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## Open-ocean convection process: A driver of the winter nutrient supply and the spring phytoplankton distribution in the Northwestern Mediterranean Sea

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1 Open-ocean convection process: a driver of the winter nutrient supply and the spring  
2 phytoplankton distribution in the Northwestern Mediterranean Sea

3

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28

29 **Key points**

30 • NW Mediterranean zonation based on nutrients during convection event, and based on  
31 fluorescence profiles during bloom

32 • Convection spatial scale drives the nutrients distribution and mixing depth drives the  
33 nutrient stoichiometry

34 • Winter nutrient supply drives spring phytoplankton distribution while stoichiometry  
35 drives community structure

36

37 **Abstract**

38 This study was a part of the DeWEX project (**Deep Water formation EXperiment**), designed to  
39 better understand the impact of dense water formation on the marine biogeochemical cycles.  
40 Here, nutrient and phytoplankton vertical and horizontal distributions were investigated during a  
41 deep open-ocean convection event and during the following spring bloom in the Northwestern  
42 Mediterranean Sea (NWM). In February 2013, the deep convection event established a surface  
43 nutrient gradient from the center of the deep convection patch to the surrounding mixed and  
44 stratified areas. In the center of the convection area, a slight but significant difference of nitrate,  
45 phosphate and silicate concentrations was observed possibly due to the different volume of deep  
46 waters included in the mixing or to the sediment resuspension occurring where the mixing  
47 reached the bottom. One of this process, or a combination of both, enriched the water column in  
48 silicate and phosphate, and altered significantly the stoichiometry in the center of the deep  
49 convection area. This alteration favored the local development of microphytoplankton in spring,  
50 whereas nanophytoplankton dominated neighboring locations where the convection reached the  
51 deep layer but not the bottom. This study shows that the convection process influences both  
52 winter nutrients distribution and spring phytoplankton distribution and community structure.  
53 Modifications of the convection spatial scale and intensity (i.e. convective mixing depth) is  
54 likely to have strong consequences on phytoplankton community structure and distribution in the  
55 NWM, and thus on the marine food web.

56

57 **Index terms:** 0460 Marine systems, 0470 Nutrients and nutrient cycling, 4273 Physical and  
58 biogeochemical interactions, 4835 Marine inorganic chemistry, 4855 Phytoplankton

59

60 **Keywords:** open-ocean convection, nutrient, stoichiometry, phytoplankton size class,  
61 Northwestern Mediterranean Sea  
62

## 63 1 Introduction

64 The Mediterranean Sea is one of the rare regions in the world where deep convection  
65 events occur [Killworth, 1983]. This process is the primary engine of the thermohaline  
66 circulation and is particularly intense in the Gulf of Lions (Northwestern Mediterranean Sea;  
67 NWM). Despite a high interannual variability [Mermex group, 2011; Herrmann *et al.*, 2013;  
68 Somot *et al.*, 2016], a general pattern is observed with two events of convection in mid- and late  
69 winter (see Houpert *et al.* 2016 for details), given rise to a confined but nonetheless very intense  
70 spring bloom [D'Ortenzio *et al.*, 2009]. The productivity of this spring bloom is controlled by the  
71 nutrient availability, which in turn depends on the meteorological and the hydrological  
72 variabilities [Gačić *et al.*, 2002; Gogou *et al.*, 2014]. Moreover, some studies showed that some  
73 deep convection events, with a mixing reaching the seabed, induced a resuspension of the  
74 sediment [Martin *et al.*, 2010; Stabholz *et al.*, 2013]. The strong vertical mixing associated with  
75 cyclonic submesoscale coherent vortices (SCVs) formed by the deep convection, induce an  
76 upward diffusion of the resuspended particles that produces a turbidity anomaly that can go up  
77 from the bottom to the surface in about a day [Durrieu de Madron *et al.*, 2017]. These cyclonic  
78 SCVs, with an averaged time life of a year, preserve the newly formed deep waters in their core,  
79 as well as a thick nepheloid layer of 1000-2000 m, and spread them possibly throughout the  
80 whole NWM basin [Boss *et al.*, 2016; Damien *et al.*, this issue]. A stimulation of the deep-sea  
81 biological activity was observed, including bioluminescence, thanks to the organic matter supply  
82 coming from the erosion of the deep sediment, and also from the surface export during the  
83 convective mixing, which is then trapped in the new deep waters [Tamburini *et al.*, 2013;  
84 Martini *et al.*, 2014; Severin *et al.*, 2016; Durrieu de Madron *et al.*, 2017]. Some impacts on the  
85 deep biogeochemical budgets should then be expected.

86           Several studies showed that the deep convection process is responsible for the  
87 introduction of a large amount of nutrients in the surface layer [*Marty and Chiavériny*, 2010;  
88 *Estrada et al.*, 2014; *Severin et al.*, 2014; *Ulses et al.*, 2016], which directly influences the  
89 intensity of the spring bloom [*Lévy et al.*, 1998; 1999; *Taylor and Ferrari*, 2011; *Backhaus et al.*,  
90 2003; *Heimbürger et al.*, 2013; *Ulses et al.*, 2016]. A monitoring of the phytoplankton pigments  
91 in March 2005 and from mid-March to September 2009 in the NWM revealed the heterogeneity  
92 of the spring bloom related to the mesoscale processes, and the phytoplankton populations  
93 succession from spring (diatoms and haptophyte) to late summer (dinoflagellate and  
94 coccolithophores) [*Estrada et al.*, 2014]. Another monitoring of the biogeochemistry parameters  
95 at DyFAMed allowed the understanding of the seasonal cycles of nutrient and phytoplanktonic  
96 groups in the Ligurian Sea [*Marty et al.*, 2002]. Nevertheless, the convection area does not  
97 always reach the Ligurian Sea. And in most of the studies, the absence of observations during  
98 both the deep convection mixing and the following spring bloom periods prevents the  
99 establishment of clear correlations between these physical and biological processes.

100           The sampling difficulties in open-ocean encourage the use of satellite ocean color remote  
101 sensing to first identify chlorophyll patterns and then explain them by known physical and  
102 ecological forces [*Longhurst*, 2006]. However, the detailed processes responsible for  
103 phytoplankton distribution remain generally partially identified because of the lack of *in situ*  
104 observations. *D’Ortenzio and Ribera d’Alcalà* [2009] determined 7 bioregions in the entire  
105 Mediterranean Sea with one specific region covering the NW Mediterranean basin, characterized  
106 by an intense bloom in February-March. This bioregion has recently been divided into two  
107 trophic regimes different in bloom timing and intensity: the “High Bloom” bioregion centered in  
108 the deep convection area, and the surrounded “Bloom” bioregion [*Mayot et al.*, 2016]. But the

109 heterogeneity of the hydrological structures of the Mediterranean Sea [Millot, 1999] and the  
110 different light and mixing regimes should produce different subsurface phytoplankton  
111 distributions. These subsurface biological patterns are not observable by remote sensing [Lavigne  
112 *et al.*, 2013; Mignot *et al.*, 2014; Cullen, 2015], although they contribute significantly to the  
113 chlorophyll distribution [Lavigne *et al.*, 2015].

114 Contrary to the well-known general circulation of the NWM [Béthoux *et al.*, 1998a; Send  
115 *et al.*, 1999; Millot and Taupier-Letage, 2005], mesoscale hydrological structures locations,  
116 frequencies and dynamic remain misunderstood. These last years, an intensification of the  
117 studies of these hydrological structures was done thanks to the development of integrated multi-  
118 platforms approaches. The DeWEX project (Deep Water EXperiment) is a multidisciplinary  
119 study composed of two main oceanographic cruises conducted during the deep convection event  
120 in February 2013 and during the following intense spring bloom in April 2013. Supported by  
121 remote sensing and modeling, the DeWEX project aimed to study the hydrological,  
122 biogeochemical and biological processes occurring in the entire NWM basin from the deep  
123 convection event in winter, to the spring phytoplankton bloom.

124 In this study, we assessed the impact of the deep convection on the winter nutrients  
125 supply, and determined the relative contribution of the resulting nutrient distribution on the  
126 phytoplankton distribution and community composition during the spring bloom. Because  
127 several stations have similar physicochemical characteristics, we (i) statistically grouped the  
128 winter stations based on their nitrate, phosphate and silicate concentrations along the water  
129 column during the intense convection event of February 2013. Hydrological structures and others  
130 physical mechanisms were investigated to understand the distribution of the resulted winter  
131 groups. We then (ii) realized a second stations grouping during the spring bloom in April 2013



132 based on their fluorescence profiles to determine the vertical and horizontal phytoplankton  
133 distribution over the NWM. In this section, we also discussed the influence of the winter nutrient  
134 supply and intrinsic spring factors on the resulted phytoplankton distribution. Finally, (iii) the  
135 resulting winter and spring groups, their nutrients and fluorescence characteristics, and the  
136 mechanisms at their origins were used to determine and discuss the spring phytoplankton size  
137 class distribution. The occurrence of some phytoplankton groups in specific area was also  
138 discussed.

139

## 140 **2 Materials and methods**

### 141 2.1 Study area and sampling

142 The DeWEX cruises took place in the Northwestern Mediterranean Sea from the 01 to 22  
143 February (Leg 1) and from the 04 to 26 April (Leg 2) 2013 aboard the R/V *Le Suroît*. A network  
144 of 76 and 100 stations were prospected during Legs 1 and 2 respectively with a Seabird 911Plus  
145 conductivity-temperature-depth (CTD) probe equipped with fluorescence Chelsea Aquatracka  
146 III, and an Underwater Vision Profiler [UVP5; *Picheral et al.*, 2010] providing concentration of  
147 large particles (particles L<sup>-1</sup>) in 27 log-based size classes between 52 µm and 27 mm. At each  
148 "biogeochemical" stations (45 during Leg 1, 59 during Leg 2), water samples were collected at  
149 12 levels along the water column with 12 L Niskin bottles mounted on a SBE 32 Carousel water  
150 sampler.

151

### 152 2.2 Fluorescence processing and calibration

153 Fluorescence profiles were corrected from the non-photochemical quenching (NPQ)  
154 effect, corrected and adjusted to a zero value at depth and calibrated by leg with the *in situ*

155 chlorophyll a concentrations measured by HPLC (High Performance Liquid Chromatography)  
156 according to *Mayot et al.* (2017). See section 2.3 for pigments analyses.

157

### 158 2.3 Nutrients

159 Samples for silicate ( $\text{Si(OH)}_4 \pm 0.05\mu\text{M}$ ), nitrate ( $\text{NO}_3 \pm 0.02\mu\text{M}$ ) and phosphate ( $\text{PO}_4 \pm$   
160  $0.01\mu\text{M}$ ) were immediately stored in 20 ml polyethylene vials at  $-20^\circ\text{C}$  until analysis. At the  
161 laboratory, samples were analyzed by colorimetry on a Seal-Bran-Luebbe autoanalyzer AA3 HR  
162 [*Aminot and K erouel*, 2007].

163

### 164 2.4 Pigments

165 Pigments samples were collected in 3 L dark bottles, immediately filtered on board  
166 through a glass fiber filter (Whatman GF/F 25 mm) sheltered from light and stored in liquid  
167 nitrogen until analysis. At the laboratory, pigments were extracted from filters in 100%  
168 methanol, disrupted by sonication and clarified by filtration through a glass fiber filter (Whatman  
169 GF/F 25 mm). The same day, pigments concentrations were measured by HPLC according to the  
170 method proposed by *Ras et al.* [2008]. Pigments analyses were performed at the SAPIGH  
171 analytical platform of the Laboratory of Oceanography of Villefranche-sur-mer (CNRS-France).

172

### 173 2.5 Phytoplanktonic groups

174 The fraction of chlorophyll *a* (Chl*a*) associated to the 3 phytoplanktonic groups micro-,  
175 nano-, and pico-phytoplankton were determined from the combination of the concentration of 7  
176 key photosynthetic pigments (in  $\mu\text{g L}^{-1}$ ): fucoxanthin (Fuco), peridinin (Perid), 19'-  
177 hexanoyloxyfucoxanthin (Hex), 19'-butanoyloxyfucoxanthin (But), alloxanthin (Allo),

178 chlorophyll *b* + divinyl chlorophyll *b* (TChlb), and zeaxanthin (Zea) according to the equations  
179 proposed by *Uitz et al.* [2006]:

$$f_{\text{micro}} = \frac{1.41[\text{Fuco}] + 1.41[\text{Perid}]}{\text{SDP}_w}$$

$$f_{\text{nano}} = \frac{1.27[\text{Hex} - \text{Fuco}] + 0.35[\text{But} - \text{Fuco}] + 0.60[\text{Allo}]}{\text{SDP}_w}$$

$$f_{\text{pico}} = \frac{1.01[\text{TChlb}] + 0.86[\text{Zea}]}{\text{SDP}_w}$$

180 Where:

$$\begin{aligned} \text{SDP}_w = & 1.41[\text{Fuco}] + 1.41[\text{Perid}] + 1.27[\text{Hex} - \text{Fuco}] + 0.35[\text{But} - \text{Fuco}] + 0.60[\text{Allo}] \\ & + 1.01[\text{TChlb}] + 0.86[\text{Zea}] \end{aligned}$$

181

## 182 2.6 Statistical zonation of the NWM

183 To understand the impact of the open-ocean convection process on the winter nutrient  
184 regime and the spring phytoplankton distribution, we statistically categorized the sampling  
185 stations based on their nutrients characteristics in February 2013, and then based on their  
186 fluorescence profiles (*Chla* proxy) in April 2013. Because the deep convection process impacts  
187 the entire water column, we chose to take into account both surface and deep biogeochemical  
188 properties in February and April to identify the winter nutrients patterns and the variability of the  
189 vertical phytoplankton distribution over the NWM. Moreover, the interannual variability cannot  
190 be assessed by sampling only one month of each key season (February for the winter convection  
191 and April for the spring bloom). Therefore, we chose to name the resulting categories “classes”  
192 and “sub-classes” rather than “bioregions” and “sub-bioregions”, the latter terms being more  
193 relevant for a biogeographical study based on several months of observations.

194 For the winter period, nitrate, phosphate and silicate surface concentrations, as well as  
195 their difference of concentrations between the deep (>700 m) and surface (< 10 m) layers were  
196 selected for the winter NWM zonation in order to take into account the convection effects on the  
197 entire water column. For instance, a concentration difference close to zero means that the mixing  
198 reached at least the nutricline and enriched the above water column with the deep nutrients  
199 stocks. For the spring period, we chose the surface fluorescence, the 0-100 m integrated  
200 fluorescence, and the depth of the fluorescence maximum as parameters for our statistical  
201 analysis. Moreover, the depth of the fluorescence maximum and the 0-100 m integrated  
202 fluorescence allowed us to also take into account the phytoplankton distribution along the water  
203 column depth that can vary according to the hydrology and light regime. For this study, we  
204 decided to use the fluorescence profiles rather than HPLC data because pigments were analyzed  
205 on only 35 stations of the 100 stations with CTD and fluorescence acquisitions.

206 Euclidian distances were calculated between the nutrients parameters of the 45  
207 “biogeochemical” stations for the winter period (Leg 1), and then between the fluorescence  
208 parameters of the 100 stations for the spring period (Leg 2) using the MATLAB R2015 software.  
209 For each period, the resulted Euclidian distances were used to build a hierarchical clustering of  
210 the sampling stations using the agglomeration method of Ward. The resulting clusters were  
211 named “classes” and “sub-classes”, as indicated before, and were used to study the NWM  
212 zonation during the winter and spring 2013.

213

## 214 3 Results

### 215 3.1 Winter NWM zonation and the associated hydrology

216 Three winter classes were distinguished in the NWM from the stations clustering (Leg1  
217 DeWEX, February 2013; Fig. 1A; Fig. S1) based on their nutrients characteristics (Fig. 2; Table  
218 1): “*Stratified*”, “*Mixed*”, and “*Deep convection*” classes.

219 The first open-sea class, named “*Stratified*” (14 green stations, Fig. 1A), regrouped  
220 stations located on the periphery of the northwestern Mediterranean basin. These stations were  
221 marked by a surface layer depleted in nutrient (Fig. 2) and a nutricline around 150 m (Table 1).  
222 Chla distributions showed inversed patterns compared to nutrients with maximum concentrations  
223 in surface layer and generally low concentrations below 150 m. According to the stratified status  
224 of these stations, the three NWM water masses were clearly identified along the water column  
225 (Fig. 3A): AW (Atlantic Waters), LIW (Levantine Intermediate Waters) and WMDW (Western  
226 Mediterranean Deep Waters). Two sub-classes were identified with the hierarchical clustering:  
227 “*Stratified 1*” and “*Stratified 2*”. The differences were mainly based on the 0-100 m integrated  
228 nitrate, phosphate and silicate concentrations significantly lower (student test, p-value < 0.01;  
229 Table 1) in the *Stratified 2* sub-class (6 stations labeled by green circles; Fig. 1A) than in the  
230 *Stratified 1* sub-class (8 stations labeled by green squares; Fig 1A). The sub-classes differences  
231 were also characterized by surface  $\text{NO}_3:\text{PO}_4$  and  $\text{Si}(\text{OH})_4:\text{NO}_3$  ratios significantly higher (student  
232 tests, p-values < 0.001 and <0.01 respectively) in the *Stratified 2* sub-class than in the *Stratified 1*  
233 sub-class ( $43.66 \pm 27.07$  and  $29.73 \pm 3.67$  respectively for  $\text{NO}_3:\text{PO}_4$  and  $1.30 \pm 0.32$ ,  $0.75 \pm 0.08$   
234 respectively for  $\text{Si}(\text{OH})_4:\text{NO}_3$ ; Table 2).

235 The second winter class was constituted of stations surrounded the Northern Current  
236 (NC) as well as in the Balearic Front (BF) and was named “*Mixed*” according to its hydrological

237 properties described hereafter (15 blue stations, Fig. 1A). In general, similar Chla and nutrients  
238 profiles were observed in this class compared to the *Stratified* class (Fig. 2) with some variations  
239 of the nutrients concentrations and stoichiometry (Tables 1 and 2). Stations of this *Mixed* class  
240 were characterized by a mixing of the AW with the upper LIW (Fig. 3B), raising the surface  
241 layer salinity to 38.11 - 38.35 (Table 1) compared to the *Stratified* class with a surface salinity  
242 range of 38.05 – 38.25. Nitrate, phosphate and silicate surface concentrations of the *Mixed* class  
243 were significantly higher than in the *Recently Stratified 1* sub-class (student tests, p-values <  
244 0.01). The hierarchical clustering also resulted in two sub-classes distinct by different locations.  
245 The first sub-class named “*Open-sea Mixed*” was composed of stations situated offshore (10  
246 stations labeled by blue circles, Fig. 1A), in opposition to the second sub-class “*Shelf Mixed*” (5  
247 stations labeled by blue squares, Fig. 1A) composed of shallower stations situated on the  
248 continental slope marked by the absence of WMDW. These sub-classes were characterized by  
249 surface nutrients concentrations and 0-100 m integrated quantities significantly higher (student  
250 tests, p-values < 0.01; Table 1) in the *Open-sea Mixed* sub-class than in the *Shelf Mixed*. Surface  
251  $\text{Si(OH)}_4\text{:NO}_3$  and  $\text{NO}_3\text{:PO}_4$  ratios were also significantly different (student tests, p-values <  
252 0.001 for both) with lower ratios in the *Open-sea Mixed* sub-class than in the *Shelf Mixed*  
253 ( $\text{Si(OH)}_4\text{:NO}_3 = 0.70 \pm 0.04$  and  $0.82 \pm 0.08$  in *Open-sea Mixed* and *Shelf Mixed* respectively,  
254  $\text{NO}_3\text{:PO}_4 = 26.44 \pm 2.93$  and  $32.99 \pm 7.55$  in *Open-sea Mixed* and *Shelf Mixed* respectively;  
255 Table 2).

256 The third class named “*Deep Convection*” was constituted of stations situated in the  
257 center of the northern gyre of the Gulf of Lions, delimited by the NC and the BF (16 red stations,  
258 Fig. 1A). This class was characterized by homogeneous nutrients distribution over the water  
259 column (Table 1 and Fig. 2). Consequently, nutrient concentrations in the 0-100 m surface layer

260 were significantly higher in the *Deep Convection* class than in the *Stratified* and *Mixed* classes  
261 (student tests, p-values < 0.01). Chla concentrations were lower in the surface layer in the *Deep*  
262 *Convection* class compared to the other classes (Fig. 2). In contrast with the *Stratified* and *Mixed*  
263 classes, Chla was also present below the euphotic zone (~100 m in winter) with an average  
264 concentration of ~0.04  $\mu\text{g L}^{-1}$  between 500 m and the bottom, while its concentration was null at  
265 these depths in the 2 others *Stratified* and *Mixed* classes (Fig. 2). Only one homogeneous water  
266 mass was observed on the  $\Theta/S$  diagram (Fig. 3C; Table 1), a characteristic of the convective  
267 water mass. Two sub-classes were also identified in the *Deep Convection* class. In the first sub-  
268 class named “*WMDW Deep Convection*” (9 stations labeled by red circles; Fig. 1A), nutrients  
269 concentrations were slightly but significantly lower (student tests, p-values < 0.05) than in the  
270 second sub-class named “*Bottom Deep Convection*” (7 stations labeled by red squares; Fig. 1A).  
271 Surface  $\text{Si(OH)}_4\text{:NO}_3$  were slightly but significantly higher (student test, p-value < 0.001) in the  
272 *Bottom Deep Convection* sub-class ( $0.93 \pm 0.01$ ; Table 2) than in the *WMDW Deep Convection*  
273 ( $0.80 \pm 0.06$ ; Table 2), while it was the contrary for the  $\text{NO}_3\text{:PO}_4$  ratios, which was significantly  
274 higher (student test, p-value < 0.001) in the *WMDW Deep Convection* sub-class ( $22.34 \pm 0.95$ )  
275 than in the *Bottom Deep Convection* sub-class ( $21.22 \pm 0.71$ ). Moreover, salinity and temperature  
276 of the *WMDW Deep Convection* were slightly higher, and significantly for the temperature  
277 (student test, p-value < 0.05), than those of *Bottom Deep Convection* (38.50 and 38.49  
278 respectively for the salinity, 13.09 and 12.05°C respectively for the temperature; Fig 3C; Table  
279 1). This was due to the smaller volume of WMDW involved in the mixing at the *WMDW Deep*  
280 *convection* sub-class, which led to a noticeable higher temperature because of the larger LIW  
281 contribution compared to the *Bottom Deep Convection* sub-class.

282

### 283 3.2 Spring NWM zonation based on vertical fluorescence profiles

284 Three spring classes were distinguished in the NWM from the stations clustering (Leg2  
285 DeWEX, April 2013; Fig. 1B; Fig. S2) based on their fluorescence profiles (Fig. 4): “*Surface*  
286 *Bloom*”, “*Deep Chlorophyll Maximum*” (*DCM*), and “*Intermediate*” classes. Phytoplankton size  
287 class distribution was then determined in each of the spring bloom class (Fig. 5).

288 The first spring class (25 red stations, Fig. 1B) was constituted of stations situated in the  
289 center of the northern gyre of the Gulf of Lions, where both winter *Deep Convection* and *Mixed*  
290 classes were located in February 2013. This centered spring class was named “*Surface Bloom*”  
291 according to the shape of the vertical Chl<sub>a</sub> distribution characterized by the absence of a *DCM*  
292 (Fig. 4), or more specifically by a shallow maximum of fluorescence ( $20.36 \pm 11.16$  m; Table 3).  
293 The 0-100 m integrated fluorescence and the maximum of fluorescence ( $113.21 \pm 16.08$  mgChl  
294  $\text{m}^{-2}$  and  $2.33 \pm 1.25$  mgChl  $\text{m}^{-3}$  respectively; Table 3) were significantly higher in the *Surface*  
295 *Bloom* class than in the *DCM* class (student tests, p-value < 0.001 for both). Microphytoplankton  
296 and nanophytoplankton were co-dominant in the *Surface Bloom* class (Fig. 5) with slight  
297 differences according to the locations. Microphytoplankton was more abundant (60%) than  
298 nanophytoplankton (40%) in the center of the Gulf of Lions, where the winter *Bottom Deep*  
299 *Convection* sub-class was situated, while in the Ligurian Sea, where both the *WMDW Deep*  
300 *Convection* and the *Open Sea Mixed* sub-classes were present, nanophytoplankton proportions  
301 were more important than microphytoplankton (50% and 40% respectively).

302 The second spring class (28 blue stations, Fig. 1B) named “*Deep Chlorophyll Maximum*”  
303 grouped the stations located at the periphery of the *Surface Bloom* class and was characterized by  
304 a clear peak of fluorescence deeper than 20 m (Fig. 4) and significantly deeper than the *Surface*  
305 *Bloom* class (student test, p-value < 0.001). Two sub-classes, named *50-DCM* and *30-DCM*,



306 were identified. Their MLD was not significantly different ( $17.63 \pm 10.57$  m and  $25.94 \pm 14.02$   
307 m for *50-DCM* and *30-DCM* respectively; Table 3). The sub-class *50-DCM* was marked by a  
308 significantly deeper DCM ( $54.00 \pm 8.03$  m) than in the second sub-class (student test, p-value <  
309 0.001), and a significantly lower 0-100 m integrated fluorescence ( $37.49 \pm 9.35$  mgChl m<sup>-2</sup>)  
310 compared to the second sub-class (student test, p-value < 0.001) and the *Intermediate* and  
311 *Surface Bloom* classes (student tests, p-values < 0.001). Stations from *50-DCM* were situated in  
312 the southern part of the Gulf of Lions (11 stations labeled by blue circles, Fig. B1). The *30-DCM*  
313 sub-class had a DCM shallower than 35 m ( $33.64 \pm 11.59$  m), with a 0-100 m integrated  
314 fluorescence ( $66.75 \pm 13.26$  mgChl m<sup>-2</sup>) also significantly lower than both *Intermediate* and  
315 *Surface Bloom* classes (student tests, p-values < 0.001 for both). Stations of *30-DCM* sub-class  
316 (17 stations labeled by blue squares, Fig. 1B) were situated in the whole periphery of the northern  
317 gyre, but mostly north to the *50-DCM* stations. Both sub-classes were dominated by  
318 nanophytoplankton (~55 %; Fig. 5), with the co-presence of picophytoplankton (~20 %) and  
319 microphytoplankton (~15 %). Some stations situated in the south of the sampling area were  
320 characterized by greater proportions of picophytoplankton (~35%) and also a particularly deep  
321 DCM (>80 m).

322 A third spring class (6 green stations, Fig. 1B) was characterized by a maximum of  
323 fluorescence spread over several meters from 20 to 60 m (Fig. 4). This last spring class, named  
324 "*Intermediate*" was only constituted of 6 stations with high 0-100 m integrated fluorescence  
325 ( $165.74 \pm 25.56$  mgChl m<sup>-2</sup>; Table 3), significantly higher than in the *DCM* and *Surface bloom*  
326 classes (student tests, p-values < 0.001 for both) and a dominance of nanophytoplankton (~60%;  
327 Fig. 5).

328

## 329 4 Discussion

330 Compared to the previous years, the open-ocean deep convection event of February 2013  
331 was particularly intense in terms of duration, spatial extent [*Houpert et al.*, 2016] and of dense  
332 water formation [*Waldman et al.*, 2016]. This event was then an interesting case to study the  
333 influence of the convection process on nutrients dynamics and distribution over the NWM, and  
334 the consequences in spring on the phytoplankton distribution and community structure.

335

### 336 4.1 Winter nutrient distribution influenced by the deep convection event

337 During the winter, the nutrient-based clustering resulted in three main classes that  
338 distinguish the NWM by a surface nitrate ( $\text{NO}_3$ ), phosphate ( $\text{PO}_4$ ) and silicate ( $\text{Si}(\text{OH})_4$ )  
339 concentration gradients from the center of the *Deep Convection* toward the *Mixed* and *Stratified*  
340 surrounding classes (Fig. 1 and Table 1). This gradient followed the water volume invested in the  
341 winter mixing (Fig. 3) confirming the strong link between spatial nutrient distribution and the  
342 deep convection process. The surface gradient was also discernable through each sub-class, even  
343 inside the *Deep convection* class where nutrients concentrations were significantly higher in the  
344 *Bottom Deep convection* sub-class than in the *WMDW Deep convection* sub-class (Table 1). This  
345 difference could be due to the higher volume of WMDW mixed in the *Bottom Deep convection*  
346 sub-class than in the *WMDW Deep Convection* sub-class, which could allow to introduce more  
347 nutrients into the water column from the deep stocks. Nevertheless, previous studies in the NWM  
348 observed homogeneous nitrate, phosphate and silicate concentrations in the deep layer, *i.e.* from  
349 800 m to the bottom [*Béthoux et al.*, 1998b; *Pujo-Pay et al.*, 2011; *Pasqueron de Fommervault et*  
350 *al.*, 2015]. In our study, the mixed layer depth (MLD) reached at least 1000 m in both *WMDW*

351 and *Bottom Deep Convection* sub-classes, similar nutrients stoichiometry should then be  
352 observed along the water column.

353 The significantly different  $\text{Si(OH)}_4\text{:NO}_3$  and  $\text{NO}_3\text{:PO}_4$  in the two *Deep Convection* sub-  
354 classes (Table 2) might be associated to the sediment resuspension induced by the deep  
355 convection event, a process yearly observed in the NWM from 2010 to 2013 [Durrieu de  
356 Madron *et al.*, 2017]. During this particular event of February 2013, UVP profiles of large  
357 particles abundance showed that deep sediment resuspension was triggered only in the *Bottom*  
358 *Deep convection* sub-class, producing a bottom nepheloid layer with a concentration up to 500  
359 particles  $\text{L}^{-1}$  between 1000 m and the bottom (Fig. 6A-B). On the contrary, particles  
360 concentration in the *WMDW Deep convection* sub-class was significantly lower and homogenous  
361 ( $\sim 100$  particles  $\text{L}^{-1}$ ) between 500 m and the bottom (Fig. 6C-D). These observations suggest a  
362 water column enrichment of the *Bottom Deep convection* sub-class by pore water release loaded  
363 in nutrients, especially in silicate [Durrieu de Madron *et al.*, 2005]. This process, never observed  
364 in open-ocean, is regularly detected in shallow lakes [Søndergaard *et al.*, 1992; Dzialowski *et al.*,  
365 2008; Niemistö *et al.*, 2008] and marine coastal waters [Mermex group, 2011] where sediment  
366 resuspension is induced by environmental events such as tidal currents, wind-induced storms  
367 [Fanning *et al.*, 1982; Tengberg *et al.*, 2003; Garcia-Robledo *et al.*, 2016] or anthropogenic  
368 activities [Durrieu de Madron *et al.*, 2005]. Most of these marine studies observed higher nitrate,  
369 ammonium and silicate injections than phosphate. But here, the sediment resuspension seemed to  
370 preferentially enrich the water column in silicate and phosphate rather than nitrate, as shown by  
371 the significantly higher  $\text{Si(OH)}_4\text{:NO}_3$  and lower  $\text{NO}_3\text{:PO}_4$  ratios in the *Bottom Deep convection*  
372 sub-class (Table 2). Nutrients measurements in sediment pore waters during a previous cruise in  
373 March 2011 [CASCADE; Severin *et al.*, 2014] showed high concentrations of silicate ( $47.03 \pm$

374 8.68  $\mu\text{M}$ ) and phosphate ( $0.70 \pm 0.18 \mu\text{M}$ ) compared to nitrate ( $12.76 \pm 0.81 \mu\text{M}$ ) in the first 2  
375 cm of the sediment cores sampled in the convection area, which resulted in high  $\text{Si}(\text{OH})_4\text{:NO}_3$   
376 ( $3.71 \pm 0.80$ ) and low  $\text{NO}_3\text{:PO}_4$  ( $18.76 \pm 3.13$ ) ratios. These measurements reinforce our  
377 hypothesis of a preferential enrichment in silicate and phosphate by sediment resuspension.  
378 Moreover, previous studies showed that in oxidized conditions, iron (III) presents in the  
379 sediment adsorbs phosphorus and favors its sequestration [*Jensen et al.*, 1992; *Søndergaard et*  
380 *al.*, 2003]. In our study, the strong convective mixing oxidized the whole water column and most  
381 probably the surface layer of the sediment, favoring phosphorus adsorption on iron (III). Thus, to  
382 observe a phosphate release like in our study, the resuspended sediment should have low iron  
383 concentration. To confirm this hypothesis, measurements of phosphate and iron concentrations in  
384 the pore water would be required to trace the influence of the sediment resuspension on the water  
385 column. Nutrients measurements along the water column prior to a convection event would help  
386 to confirm their homogeneity in the deep layer and the inability of different MLD to significantly  
387 change the nutrients ratios along the water column.

388         A previous study on a secondary convection event in the NWM showed that the nutrient  
389 supplies by a single event was equivalent to the annual supply by the Gulf of Lions rivers, even  
390 for an event limited in space ( $1000 \text{ km}^2$ ) and time (8 days) for which the MLD only reached the  
391 WMDW [*Severin et al.*, 2014]. The convection event of March 2011 was preceded by a first  
392 deep convection event in February 2011 that reached the bottom. This induced the formation of a  
393 bottom nepheloid layer by sediment resuspension that can last almost a year [*Puig et al.*, 2013]  
394 and was then in theory still observable during the secondary convection event sampled in March.  
395 This previous bottom reaching mixing can explain the similar nutrients concentrations and  
396 stoichiometry observed in March 2011 and in February 2013, because of either the dilution effect

397 of a higher volume of the WMDW or the pore water release as explain above. Nevertheless, the  
398 convection episode of February 2013 was more extended than the event of March 2011 with an  
399 area estimated to 23 600 km<sup>2</sup> [Houpert et al., 2016]. Using the 0-100 m averaged integrated  
400 nutrients quantities of the *Deep Convection* class, NO<sub>3</sub>, PO<sub>4</sub> and Si(OH)<sub>4</sub> supplies were then  
401 evaluated to  $1.87 \pm 0.11 \cdot 10^{10}$ ,  $8.60 \pm 0.78 \cdot 10^8$  and  $1.63 \pm 0.26 \cdot 10^{10}$  mol respectively, so 23 times  
402 more nutrients than in March 2011 and only 1.5 times more than in February 2011 [Severin et  
403 al., 2014]. Using physical/biogeochemical coupled modeling, Ulses et al. [2016] estimated  
404 supplies of nutrients at 100 m depth in the NWM. They obtained 5 times more than our estimates  
405 for the strongly convective winter 2004-2005, and 2.5 and 1.7 more than our estimates for the  
406 less convective winters, respectively 2005-2006 and 2003-2004 winters. Unfortunately, these  
407 studies used different criteria to delimit the convection area, which lead to significant variations  
408 in the nutrients supplies estimates [Houpert et al., 2016]. An over or underestimation of the  
409 nutrients budgets can then result from it, highlighting the necessity to choose a unique criterion  
410 to determine the convection area.

411

412 4.2 Spring phytoplankton abundance and horizontal distribution influenced by winter  
413 nutrients supply

414 In spring, the superposition of the fluorescence-based classes with the winter nutrient-  
415 based classes (Fig. 1) confirmed the previous observations that the winter nutrients supply by the  
416 convection process is one the main factors influencing the spring phytoplankton bloom [Lévy et  
417 al., 1998; Gačić et al., 2002; Heimbürger et al., 2013]. Indeed, the fluorescence characteristics  
418 (Table 3) indicated that the phytoplankton bloom was centered in the northern cyclonic gyre of  
419 the NWM, *i.e.* in the *Surface Bloom* class which corresponded to the winter *Open Sea Mixed* and

420 *Deep Convection* classes (Fig. 1). Consequently, the convection process controls the winter  
421 nutrients supply (Table 1), which in turn influences the phytoplankton surface abundance and  
422 horizontal distribution in spring. The predicted decrease in intensity and coverage of the  
423 convection process with the climate change [Giorgi, 2006, Somot et al., 2006] could then have  
424 consequences on the phytoplankton ecosystem, as already observed in some predictive models  
425 [Herrmann et al., 2014; Macias et al., 2015].

426 But while the large winter nutrients supply induced a bloom with a surface fluorescence  
427 maximum (Fig. 4; Table 3), the phytoplankton vertical distribution in the surrounding *DCM* and  
428 *Intermediate* classes cannot be explain by the deep convection process. Because the *DCM* class  
429 was located where the winter *Stratified* class was, the nutrient depleted surface layer certainly  
430 favored a deep phytoplankton development closer to the nutricline (Table 3), and thus the  
431 formation of a *DCM*. Moreover, the significant correlation between the MLD and the depth of  
432 fluorescence maximum (Spearman test,  $r = -0.322$ ,  $p \text{ value} < 0.05$ ; Table S1) indicated that MLD  
433 variations could be responsible for the different *DCM* observed (*50-DCM* vs. *30-DCM* sub-  
434 classes), as well as some stations mismatches between the winter and spring classes (Fig. 1). For  
435 instance, spring stations 23, 25 and the southern stations 83 and 85 did not benefit from the  
436 winter nutrients supply, but a short MLD deepening prior the sampling enable a surface  
437 phytoplankton development characteristic of the *Surface Bloom* class (Fig. 4; Table 3). Inversely,  
438 the spring station 78 was in the winter *Deep Convection* class, but an early MLD shallowing in  
439 spring resulted in a low and deep fluorescence maximum, a *DCM* class characteristic (Fig. 4;  
440 Table 3). Thus, in nutrient depleted waters, the shallower is the MLD, the deeper is the *DCM* and  
441 reciprocally. In our study the phytoplankton distribution was evaluated via fluorescence  
442 measurements, the observed *DCMs* could then be a consequence of photoacclimation processes

443 and not an actual deep phytoplankton biomass maximum. In this case, the maximum of  
444 fluorescence should increase with the deepening of the DCM. Here, the maximum of  
445 fluorescence was significantly lower in the *50-DCM* than in the *30-DCM* sub-classes (Table 3),  
446 which give insight that the DCM was associated to a biomass maximum. Phytoplankton cells  
447 counting along the water column would be necessary to confirm this hypothesis.

448         Several studies showed the influence of the MLD on the phytoplankton vertical  
449 distribution, in association with others biotic and abiotic mechanisms such as the light regime,  
450 predations or phytoplankton growth and sinking [*Morel and Berthon*, 1989; *Estrada et al.*, 1993;  
451 *Mignot et al.*, 2014; *Lavigne et al.*, 2015; *Cullen*, 2015 and references therein]. Unfortunately,  
452 the sampling grid of our twice one-month study (February vs. April) prevents to identify these  
453 other mechanisms, as shown by the absence of correlation between the fluorescence maximum  
454 depth and the euphotic depth or the nutriclines (Table S1). Nevertheless, a study showed that the  
455 duration and depth of the convective mixing directly shape both the phenology and the  
456 magnitude of the spring bloom in the NWM [*Lavigne et al.*, 2013]. Moreover, a one-year study  
457 covering the 2013 deep convection event and spring bloom [*Mayot et al.*, 2017] confirmed this  
458 hypothesis, which strengthens our study which uses data from the convection event in February  
459 to explain the phytoplankton distribution in April. In this study, they observed two bioregions  
460 similar to our *Surface Bloom* and *DCM* classes with a significant higher phytoplankton  
461 accumulation in the former class like in our study. Similarly, they explained this difference by  
462 higher silicate availability and a reduced zooplankton grazing pressure because of a greater  
463 dilution by the convective mixing [*Behrenfeld et al.*, 2010].

464

### 465 4.3 Winter nutrient supply induced the spring phytoplankton size class distribution

466 Several studies showed clear correlations between phytoplankton size classes and nutrient  
467 stocks and stoichiometry [Staeher *et al.*, 2002; Elser *et al.*, 2003; Conan *et al.*, 2007; Meyer *et al.*,  
468 2016]. The *Surface Bloom* class, characterized by the highest winter nutrients replenishment in  
469 our study, was co-dominated by microphytoplankton and nanophytoplankton as expected (i.e.  
470 larger cells), while nanophytoplankton and picophytoplankton dominated the *DCM* class (Fig. 5).

471 In this classical general scheme, another pattern was observable when considering the  
472 spring proportion of micro- and nano- phytoplankton in the winter classes. Within the *Surface*  
473 *Bloom* class, microphytoplankton was dominant where the winter *Bottom Deep Convection* sub-  
474 class was located, while nanophytoplankton dominated the *WMDW Deep Convection* and the  
475 *Open-Sea Mixed* sub-classes. To explain such a difference, it is necessary to consider the winter  
476 nutrients stoichiometry (Table 2). Microphytoplankton was clearly related with elevated winter  
477 concentrations of  $\text{NO}_3$ ,  $\text{PO}_4$  and  $\text{Si}(\text{OH})_4$ , but also with relatively low  $\text{NO}_3:\text{PO}_4$  and high  
478  $\text{Si}(\text{OH})_4:\text{NO}_3$  ratios. In our study, microphytoplankton group was defined using fucoxanthin and  
479 peridinin, characteristic pigments of diatoms and dinoflagellates respectively [Uitz *et al.*, 2006].  
480 Diatoms are known to be opportunist and to grow in enriched environment with relatively low  
481  $\text{Si}(\text{OH})_4:\text{NO}_3:\text{PO}_4$  ratios [Conan *et al.* 2007]. The large silicate supply in the *Bottom Deep*  
482 *Convection* sub-class, evidenced by the high  $\text{Si}(\text{OH})_4:\text{NO}_3$ , seemed to favor diatoms rather than  
483 dinoflagellates. This was confirmed by the 0-100 m integrated fucoxanthin to peridinin  
484 proportion index ( $\text{Fucoxanthin}/[\text{Fucoxanthin} + \text{Peridinin}]$ ) higher in the *Surface Bloom* stations  
485 previously located in the *Bottom Deep Convection* sub-class ( $99.81 \pm 2.74$ ) than in the *WMDW*  
486 *Deep Convection* and *Open-Sea Mixed* sub-classes ( $86.16 \pm 7.60$ ). The only exceptions were the  
487 previously mentioned spring stations 23 and 25 (Fig. 1B) dominated by microphytoplankton and



488 nanophytoplankton respectively (Fig. 5) and the southern stations 83 and 85 also (Fig. 1B)  
489 dominated by nanophytoplankton (Fig. 5), while they were located in the nutrient-depleted  
490 winter *Stratified* class. The short MLD deepening enriched enough these stations to have a  
491 similar phytoplankton development than the nutrient-enriched *Deep Convection* and *Mixed*  
492 classes. Nevertheless the large size range of the diatoms, from nano- to micro-sized classes, is  
493 not taken into account with the method used in our study to determine the phytoplankton  
494 community structure [Uitz *et al.*, 2006]. While previous studies in the NWM observed diatoms  
495 bloom of the microphytoplankton size class [Percopo *et al.*, 2011; Rigual-Hernandez *et al.*,  
496 2013], it is possible that smaller diatoms taxa become dominant like in the North Atlantic spring  
497 bloom because of modifications of the environmental conditions [Daniels *et al.*, 2015].

498         Concerning the nano- and pico- phytoplankton that dominated the *DCM* class, the  
499 nutrient-depleted surface layer and the high  $\text{NO}_3:\text{PO}_4$  and low  $\text{Si}(\text{OH})_4:\text{NO}_3$  ratios (Tables 1 and  
500 2) combined to favor smaller cells development [Pujo-Pay *et al.*, 2011]. Moreover,  
501 picophytoplankton was more abundant in the southern stations of the *50-DCM* sub-class, where  
502 was the winter *Stratified 2* sub-class (Fig. 1B) characterized by the lower surface nutrients  
503 concentrations and the highest surface  $\text{NO}_3:\text{PO}_4$  and  $\text{Si}(\text{OH})_4:\text{NO}_3$  ratios (Table 2). These  
504 nutrients stocks, in association with the significantly deeper euphotic depth in the *50-DCM* than  
505 in the *30-DCM* sub-classes (Table 3; student test, p-value = 0.041) created the ideal conditions to  
506 promote the picophytoplankton development more adapted to oligotrophic waters [Clark *et al.*,  
507 2013]. Finally, the presence of some microphytoplankton in the northern stations from the *30-*  
508 *DCM* sub-class (~30%; Fig. 1B and 5) could be due to a nutrient enrichment by the rivers  
509 discharge. Even if the annual nutrient supply by the rivers is significantly lower than the supply

510 by a single convection event [Severin et al., 2014], this input in coastal waters was enough to  
511 favor a microphytoplankton development.

512

## 513 **5 Conclusion**

514 In this study we showed that the spatial extent of the deep convection process directly  
515 determines silicate, nitrate and phosphate concentrations distribution over the NWM, while the  
516 convective mixing depth conditions the nutrients stoichiometry by dilution effect of the WMDW  
517 or because of the sediment resuspension triggered by bottom reaching mixing. In turn, the winter  
518 nutrients supply influences the spring phytoplankton abundance and horizontal distribution,  
519 while the winter nutrients stoichiometry impacts the spring phytoplankton community structure,  
520 favoring diatoms in the center of the deep convection area enriched in silicate

521 The expecting modifications of the convection process with the climate change will have  
522 consequences on the phytoplankton abundance and community structure in spring. Reduced  
523 convection events in time, space and in mixing depth, like in 2008, will diminish the nutrient  
524 supplies, especially in silicate. This can lead to an ecosystem shift by favoring dinoflagellates, or  
525 picophytoplankton if the deep convection process completely disappears, with consequences on  
526 the biogeochemical cycles and on the entire marine food web.

527

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759 **Tables**

760 Table 1: Phosphate (PO<sub>4</sub>), nitrate (NO<sub>3</sub>), silicate (Si(OH)<sub>4</sub>) and chlorophyll a (Chl<sub>a</sub>) mean  
 761 concentrations at 10 m and more than 2000 m (in μM for nutrient and in μg.L<sup>-1</sup> for Chl<sub>a</sub>) and  
 762 mean integrated (0-100 m) quantities (in mmol.m<sup>-2</sup> for nutrient and in mg.m<sup>-2</sup> for Chl<sub>a</sub>), as well  
 763 as mean temperature (T in °C), salinity (S) and density anomaly (d in kg.m<sup>-3</sup>) of each winter  
 764 class and sub-class of Leg 1. Standard deviations are indicated after ±. NA for not available data.

		Stratified		Mixed		Deep convection	
		1	2	1-Open sea	2-Shelf	1-WMDW	2-Bottom
Surface concentrations (10 m)	NO <sub>3</sub>	2.95±0.69	0.82±0.28	5.06±0.45	2.61±0.62	7.64±0.22	8.42±0.34
	PO <sub>4</sub>	0.11±0.03	0.03±0.01	0.20±0.03	0.09±0.01	0.35±0.01	0.39±0.01
	Si(OH) <sub>4</sub>	2.33±0.34	1.34±0.21	3.63±0.49	2.24±0.38	6.32±0.55	7.87±0.30
	Chl <sub>a</sub>	0.45±0.08	0.53±0.08	0.43±0.16	0.53±0.08	0.16±0.07	0.05±0.01
Deep concentrations (>2000m)	NO <sub>3</sub>	8.83±0.25	8.78±0.17	8.70±0.2	NA	8.69±0.10	8.51±0.51
	PO <sub>4</sub>	0.41±0.03	0.39±0.00	0.39±0.01	NA	0.40±0.00	0.40±0.01
	Si(OH) <sub>4</sub>	8.84±0.09	8.79±0.22	8.8±0.17	NA	8.75±0.12	8.32±0.45
Integrated quantities (0-100 m)	NO <sub>3</sub>	326±69	127±45	567±97	262±57	758±34	825±64
	PO <sub>4</sub>	11.74±2.88	3.97±1.35	22.53±5.77	8.29±0.8	34.1±2.05	38.81±3.25
	Si(OH) <sub>4</sub>	244±35	151±27	408±90	224±34	611±42	769±64
	Chl <sub>a</sub>	34.23±17.9	15.64±22.1	16.1±20.6	27.7±25.5	7.28±9.56	2.9±2.85
Hydrology (10 m)	T	13.09±0.07	13.51±0.23	13.09±0.12	12.88±0.54	13.09±0.09	12.95±0.02
	S	38.25±0.04	38.05±0.09	38.35±0.09	38.11±0.16	38.50±0.02	38.49±0.005
	d	28.89±0.04	28.65±0.12	28.97±0.08	28.83±0.06	29.09±0.005	29.11±0.004

765

766 Table 2: Mean nitrate to phosphate (N:P) and silicate to nitrate (Si:N) ratios between 0 and 100  
 767 m and deeper than 700 m of each winter class and sub-class of Leg 1 (Fig. 2). NA for not  
 768 available data.

		Stratified		Mixed		Deep convection	
		1	2	1-Open sea	2-Shelf	1-WMDW	2-Bottom
Mean surface ratio (0-100 m)	N:P	29.73±3.67	43.66±27.07	26.44±2.93	32.99±7.55	22.34±0.95	21.22±0.71
	Si:N	0.75±0.08	1.30±0.32	0.70±0.04	0.82±0.08	0.80±0.06	0.93±0.01
Mean deep ratio (>700 m)	N:P	21.41±0.67	21.53±1.15	21.42±1.30	NA	21.61±0.47	21.29±0.83
	Si:N	1.00±0.03	0.99±0.02	1.00±0.03	NA	0.99±0.04	0.96±0.03

769

770

771

772 Table 3: Averages of 0-100 m integrated fluorescence (Integrated fluo. in mgChla m<sup>-2</sup>),  
 773 maximum of fluorescence (Fluo. max. in mgChl m<sup>-3</sup>), depth of the fluorescence maximum (z<sub>fluo-</sub>  
 774 <sub>max</sub> in m), nitracline (in m), silicline (in m), mixed layer depth (MLD in m) calculated with a  
 775 potential density anomaly difference of 0.003 kg m<sup>-3</sup>, and euphotic depth (z<sub>e</sub> in m) calculated as  
 776 the depth with 1% of the photosynthetic active radiation for each spring class and sub-class of  
 777 Leg 2. Standard deviations are indicated after ±.

	DCM		Intermediate	Surface Bloom
	50-DCM	30-DCM		
Integrated fluo.	37.49±9.35	66.75±13.26	165.74±25.56	113.21±16.08
Fluo. max.	1.09±0.33	1.26±0.76	2.38±1.44	2.33±1.25
Z <sub>fluo-max</sub>	54±8.03	33.64±11.59	9.83±8.2	20.36±11.16
Nitracline	51.36±19.5	70.29±44.1	50±16.73	55.6±40.7
Silicline	94.54±50.27	87.64±58.15	83.33±38.81	74±39.89
MLD	17.63±10.57	25.94±14.02	30±22.03	22±15.57
z <sub>e</sub>	51.78±37.20	25.88±21.74	17.50±15.02	30.29±20.85

778

779 **Figures legends:**

780

781 Figure 1: Sampling map during (A) the winter deep convection event (Leg 1 DeWEX cruise,  
782 February 2013) and during (B) the spring bloom (Leg 2 DeWEX cruise, April 2013). Colors  
783 represent the 3 classes of each month. (A) red: *Deep convection*, blue: *Mixed*, green: *Stratified*;  
784 circles are the first sub-classes and squares are the seconds (refer to section 3.2 for explanations).  
785 (B) blue: *DCM*, green: *Intermediate*, red: *Surface Bloom*, circles are stations in the *50-DCM* sub-  
786 class (DCM > 50 m) and squares are the stations in the *30-DCM* sub-class (DCM < 30 m) (refer  
787 to section 3.3 for explanations).

788

789 Figure 2: NO<sub>3</sub>, PO<sub>4</sub>, Si(OH)<sub>4</sub> (in μM) and Chl<sub>a</sub> (in μg L<sup>-1</sup> from HPLC analyses) profiles of each  
790 station of the winter class (Leg 1 DeWEX, February 2013). Colors represent the winter classes  
791 presented in Fig. A1 (red: *Deep convection*, blue: *Mixed*, green: *Stratified*), circles are the first  
792 sub-classes and squares the second sub-classes.

793

794 Figure 3: Temperature-Salinity diagrams of each stations of the winter classes (Leg 1 DeWEX,  
795 February 2013): (A) *Stratified* (in green), (B) *Mixed* (in blue) and (C) *Deep Convection* (in red).  
796 Circles are the first sub-classes and squares the seconds sub-classes presented in Fig. 1A.

797

798 Figure 4: Averaged fluorescence profiles (colored lines) with their standard deviation (grey lines)  
799 for each spring class (from left to right): *50-DCM* (blue), *30-DCM* (blue), *Intermediate* (green)  
800 and *Surface Bloom* (red) (Leg2 DeWEX, April 2013).

801

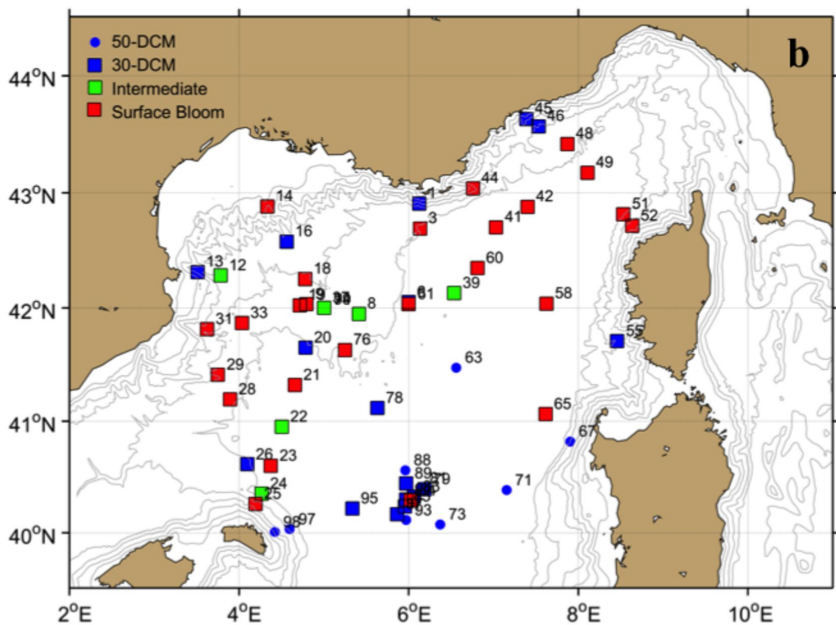
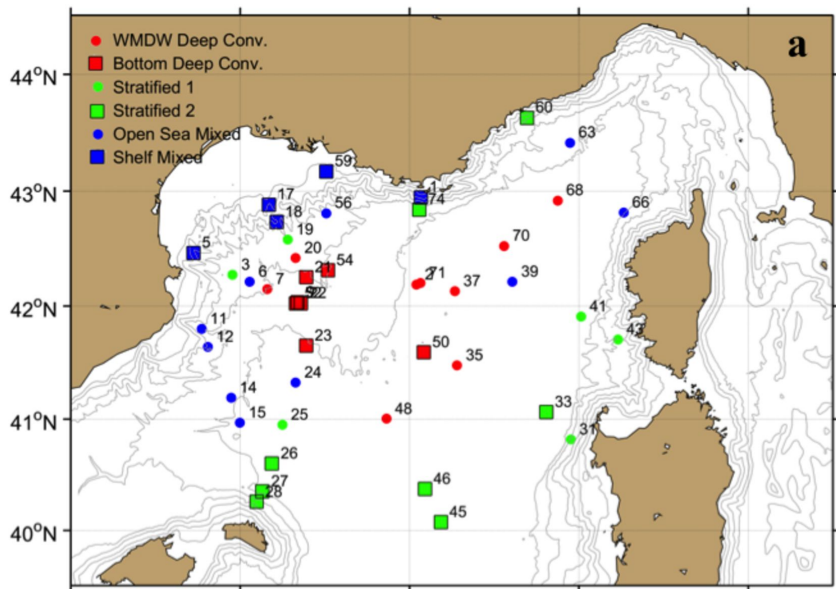
802 Figure 5: Distribution of the column-integrated fraction of microphytoplankton (left),  
803 nanophytoplankton (middle) and picophytoplankton (right) with respect to the Chl $a$  quantities in  
804 spring (leg2 DeWEX, April 2013). Shapes represent the spring classes and sub-classes presented  
805 in Fig. B1: diamonds: *Surface Bloom*, triangles: *Intermediate*, solid circles: *50-DCM*, empty  
806 circles: *30-DCM*.

807

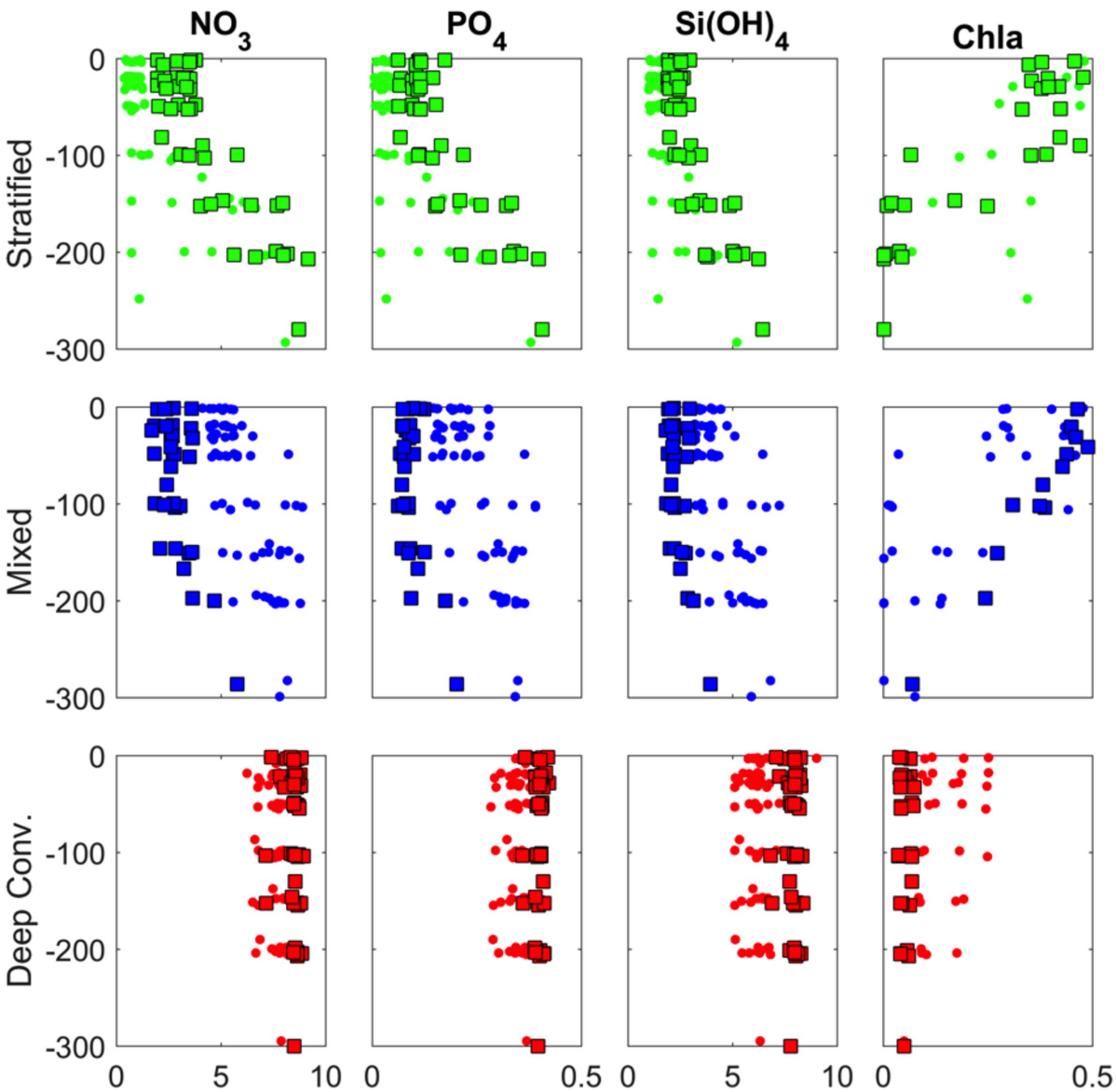
808 Figure 6: Sampling maps of the winter stations of (A) the WMDW Deep Convection and (B) the  
809 Bottom Deep Convection sub-classes, and (C and D) their associated particles concentrations  
810 profiles (in particles L $^{-1}$ ) during the winter deep convection event (Leg 1 DeWEX cruise,  
811 February 2013).

**Figure 1.**

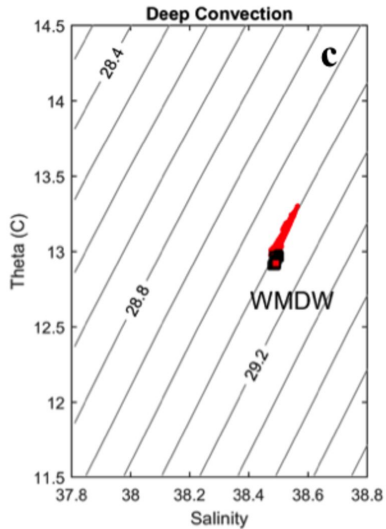
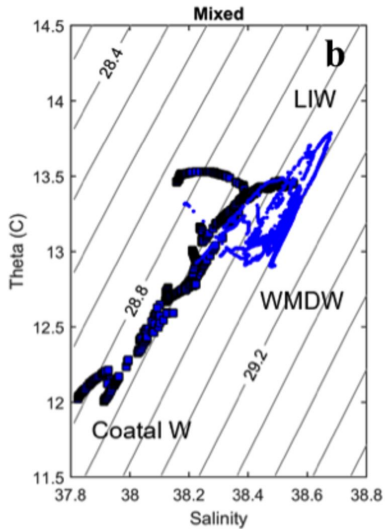
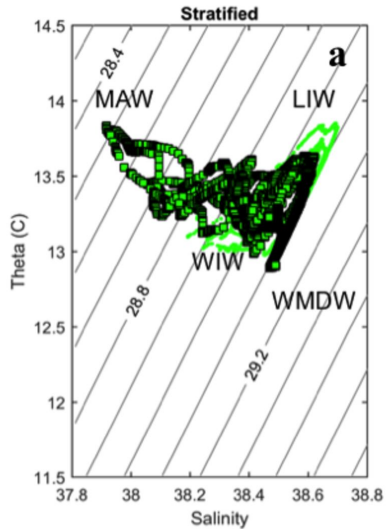




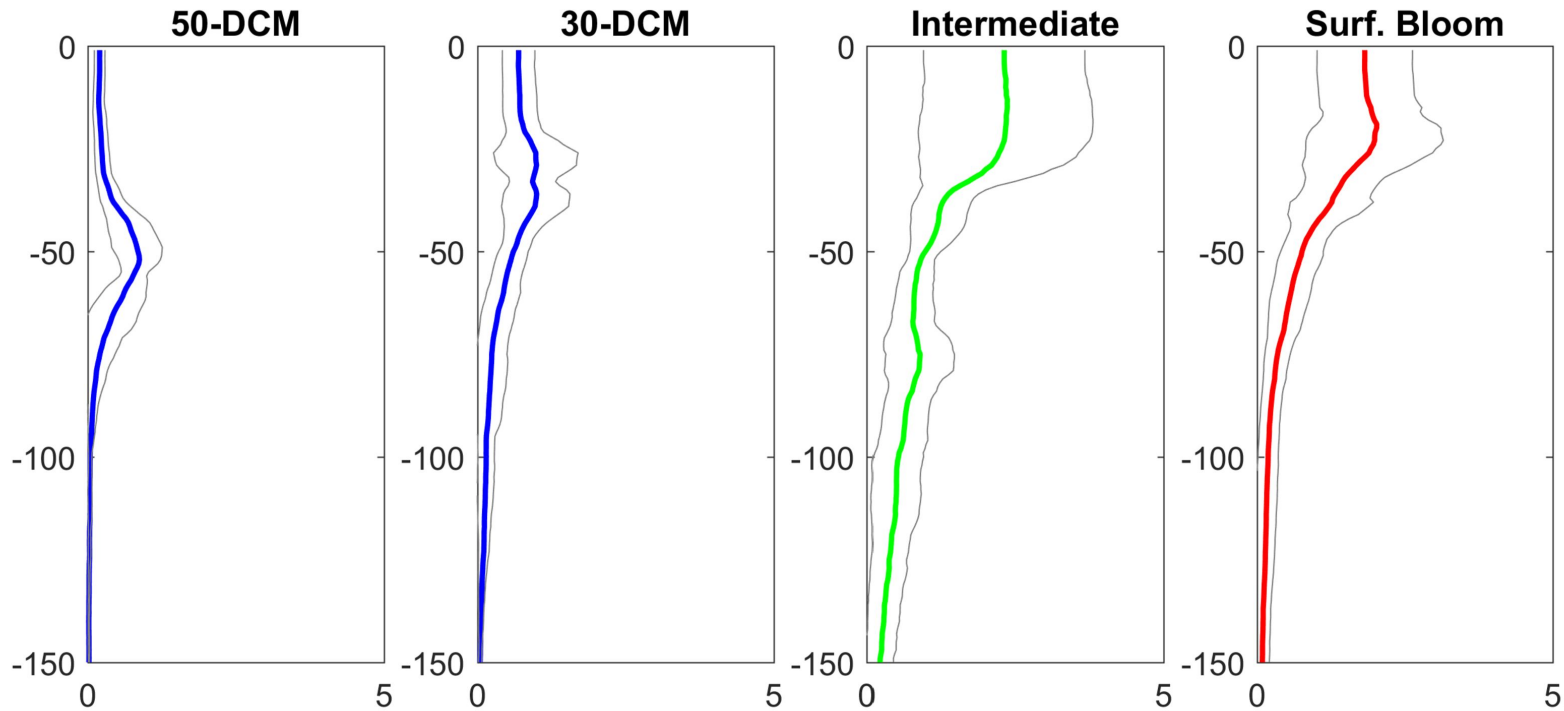
**Figure 2.**



**Figure 3.**

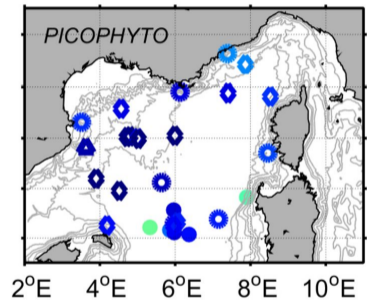
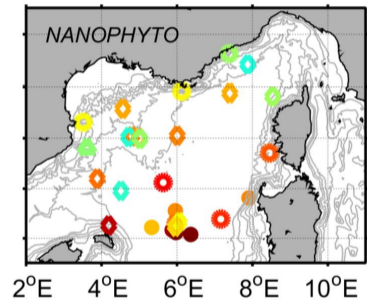
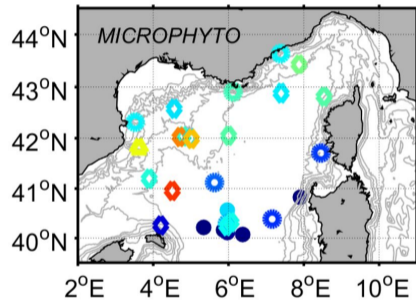


**Figure 4.**



**Figure 5.**





**Figure 6.**

