613 as well as the depth of the mixed Layer (MLD, orange dasher line) are superimposed. (b)  
614 Zonally averaged cross-shore Chl-*a* transect from the coast to 50 km for the High-Biomass  
615 (green), the transition (yellow), and the Low-Biomass (blue) seasons. The horizontal line shows  
616 the  $0.5 \text{ mg m}^{-3}$  limit used to compute the integrated index, detailed in Fig. 8 and Fig. 9.

617 **Figure 8.** Time-space diagrams of the longitudinal variability ( $2.2^{\circ}\text{W}$  to  $8.7^{\circ}\text{E}$ ) of three Chl-*a*  
618 associated indices in the Algerian Basin from August to July. The four distances considered (a)  
619 were: the distance of 10 km from the coast (green line), the average maximum distance of the  $0.5$   
620  $\text{mg m}^{-3}$  isopleth, the  $\text{Dist}_{0.5\text{mg}}^{\text{max}}$  (red line), the 80 km maximum distance allowed for  $\text{I}_B$  (gray solid  
621 line), and the middle distance from the northern coastlines (gray dashed line). (b) the distance  
622 from the coast of the Chl-*a* concentration  $\geq 0.5 \text{ mg m}^{-3}$ . (c) the Chl-*a* averaged over the same  
623 area. (d) the integrated biomass index ( $\text{I}_B$ ) from whole basin.

624 **Figure 9.** Time-space diagrams of the alongshore variability ( $2.2^{\circ}\text{W}$   $8.7^{\circ}\text{E}$ ) of the Chl-*a* and  
625 biomass index  $\text{I}_B$ : (a) the Chl-*a* averaged in the coastal area (0-10 km) and (b) in the offshore  
626 area ( $10\text{-Dist}_{0.5\text{mg}}^{\text{max}}$  km), the biomass index ( $\text{I}_B$ ) integrated from (c) the coastline to a maximum  
627 distance of 10 km, and (d) from 10 km to the maximum distance  $\text{Dist}_{0.5\text{mg}}^{\text{max}}$ .

628 **Figure 10.** Average seasonality of the integrated biomass index (orange bars) at three locations :  
629  $1^{\circ}\text{W}$  (a),  $4.5^{\circ}\text{E}$  (b), and  $7.5^{\circ}$  (c) situated outside coastal influences (see Fig. 8a for precise  
630 locations). The climatological values of the Mixed Layer Depth (MLD, blue line), and the Total  
631 Kinetic Energy (TKE, black line) at the same locations are superimposed.

632 **Figure 11.** Longitudinal variability of the offshore (blue line) and coastal (green line) yearly  
633 averages of the integrated biomass index, with the “ $\text{I}_B$  coastal / offshore” ratio superimposed (red



634 line). Areas with high coastal biomass index are highlighted with green rectangles (1-15) by  
635 comparison with Low-Biomass coastal Chl-*a* areas (1-16) left blank. The wadis discharges, the  
636 coast type (sandy coast in yellow and rocky coast in blue), and the size of nearby cities (red dots)  
637 are superimposed. The coast type is deduced from the “Google Map” images (Google Maps,  
638 2021). The wadis names are respectively : (1) Seybouse Wadi, (2) El-Kebir Wadi, (3) Z'Hor  
639 Wadi, (4) El-Kebir Wadi, (5) Soummam Wadi, (6) Bou-Douaou Wadi, (7) El-Hamiz Wadi, (8)  
640 El-Harrach Wadi, (9) Mazafran Wadi, (10) Cheliff Wadi, (11) El-Hammam Wadi.

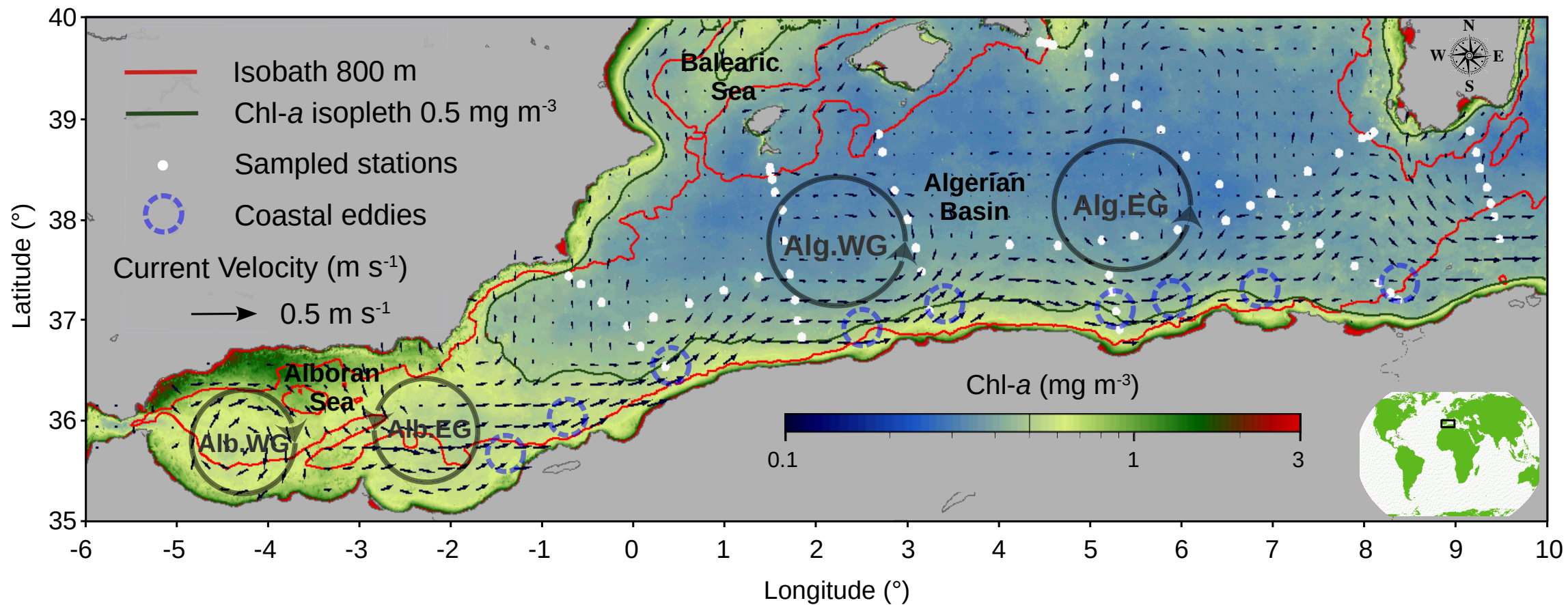
641 **Figure 12.** Seasonal variability of the Mazafran and the El-harrach wadis flows (in  $\text{m}^3 \text{s}^{-1}$ , orange  
642 line) and the corresponding Chl-*a* concentration (green line) averaged at the isobath <50 m from  
643 2003 to 2012 : (a) in the Bou-Ismaïl bay and (b) in the Algiers bay. The maps (a' and b') show  
644 the Chl-*a* yearly average at each location.

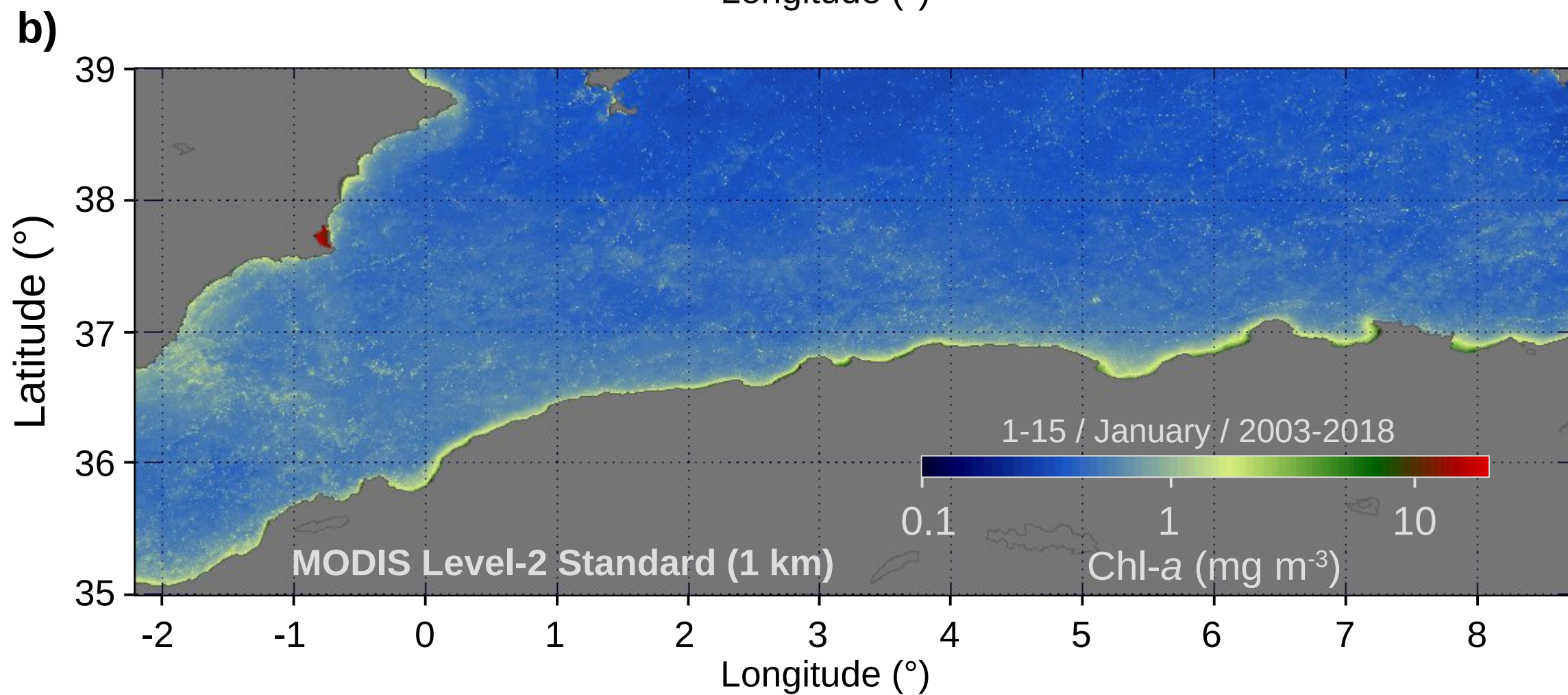
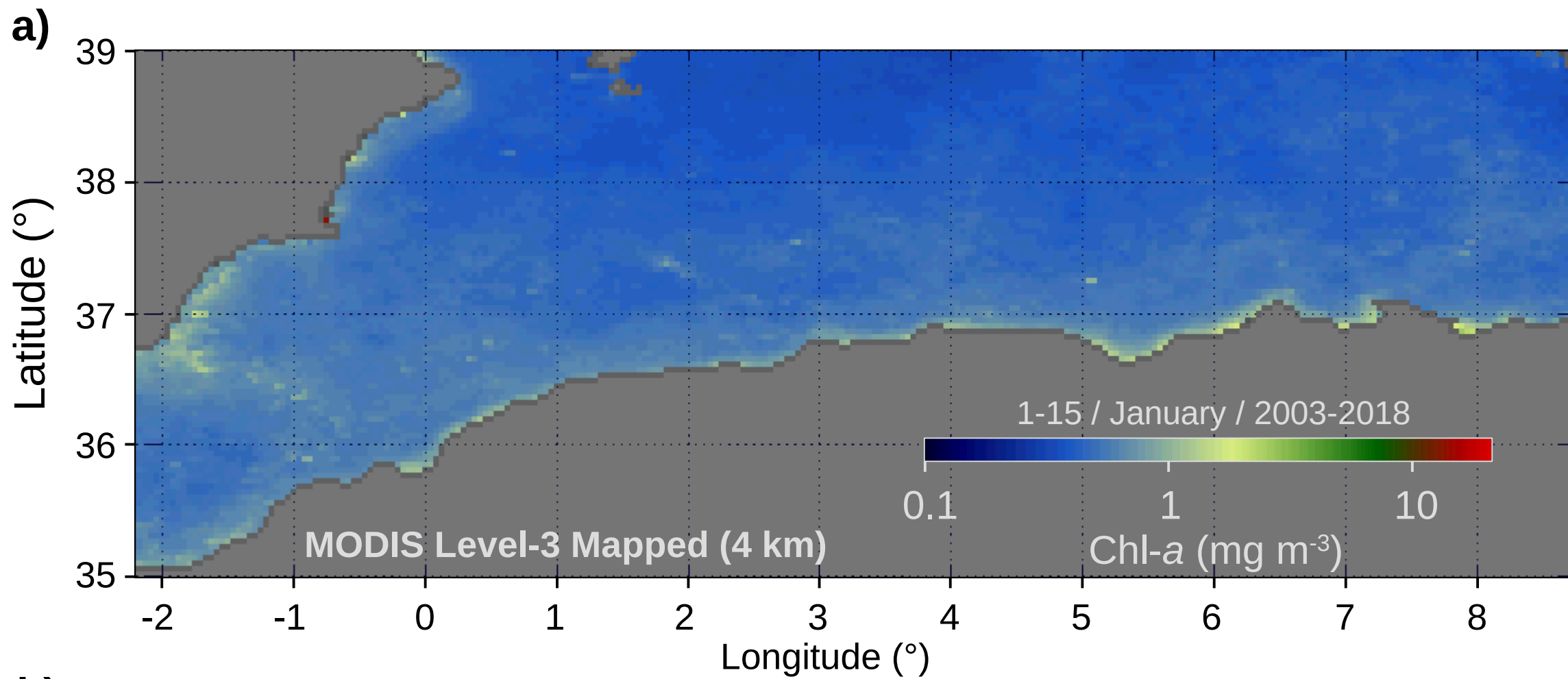
645 **Table 1.** Spatially integrated biomass index ( $I_B$ , in  $\text{g m}^{-2}$ ) seasonally cumulated between 2003  
646 and 2018 for regions of high and low biomass (as displayed in Fig. 11) for the coastal and  
647 offshore domains. The last line shows the relative importance of the High vs Low  $I_B$  index and  
648 the right part of the table shows the ratio between the coastal and offshore domains for both  
649 types of regions.

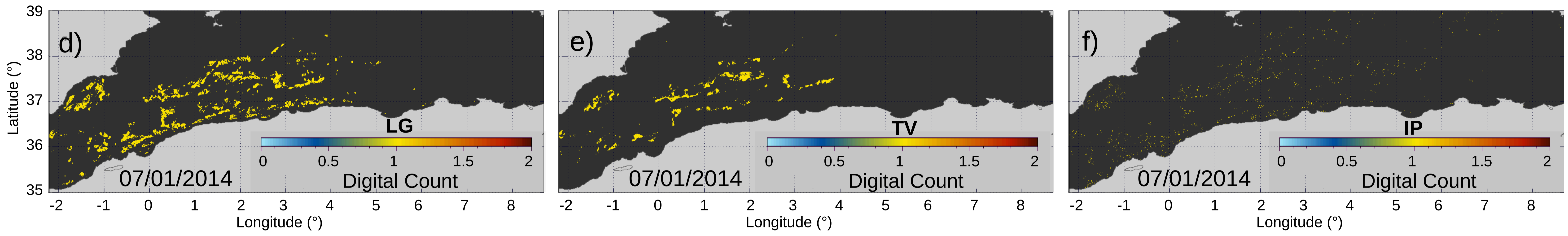
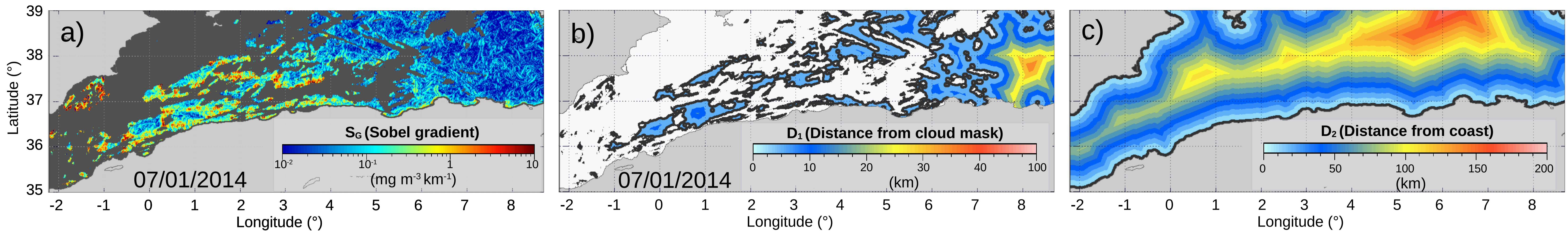
650 **Table 2.** Summary of the characteristics of the LBC (numbered 1-16) and HBC (numbered 1-  
651 15) regions as manually selected in Fig. 11. Both Chl-*a* and  $I_B$  variables were averaged for each  
652 LBC (white rectangles, 1-16) and HBC (green rectangles, 1-15) of Fig. 11. The City size [0-3] is  
653 defined by respectively: 0 (no city), 1: [0 50k] inhabitants (small red dot), 2 [50k- 100k]  
654 (intermediate red dot), 3: >100k (large red dot). The Coast-type is either Sandy(S) or Rocky(R).  
655 The small black dots represent aquaculture cages.

656 **Table 3.** Parameters of the linear models calculated to evaluate the interactions between the  
657 coastal Chl-*a* biomass or the  $I_B$  index and the four aforementioned variables of different of

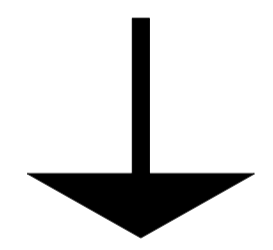
658 coastal enrichment sources. The averages of  $I_B$  and Chl-*a* in winter and summer are calculated  
659 according to the High and the Low-Biomass months shown in Fig. 7a.



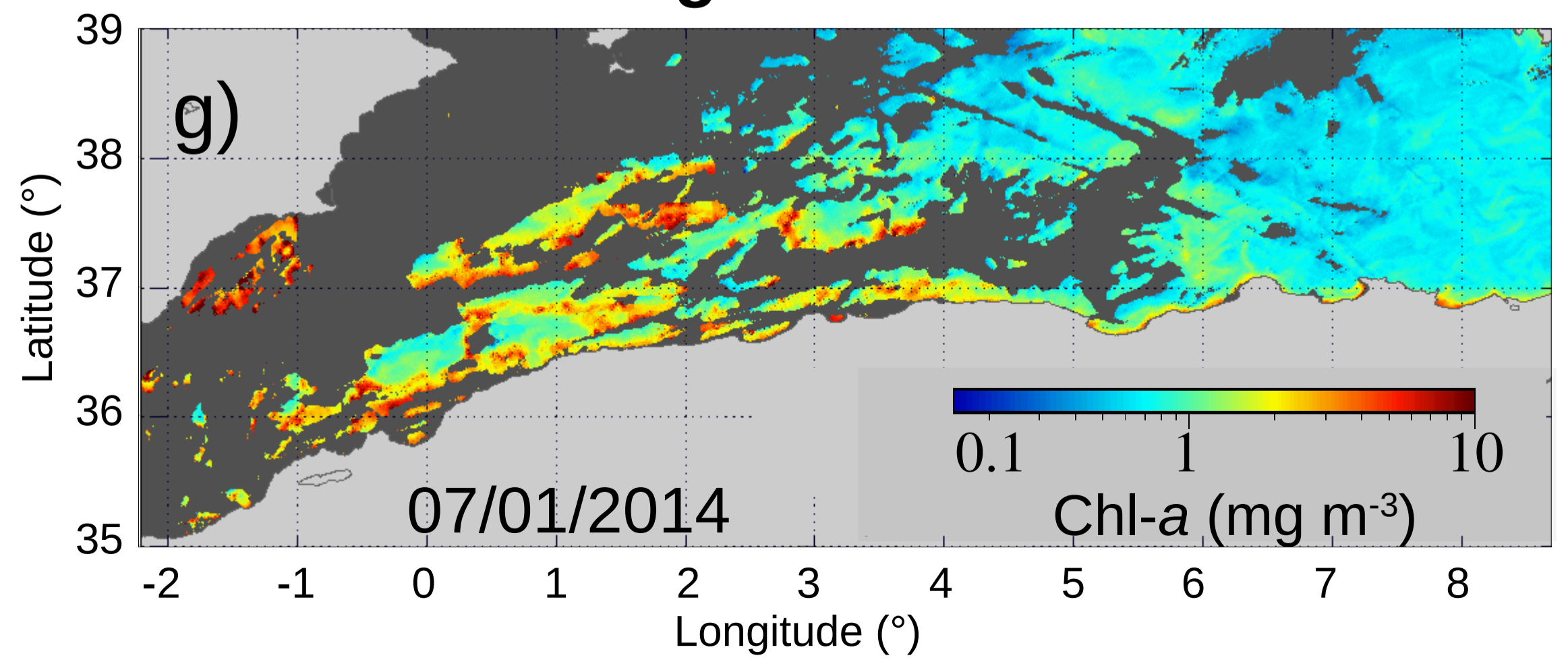




Combination



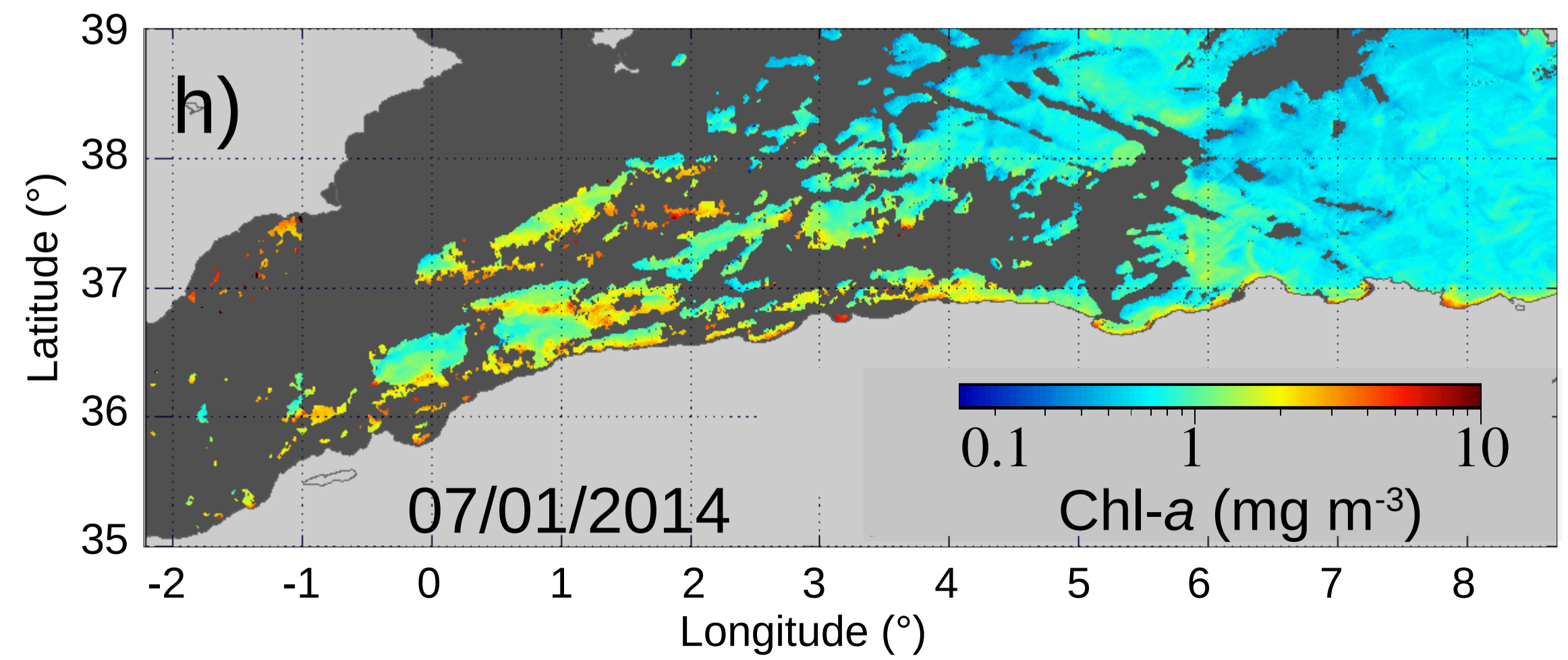
Original data

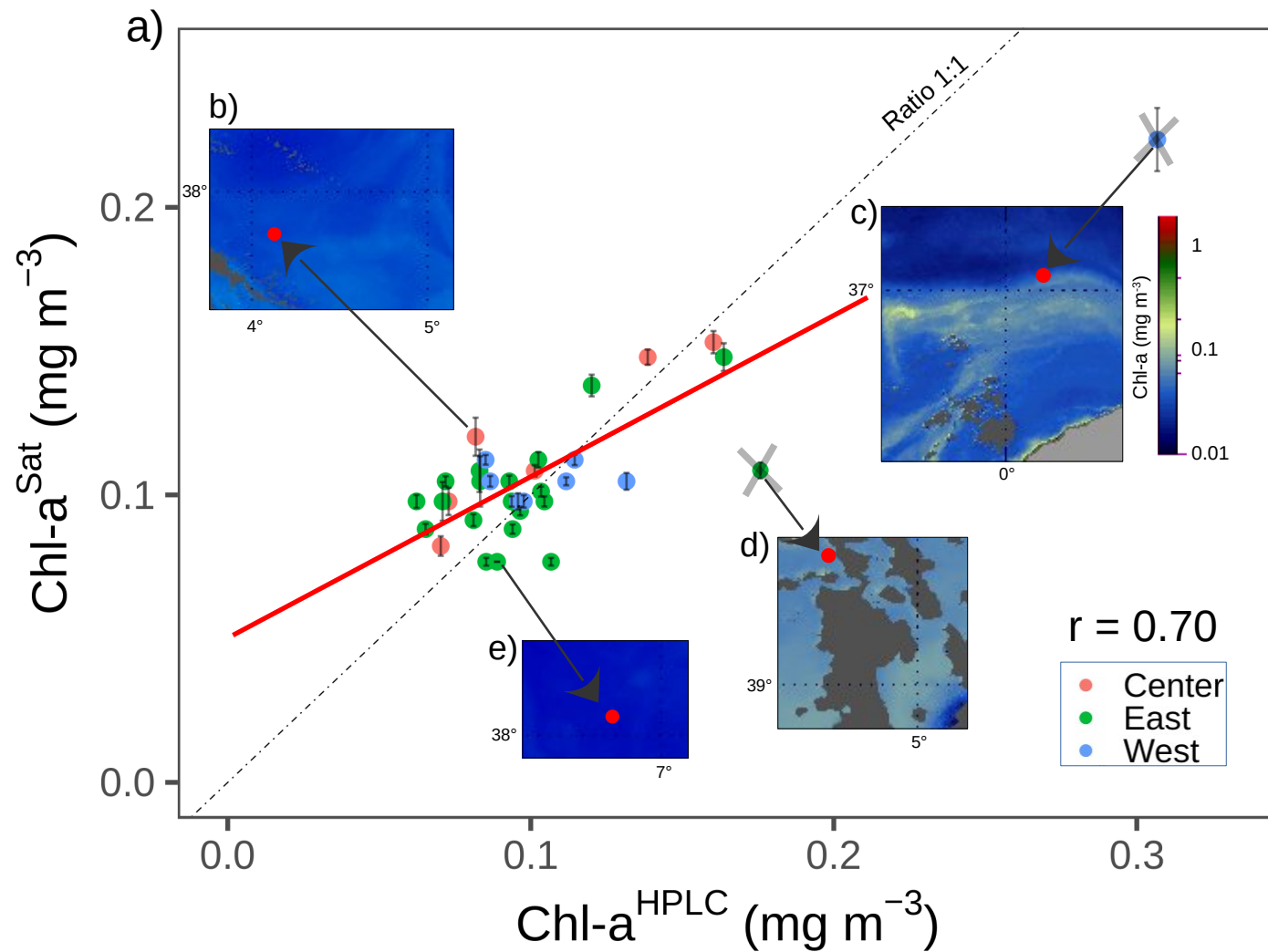


1 day

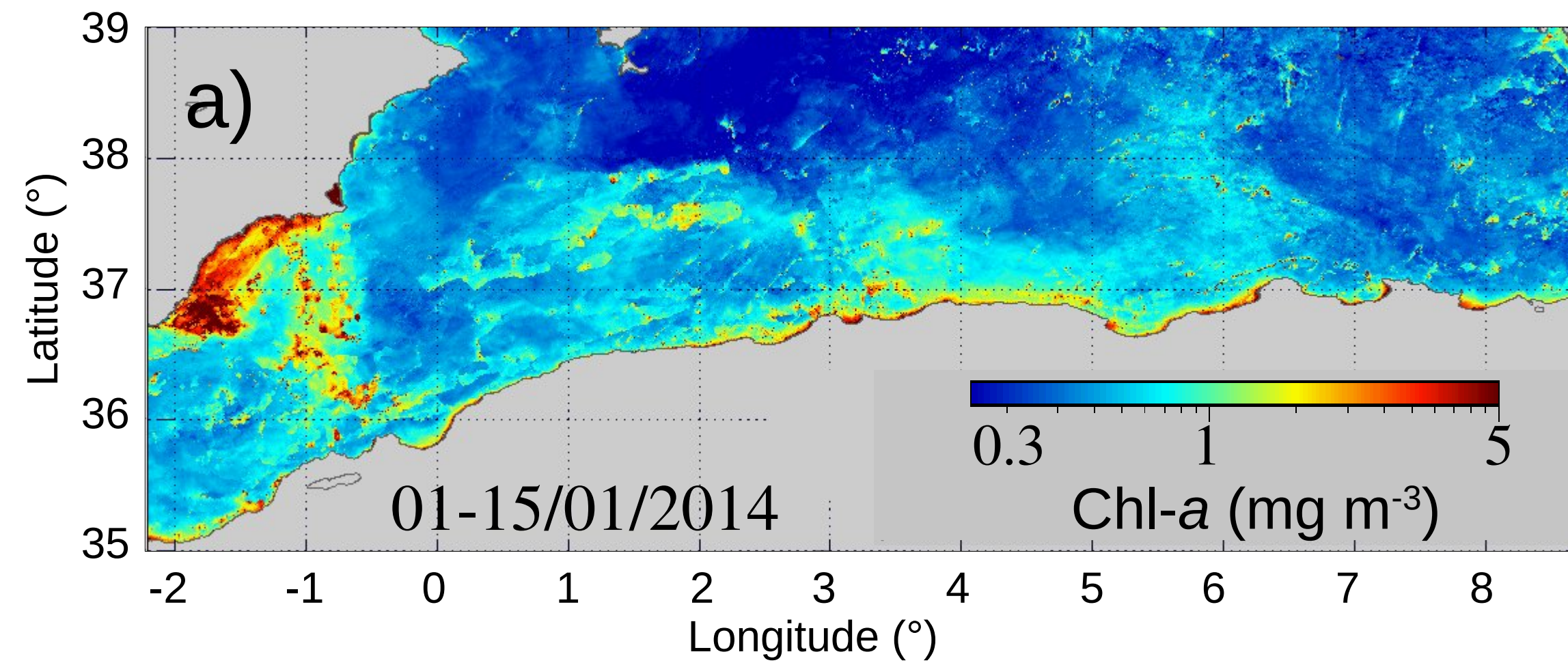


Corrected data

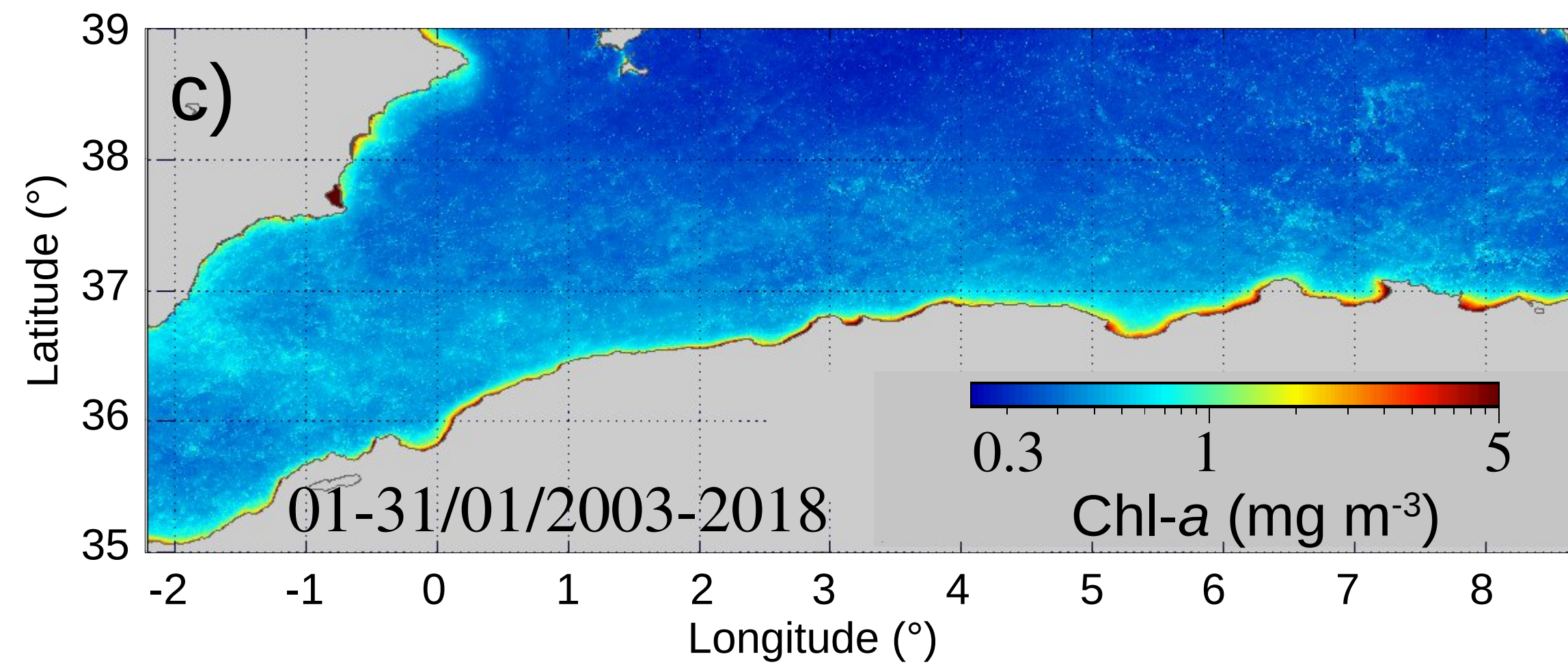
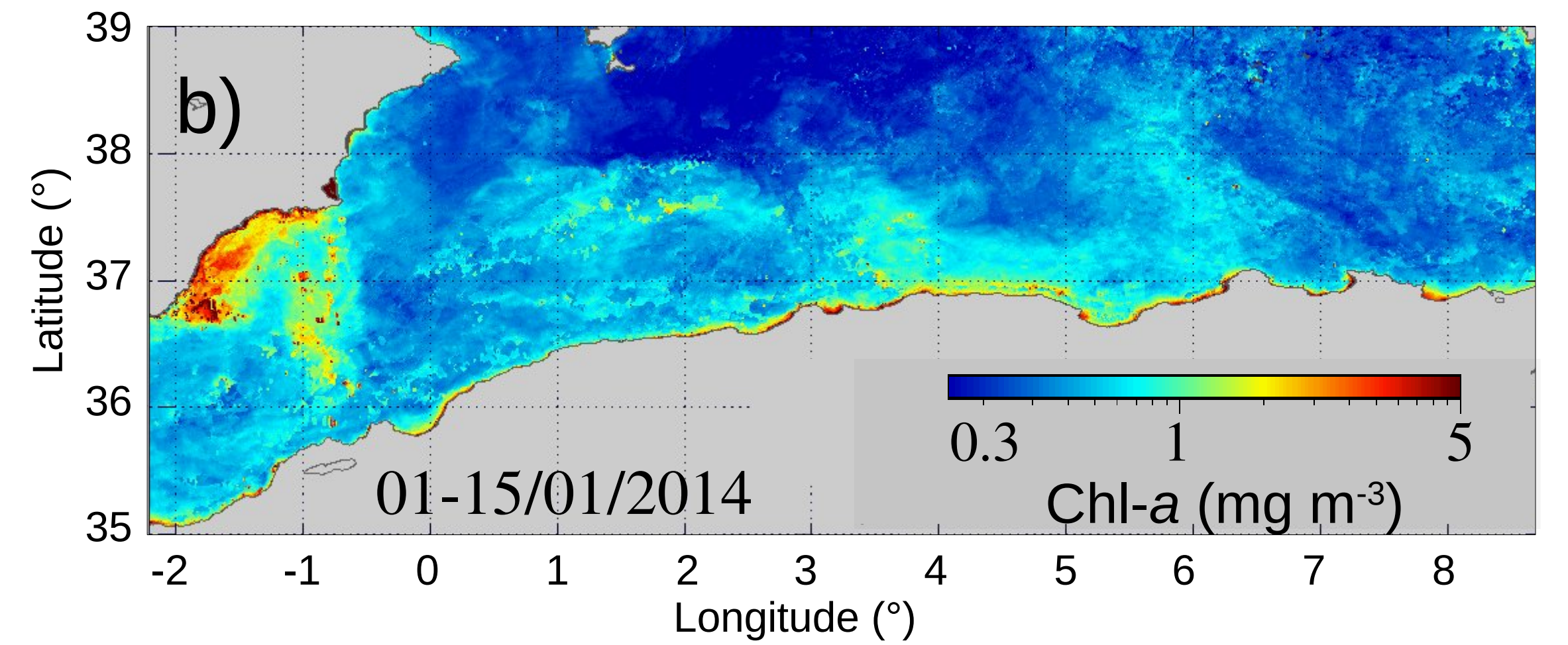




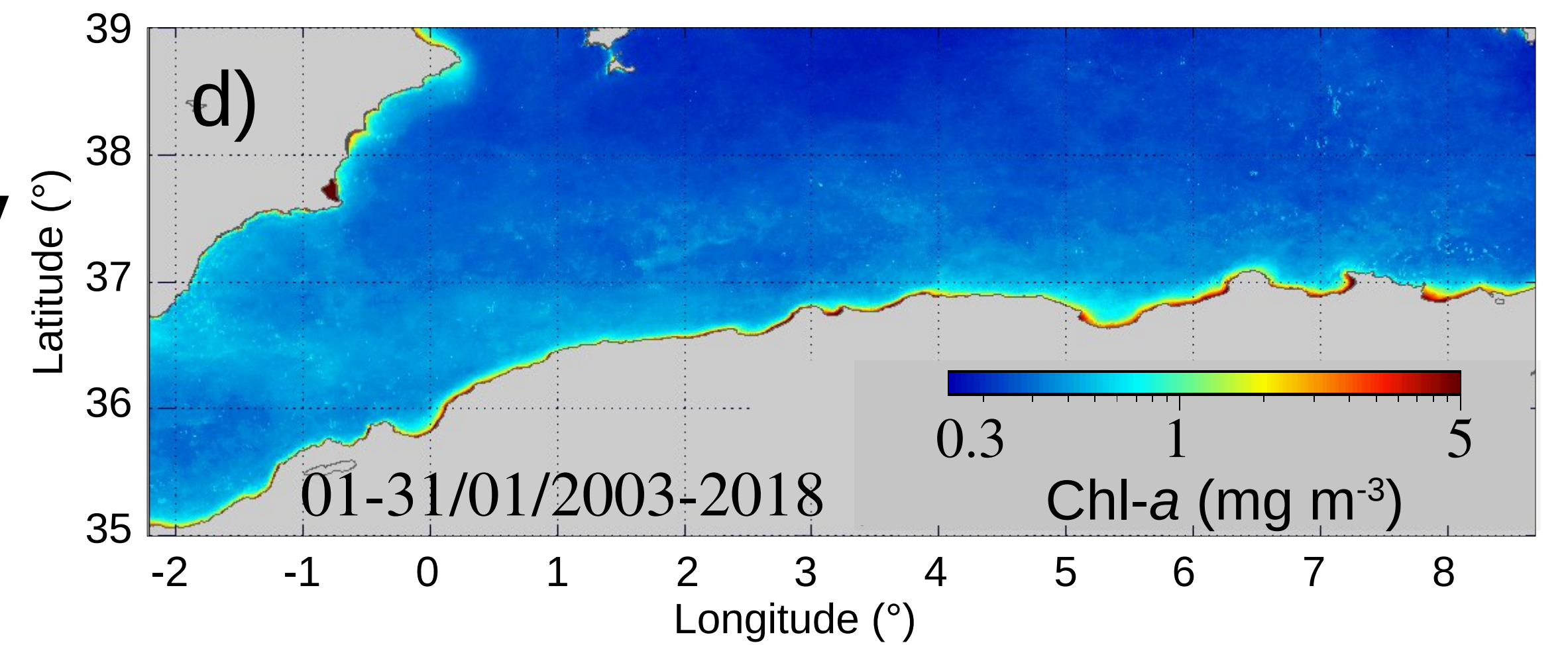
## Original data



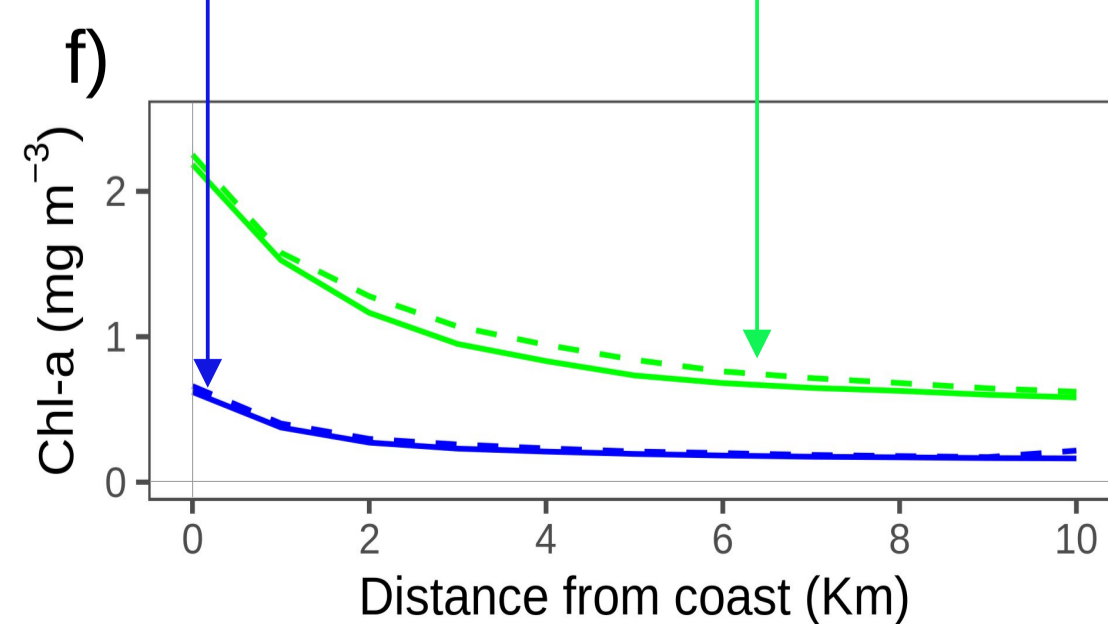
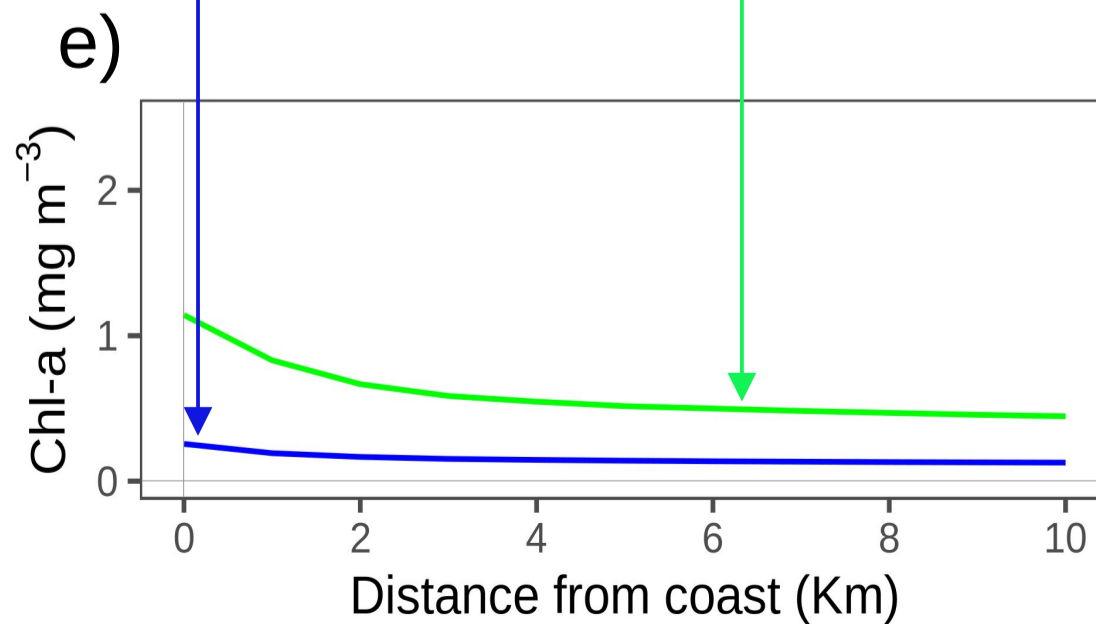
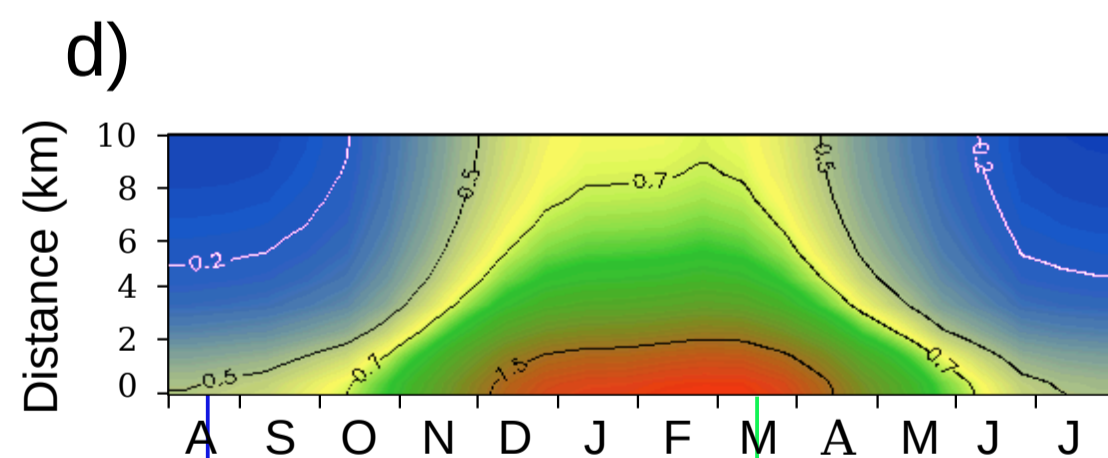
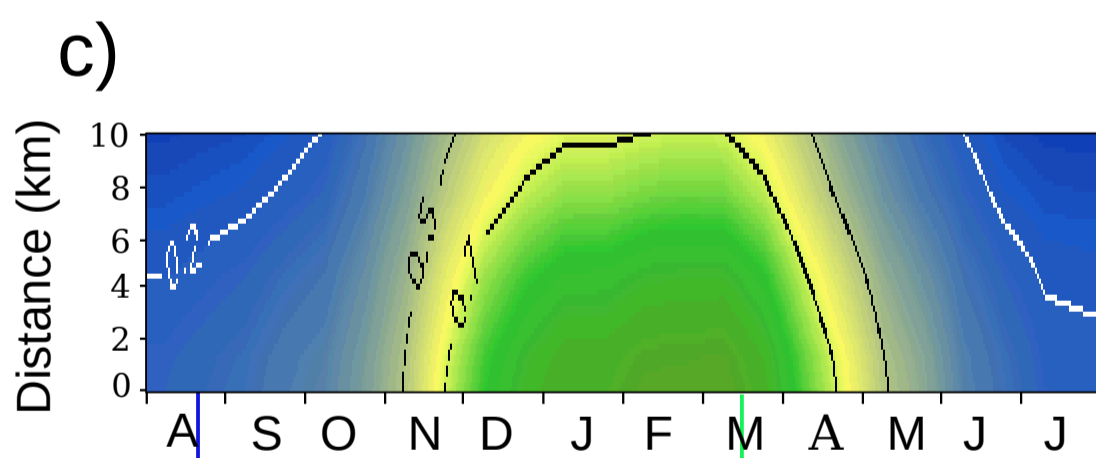
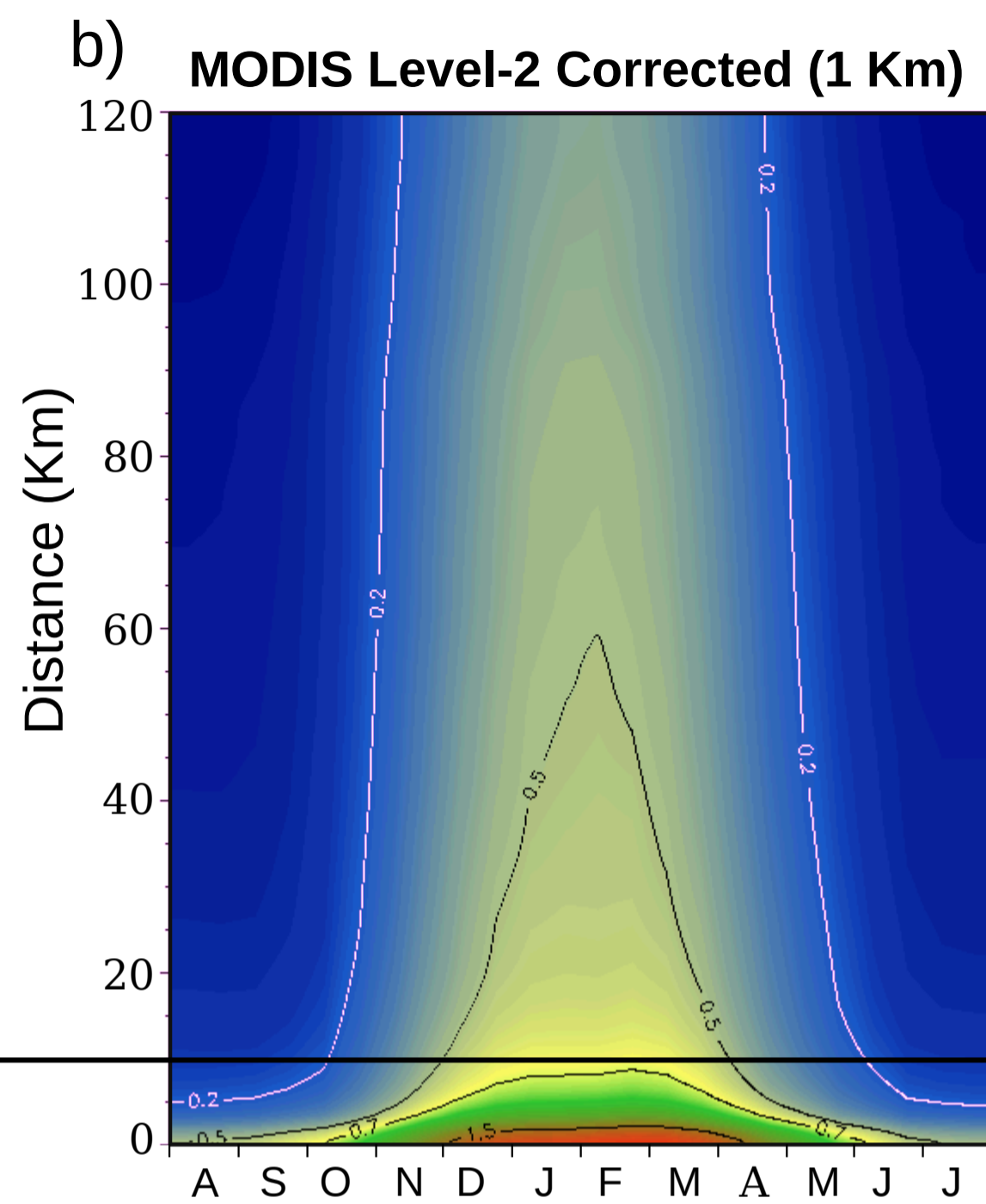
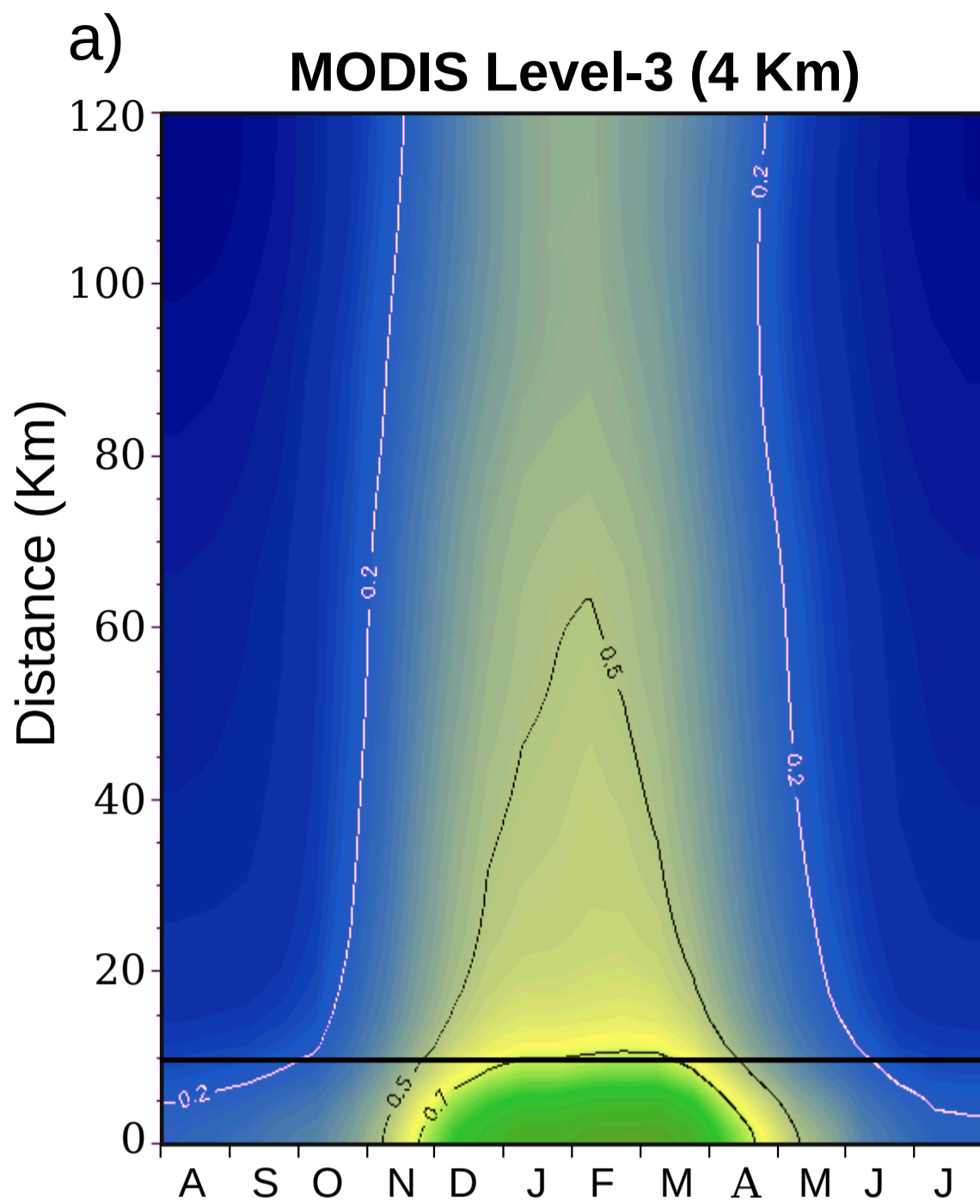
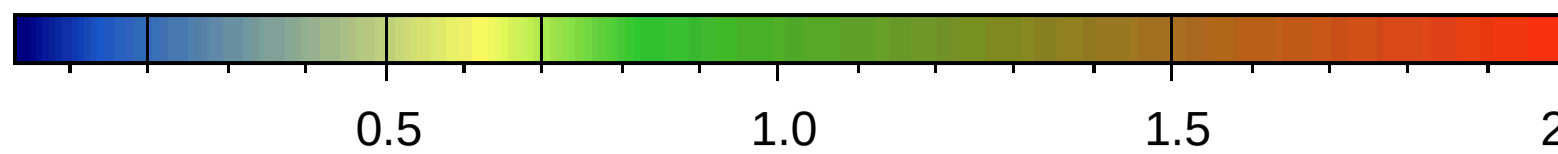
Fortnightly average



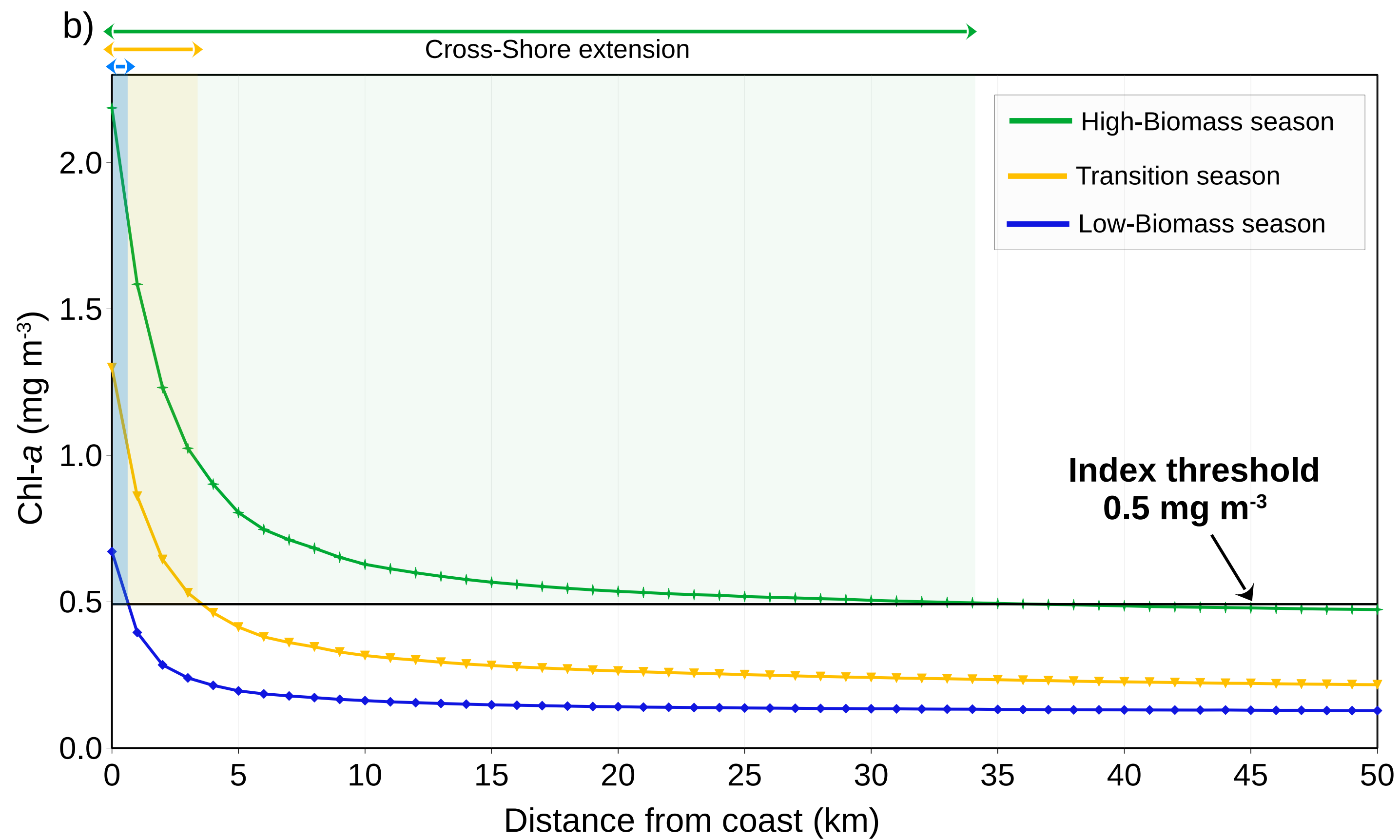
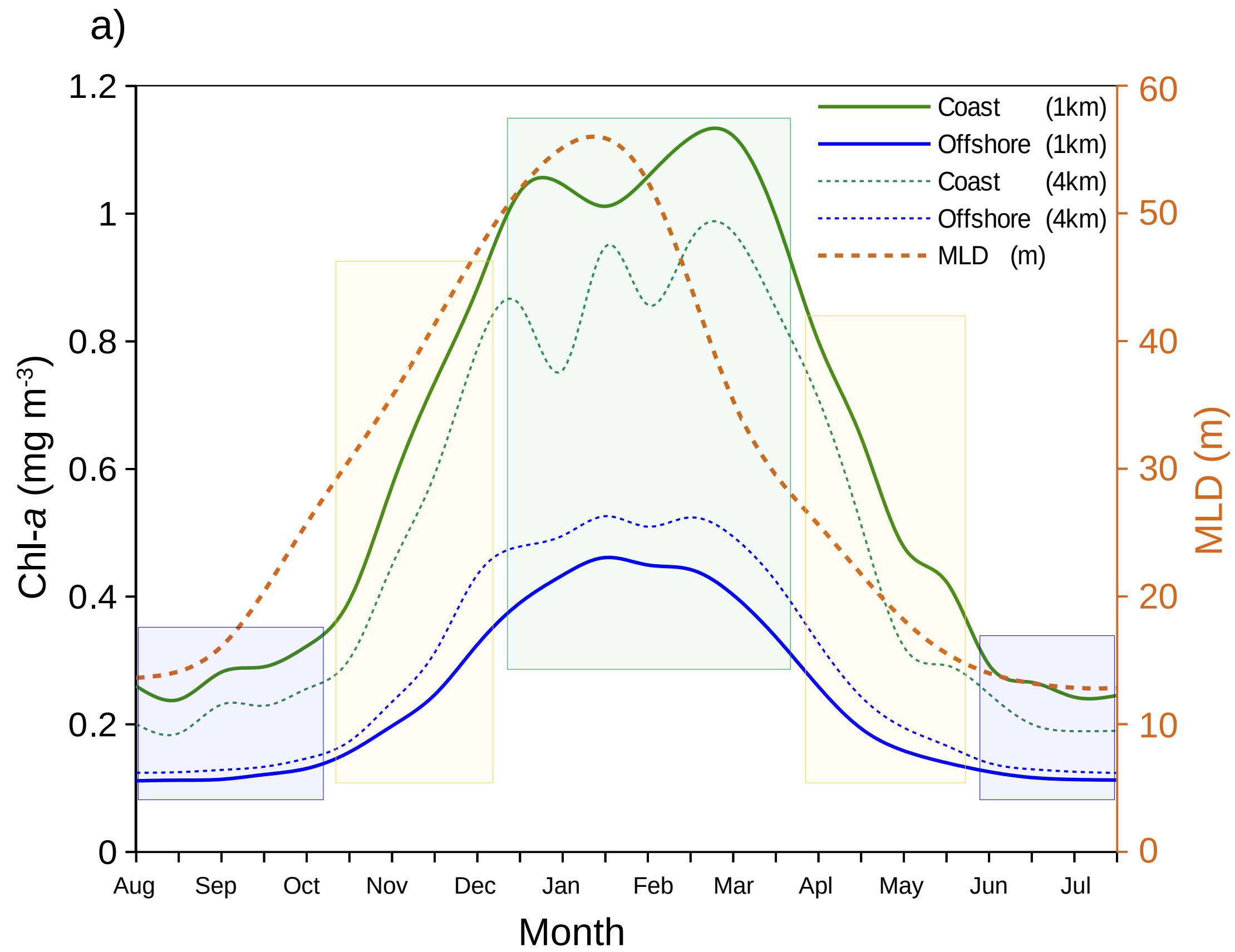
Monthly climatology

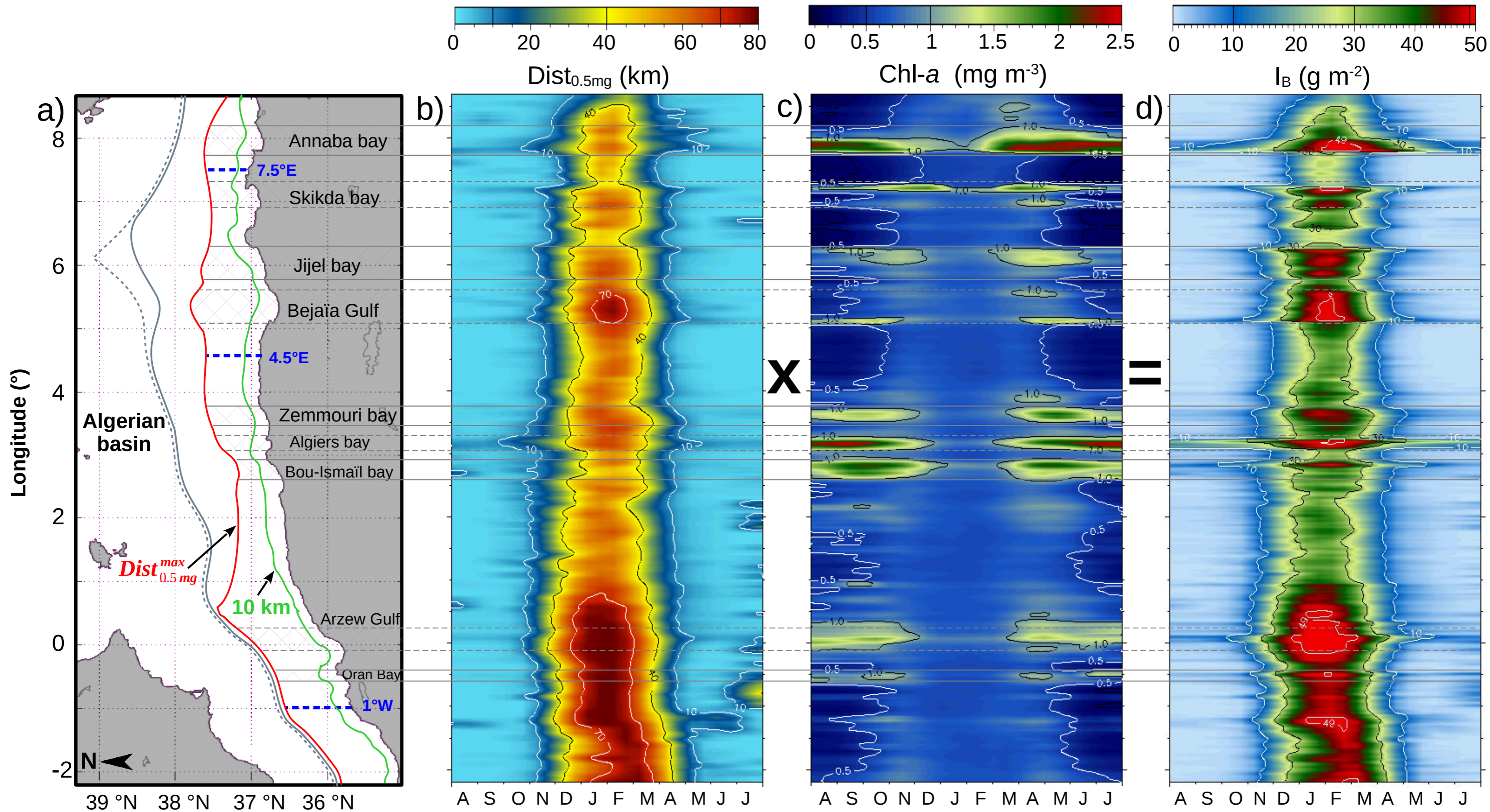


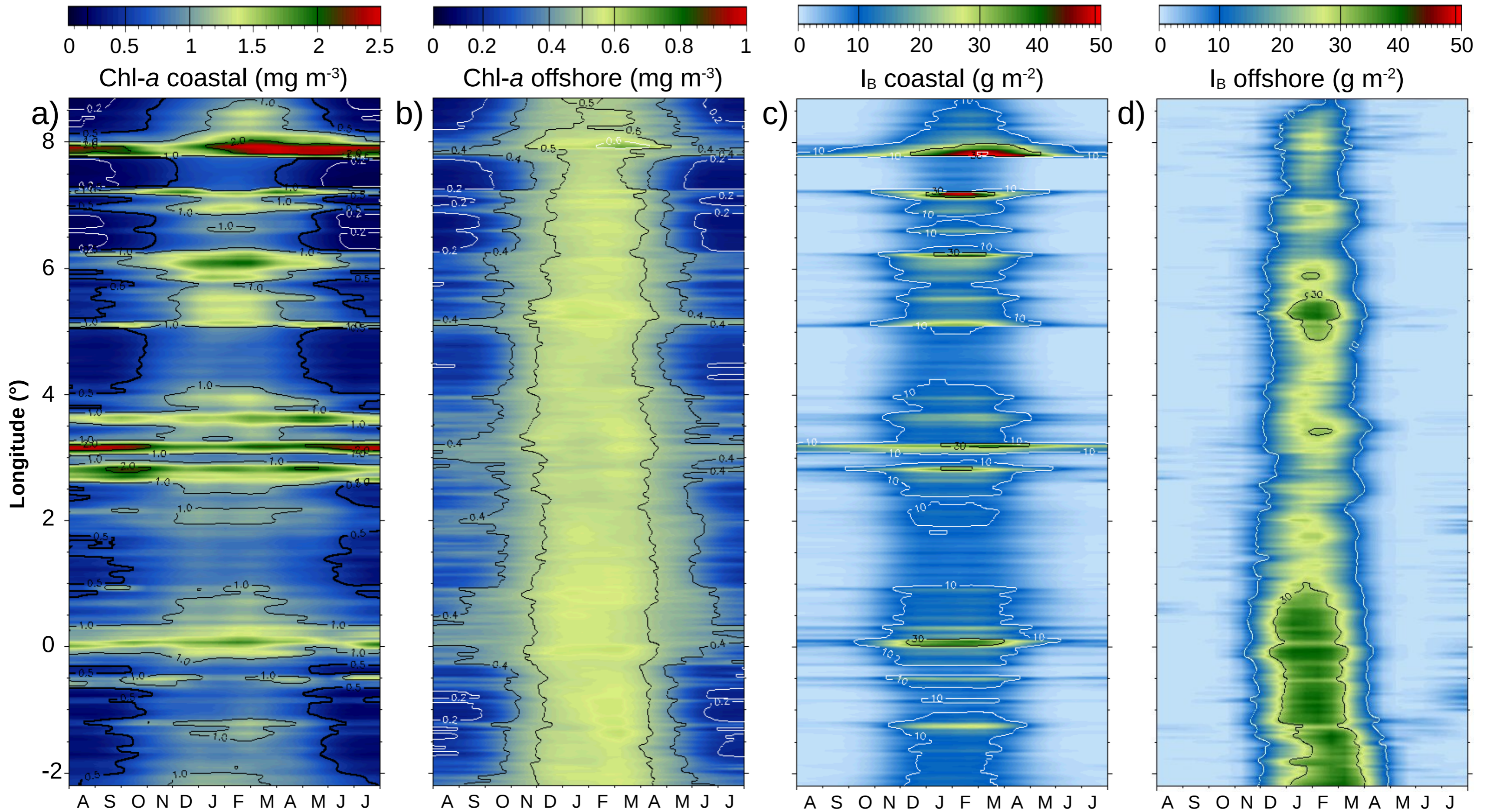
Chl-a ( $\text{mg m}^{-3}$ )

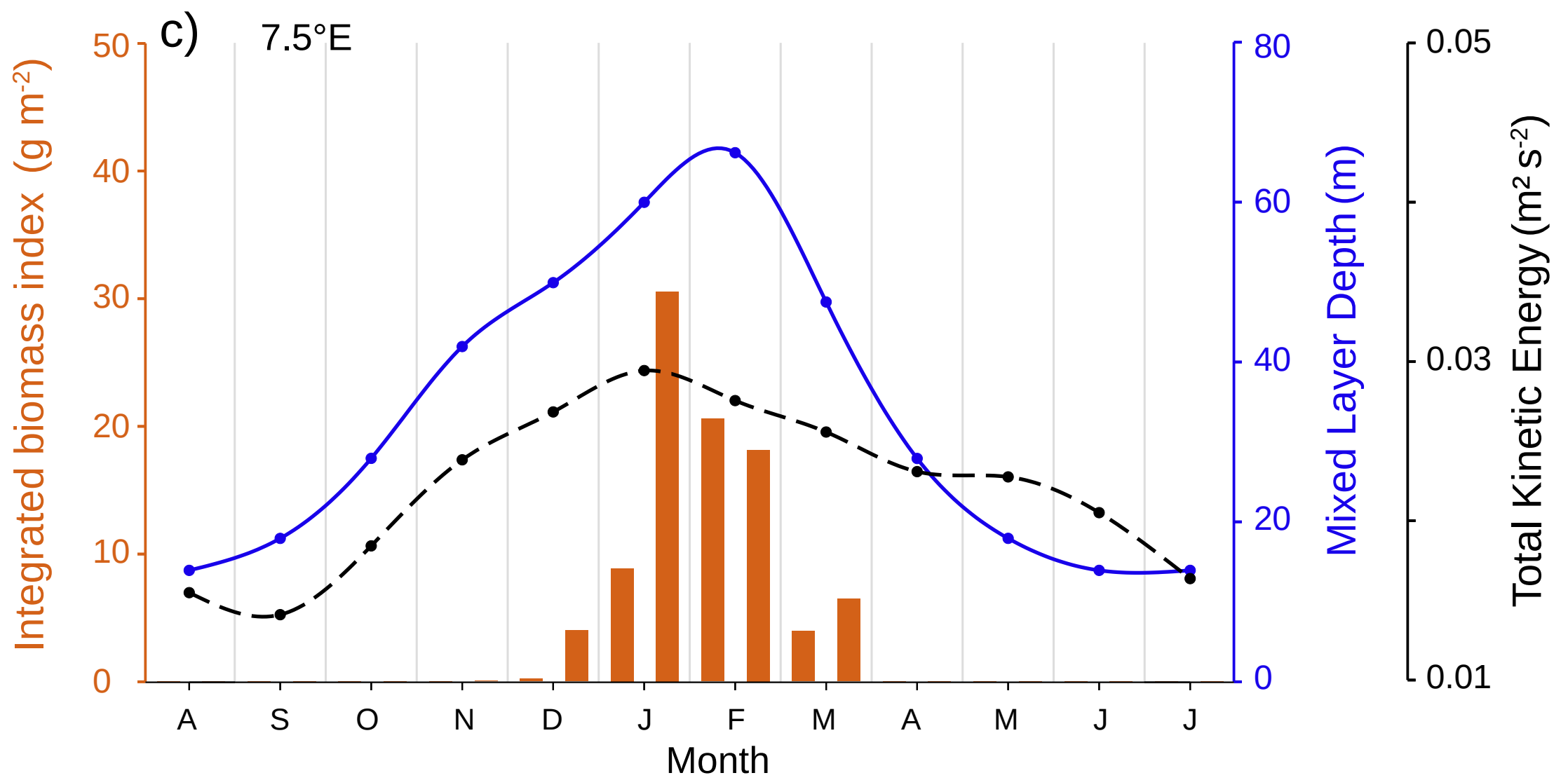
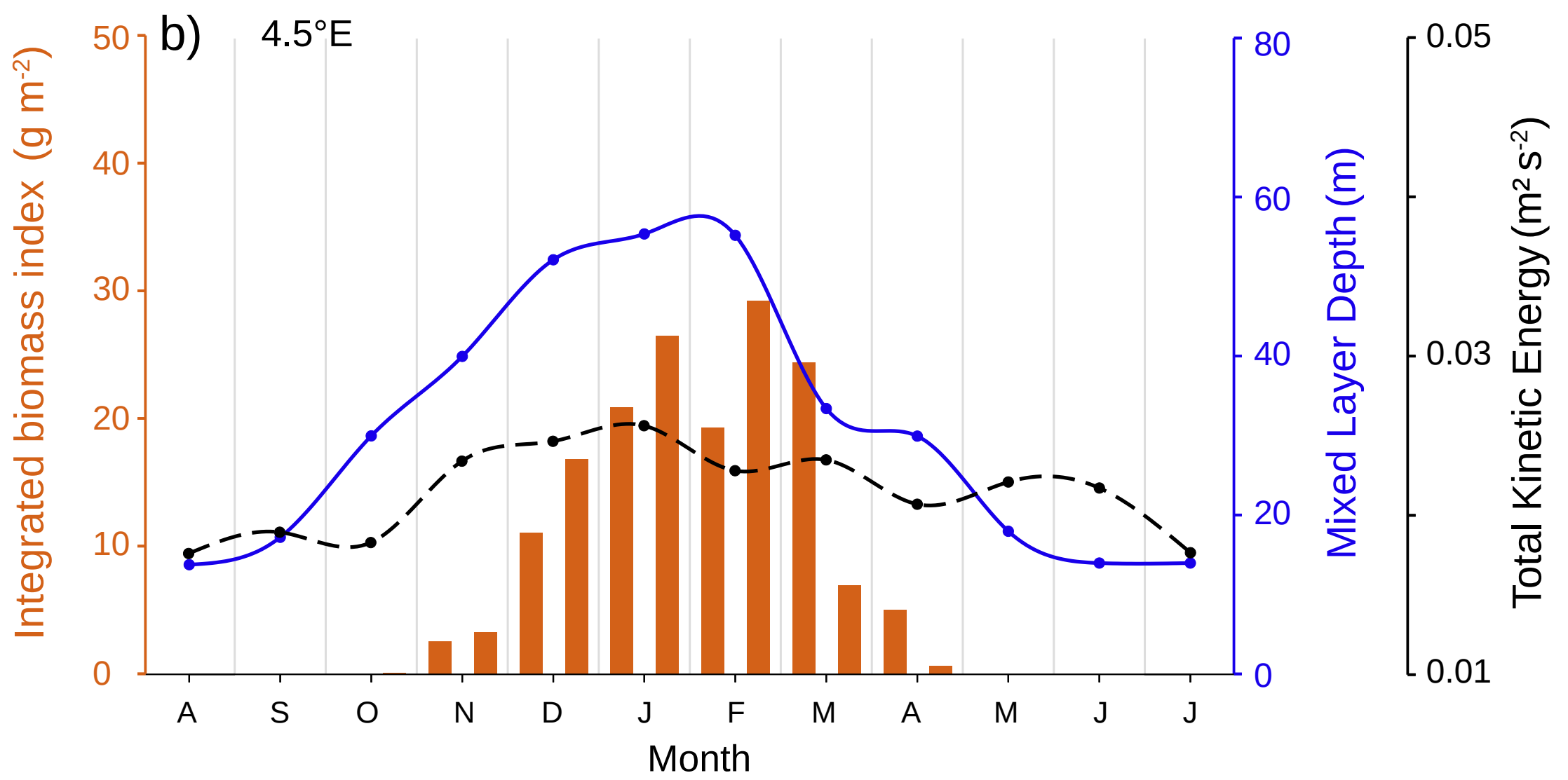
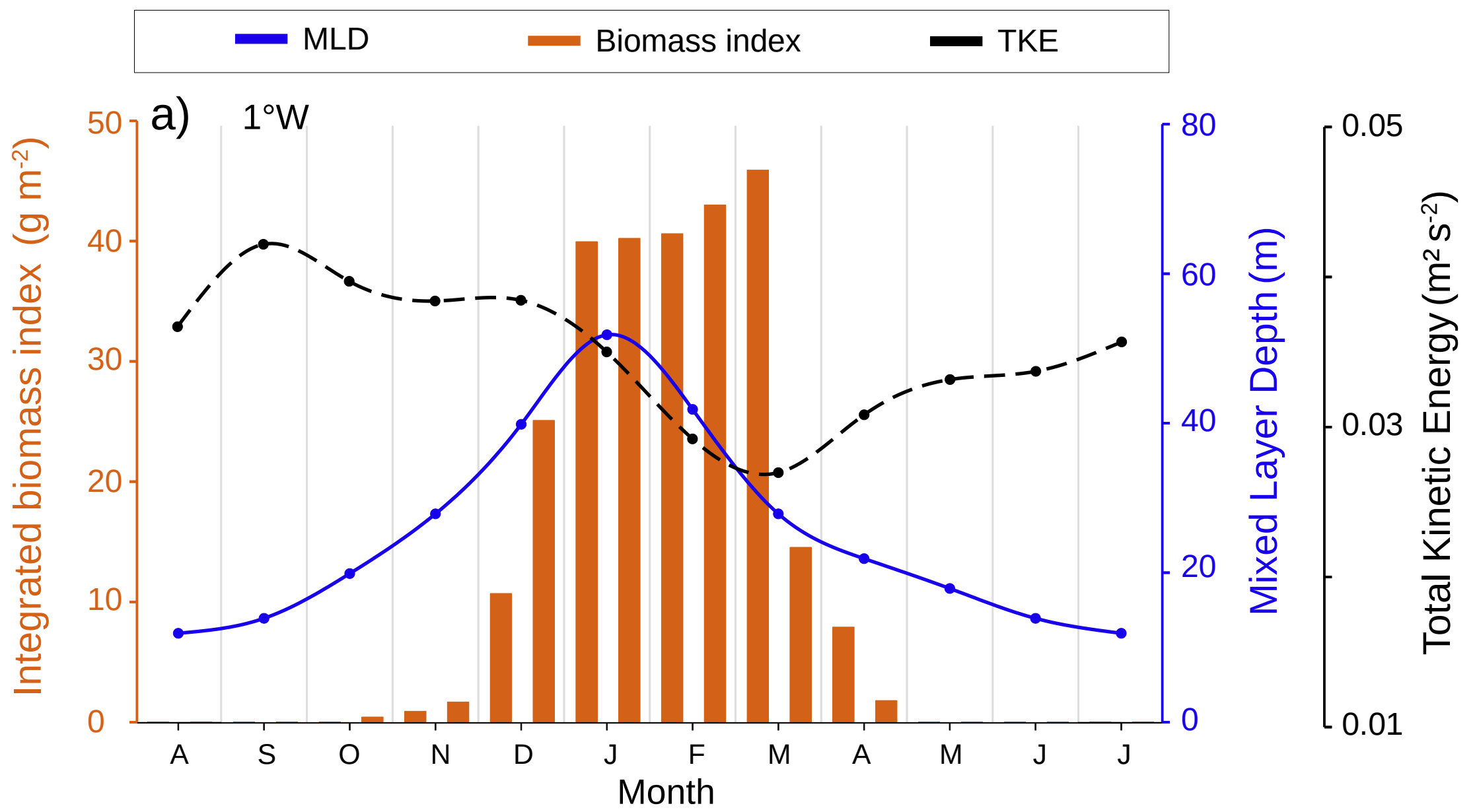


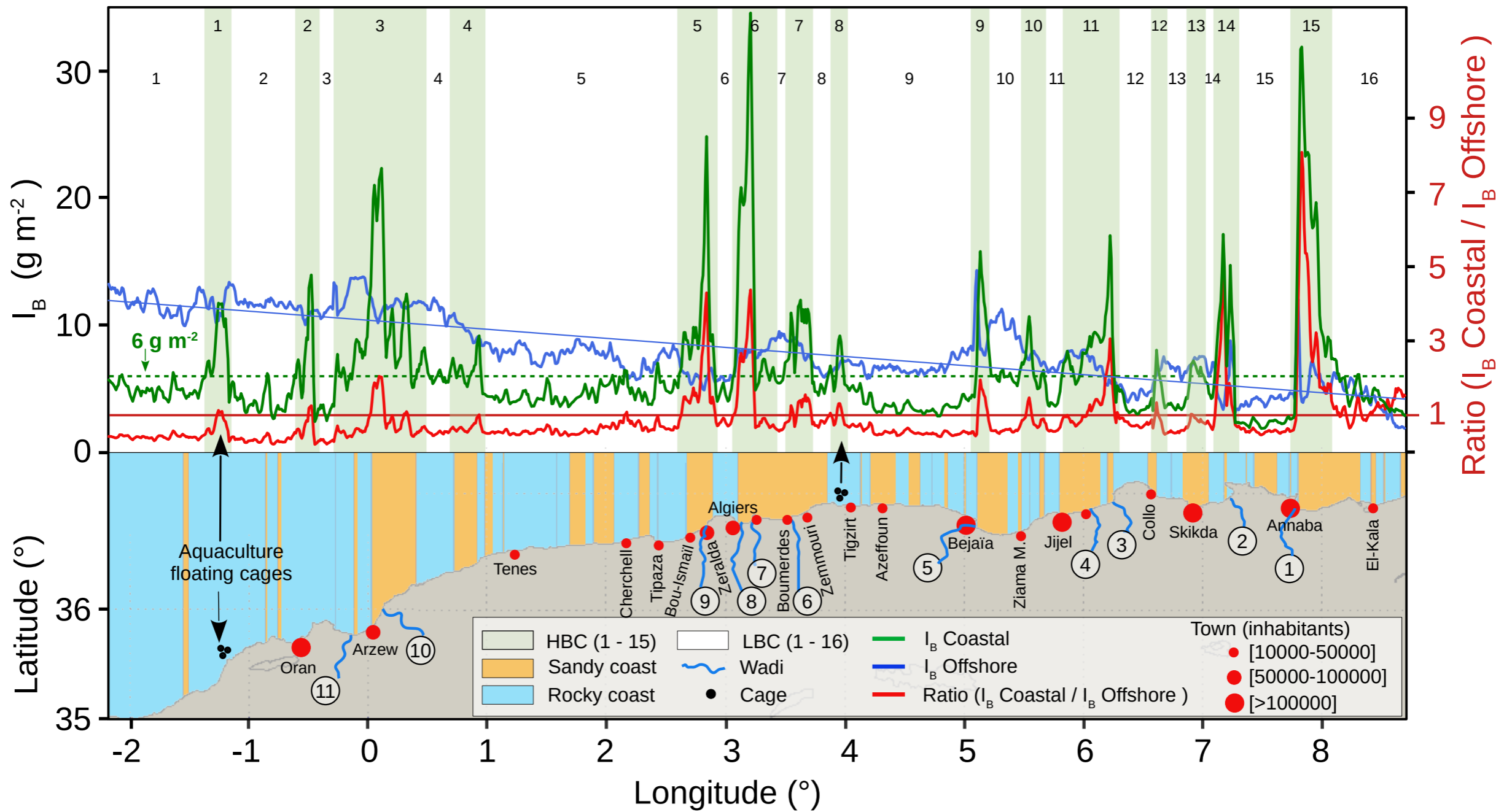


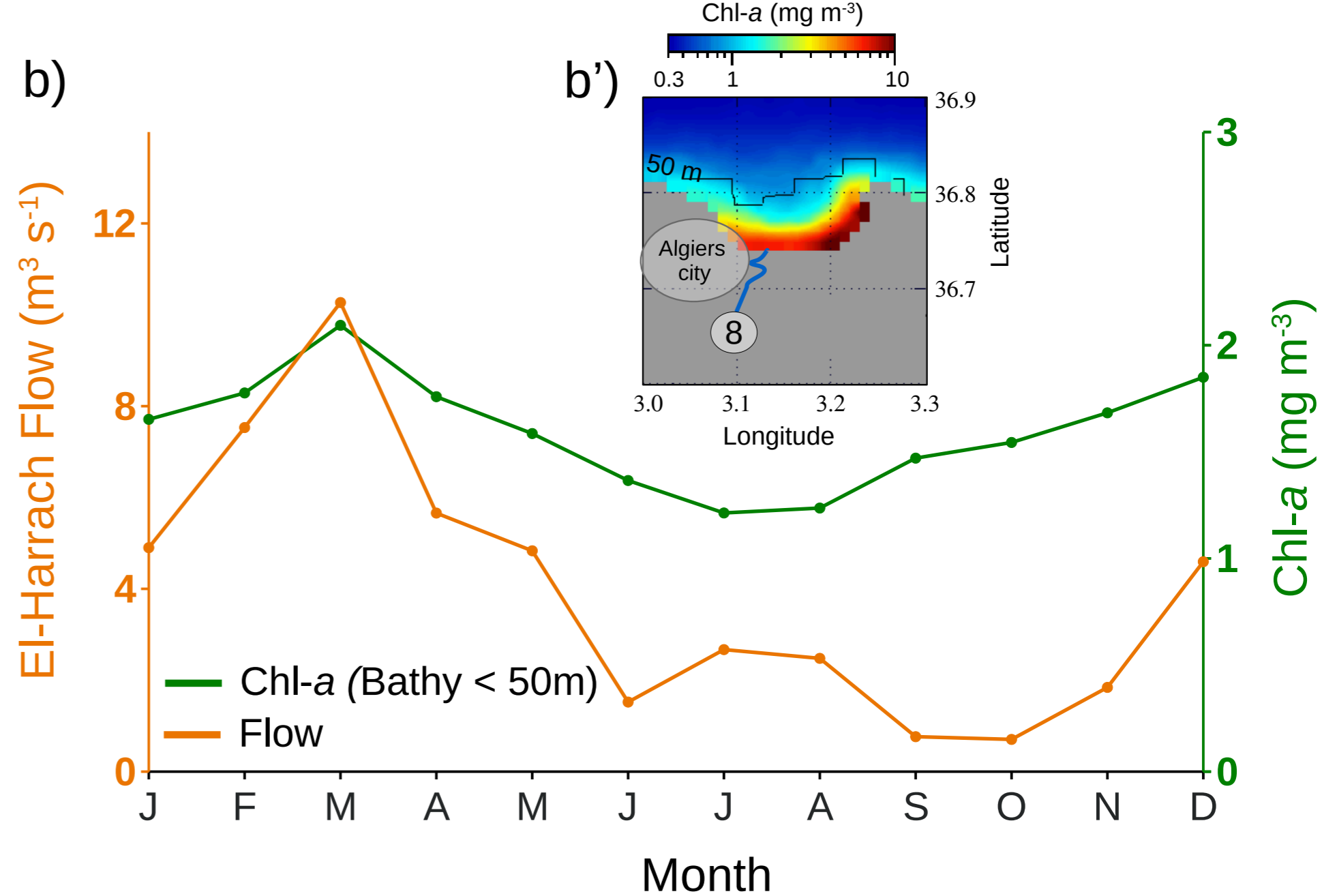
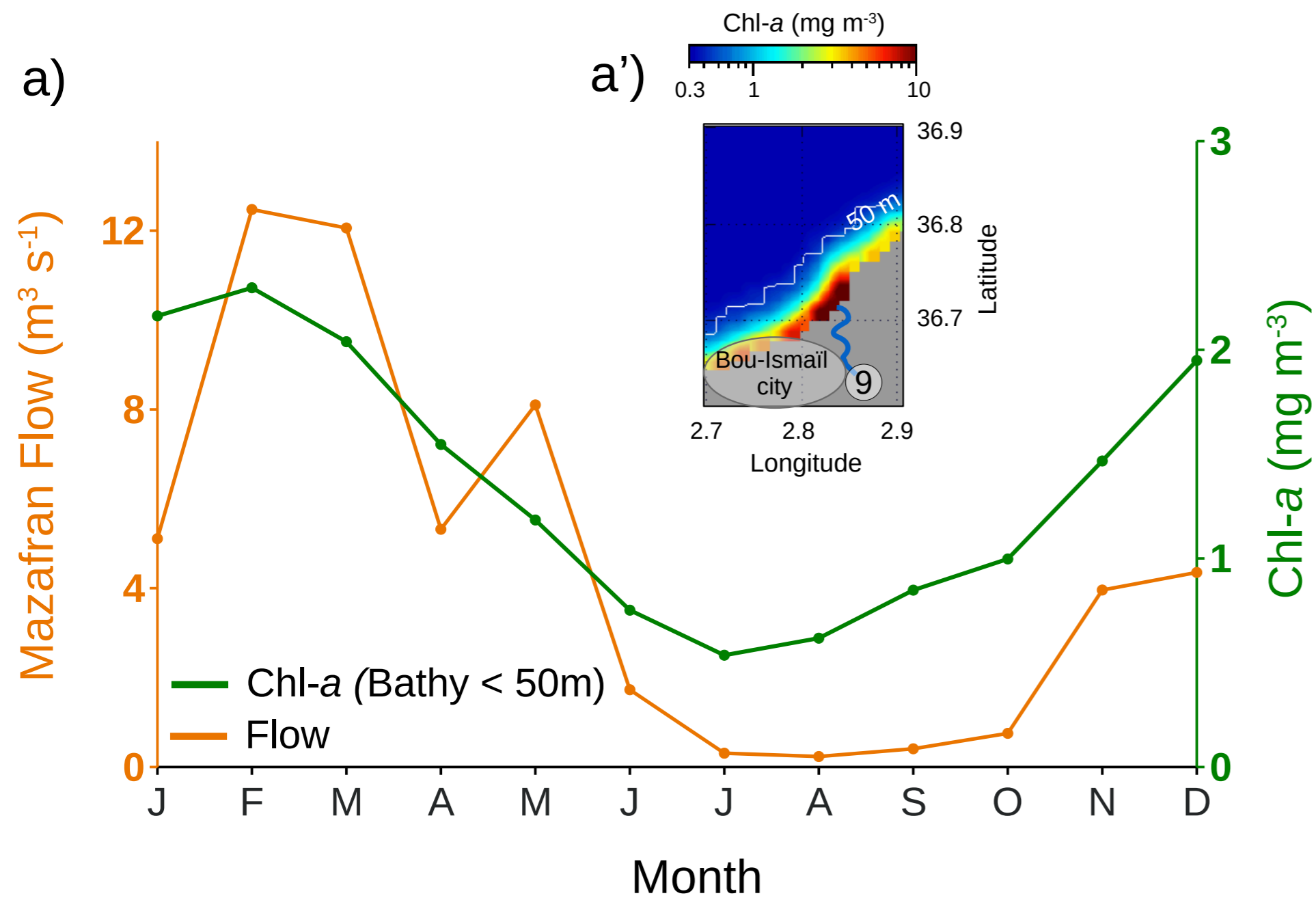












Season	$I_B$ Coastal ( $g\ m^{-2}$ )		$I_B$ Offshore ( $g\ m^{-2}$ )		$I_B$ Coastal / $I_B$ Offshore	
	<i>summer</i>	<i>winter</i>	<i>summer</i>	<i>winter</i>	<i>Jan &amp; Feb</i>	<i>Dec &amp; Mar</i>
LBC	0.7	10.1	0.317	23.2	<b>0.64</b>	<b>2.57</b>
HBC	2.9	18.2	0.626	24.8	<b>0.73</b>	<b>4.14</b>
HBC / LBC (%)	<b>+305%</b>	<b>+80%</b>	<b>+97%</b>	<b>+7%</b>		

LBC n°	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Chl- <i>a</i> (mg m <sup>-3</sup> )	0.67	0.50	0.46	0.76	0.63	0.72	0.69	0.77	0.55	0.76	0.65	0.54	0.54	0.60	0.37	0.61
I <sub>B</sub> (g m <sup>-2</sup> )	4.9	4.0	3.2	5.7	4.6	4.7	5.6	5.3	3.8	5.9	4.8	3.7	3.8	4.5	2.4	4.2
City size [0-3]					●				●							●
Coast-type	R	R	R	R	R	R	S	S	R	S	R	R	R	R	S	S
Wadi presence																
Bay (or gulf)											B					

HBC n°	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Chl- <i>a</i> (mg m <sup>-3</sup> )	0.71	0.75	1.00	0.81	1.11	1.47	1.14	1.11	1.12	0.84	1.04	0.63	0.85	1.22	1.59
I <sub>B</sub> (g m <sup>-2</sup> )	8.6	8.0	9.7	6.5	10.0	13.2	9.4	8.7	11.6	7.9	8.6	7.2	6.5	11.5	14.4
City size [0-3]		●	●		●	●	●		●	●	●	●	●		●
Coast-type	R, ●	R	S	S	S	S	S	R, ●	S	R	S	S	S	R	S
Wadi presence			~~~~~		~~~~~	~~~~~	~~~~~		~~~~~					~~~~~	~~~~~
Bay (or gulf)		B	B		B	B	B		B	B	B		B	B	B



Model	Season	Response variables	Explanatory variables	p-value	Model %
m1	All seasons	[HBC ; LBC]	Coast type	-	67%
			Bay	-	
			Wadi	-	
			City	**	
m2	Winter	Chl-a $\geq$ 1.5	Coast type	-	79%
			Bay	-	
			Wadi	***	
			City	*	
m3	Winter	I <sub>B</sub> $\geq$ 13	Coast type	-	77%
			Bay	**	
			Wadi	-	
			City	**	
m4	Summer	Chl-a $\geq$ 0.5	Coast type	-	57%
			Bay	-	
			Wadi	*	
			City	-	
m5	Summer	I <sub>B</sub> $\geq$ 2.4	Coast type	-	78%
			Bay	*	
			Wadi	*	
			City	-	

Statistical signification of p-value (correlation is significant with p-value < 0.05 (5%)):  
\*\*\* < 0.1 % ; \*\* < 1% ; \* < 5% ; 5% < . < 10% ; - > 10%