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Discussions

1 Potential effects of deep seawater discharge by an Ocean Thermal Energy
2 Conversion plant on the marine microorganisms in oligotrophic waters

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9 ## Abstract

10   Installation of an Ocean Thermal Energy Conversion pilot plant (OTEC) off the Caribbean coast
11 of Martinique is expected to use approximately 100 000 $m^3\,h^{-1}$ of deep seawater for its functioning.
12 This study examined the potential effects of the cold nutrient-rich deep seawater discharge on the
13 phytoplankton community before the installation of the pilot plant. Thermal effect induced by the
14 deep seawater upwelled by the OTEC was described using the Regional Ocean Modeling System.
15 Numerical simulations of deep seawater discharge showed that a 3.0 °C temperature change,
16 considered as a critical threshold for temperature impact, was never reached during an annual cycle
17 on the top 150 m of the water column on two considered sections centered on the OTEC. The
18 thermal effect should be limited, less than 1 km^2 on the area exhibited a temperature difference of
19 0.3 °C (absolute value). The impact on phytoplankton of the resulting mixed deep and surface
20 seawater was evaluated by *in situ* microcosm experiments. Two scenario of water mix ratio (2 % and
21 10 % of deep water) were tested at two incubation depths (deep chlorophyll-*a* maximum: DCM and
22 bottom of the euphotic layer: BEL). The larger impact was obtained at DCM for the highest deep
23 seawater addition (10 %), with a development of diatoms, whereas 2 % addition induced only a
24 limited change of the phytoplankton community. This study suggested that the OTEC plant would
25 significantly modify the phytoplankton assemblage only in the case of a discharge affecting the DCM
26 and would be restricted to a local scale.

27 ## 1. Introduction

28   Ocean Thermal Energy Conversion (OTEC) uses the solar energy by exploiting the temperature
29 gradient between surface and bottom seawater. In an OTEC plant, the cold deep seawater pumped
30 close to sea bottom is used to condense a working fluid (like ammonia), whereas warm surface
31 waters, pumped close to the surface, serve to evaporate it. The difference of pressure, generated by
32 the evaporation and condensation of the fluid, drives a turbine that produces mechanical energy.

33   This energy is then converted to electrical energy in a generator. Due to the need of a 20 °C

34   difference between the cold deep and the warm surface waters for the OTEC exploitation, tropical

35   areas are well suited for the installation of OTEC plants.

36   The Martinique, a tropical island of Lesser Antilles, is ideally suited for OTEC functioning with its

37   narrow continental slope in the Caribbean part of the island, allowing an implementation of the plant

38   close to the coast. The implementation of a 10 MW OTEC pilot plant off the Caribbean coast of

39   Martinique is expected in 2020 as part of the french NEMO project (Akuo Energy, DCNS). This

40   OTEC will pump approximately 100 000 $m^3.h^{-1}$ of deep seawater at 1100 m depth. In order to

41   optimize the energy efficiency, the deep seawater should be rejected close to the surface. However,

42   this large discharge could induce important disturbances on the upper ocean ecosystem, and this

43   impact should be estimated.

44   Environmental assessment of OTEC functioning was studied since the 1980's (NOAA, 1981;

45   2010). The deep seawater discharge was described as one of the major drivers impacting the marine

46   environment in OTEC plant. However, only a few studies specifically detailed this critical aspect

47   (Taguchi et al., 1987; Rocheleau et al., 2012). The deep seawater discharge in OTEC plant generates

48   a phenomenon similar to the one naturally occurring in the ocean within upwelling systems.

49   Equatorward winds along the coast in the eastern Atlantic and Pacific linked to atmospheric high-

50   pressure systems force Ekman transport and pumping, relocating coastal surface waters offshore.

51   Thereby, deep water transport towards the surface is generated close to the coast. In these systems,

52   the large amount of macronutrients and trace metals carried to the euphotic zone by the enriched

53   deep seawater supports a large development of the phytoplankton, making upwelling the most

54   productive oceanic regions (Bakun, 1990; Pauly and Christensen, 1995; Chavez and Toggweiler,

55   1995; Carr and Kearns, 2003). The tropical surface waters off the Caribbean coast of Martinique

56   exhibit low nutrients concentrations and can be significantly enriched by the deep seawater

57   discharge. Whereas phytoplankton assemblages in upwelling systems are usually dominated by large

58   phytoplankton and particularly by diatoms (Bruland et al., 2001; Van Oostende et al., 2015), the

59   phytoplankton community in oligotrophic systems is composed of smaller organisms (Agawin et al.,

60   2000).

61   Due to these important differences, it is thus of critical interest to investigate the potential effects of

62   the deep seawater discharge of the planned OTEC plant on the phytoplankton community off

63   Martinique.

64   In this study, the impact of deep seawater discharge on the thermal structure of surface

65   waters was first assessed. Modification of the surface waters stratification should indeed impact the

66   phytoplankton community. It is crucial to provide a depth where the deep seawater could be

67   discharged without significant effect on the surface layer where phytoplankton is the most abundant.

68   A high-resolution oceanic model was used to examine the thermal impact induced by the deep

69   seawater dispersion. Eight configurations of discharge depth were tested, corresponding to the

70   deep chlorophyll-*a* maximum (DCM), the bottom of the euphotic layer (BEL) and five depths below

71   the BEL. Temperature differences between numerical simulations without and with the deep

72   seawater discharge were compared on the upper 150 m of a vertical section.

73   The distribution of the ambient phytoplankton community and the biogeochemical

74   properties of the deep and surface seawater mixture that could impact the phytoplankton

75   community were then described. Phytoplankton distribution and assemblage were detailed in order

76   to assess short time and small scales variabilities of phytoplankton assemblage and primary

77   production in the study site.

78   Finally, in order to simulate the OTEC deep seawater input, enrichment experiments were

79   conducted on the future site of the pilot plant. Enrichment experiments are commonly used in

80   oceanography to assess the effects on phytoplankton community and primary production. For

81   example, large iron (Fe) enrichment experiments were conducted from 1993 to 2005 to estimate the

82   potential of Fe limitation on ocean primary production (De Baar et al., 2005; Boyd et al., 2007).

83   Several experiments also showed that macro- and micro-nutrients enrichments induce changes in the

84   phytoplankton community in upwelling regions (Hutchins et al., 2002) as well as in oligotrophic

85   regions (Kress et al., 2005). Enrichment experiments were usually conducted with mesocosms

86   immerged close to the surface (Escaravage et al., 1996; Duarte et al., 2000) or in laboratory under

87   artificial light and temperature using phytoplankton model species (Brzezinski, 1985). A laboratory

88   experiment intended to evaluate the effects of an OTEC seawater discharge in Hawaiian waters on

89   the natural phytoplankton community was previously conducted (Taguchi et al., 1987) under such

90   artificial conditions, and thus, it could not totally reproduce what occurred in the natural

91   environment. Other deep seawater discharge experiments were realized *in situ* (Aure et al., 2007;

92   Handå et al., 2014). For example, the use of a moored platform to upwell deep seawater and

93   discharge it close to the surface has shown an increase in primary production in a western

94   Norwegian fjord where the euphotic zone is nutrient-depleted during summer (Aure et al., 2007), as

95   it would be expected with the OTEC discharge. Whereas such a pumping system is well adapted for

96   pumping seawater at 30 m depth for example, it cannot be applied for OTEC experiments where

97   deep seawater must be collected far deeper (1100 m depth) and also discharged more deeply in the

98   water column to reduce the potential effects on the phytoplankton community. These conditions can

99   be obtained by the use of *in situ* microcosms, in which light and temperature are the same as in the

100   natural surrounding waters, avoiding additional bias, and several conditions (enrichment, incubation

101 depth) can be simulated. Therefore, we used the unique device of immerged microcosms we

102 developed (Giraud et al., 2016) for assessing the effects of deep seawater discharge on the

103 phytoplankton community. Two incubation depths (DCM and BEL) with two ratios of enriched

104 seawater (mixtures of surface water with 2 % and 10 % of deep seawater) were tested. These

105 experiments allowed the evaluation of critical mixing rate and discharging depth where effect was

106 maximal.

107

108 **2. Materials and methods**

109 **2.1. Modelling the thermal effect**

110   The hydrodynamic numerical model ROMS-Regional Ocean Model System (Shchepetkin and

111 McWilliams, 2005; 2009) was used to describe the resulting thermal effect due to OTEC functioning.

112 The model was run in a 2-ways AGRIF configuration allowing to define a parent and child domains

113 around the Martinique Island which are run simultaneously, transferring automatically open boundary

114 conditions. The parent grid ranges from 63° W to 59° W and 13° N to 15.9° N with a resolution of

115 1/60° (around 1.8 km) while the child domain narrows the parent one and was from 61.74° W to

116 60.41° W and 14.21° N to 15.11° N with a resolution down to 1/180° (around 600 m). The bottom

117 topography and coastline are interpolated from the GINA database (1/120°,

118 www.gina.alaska.edu/data/gtopo-dem-bathymetry) (Fig. 1).

119   The model is forced by the monthly Climate Forecast System Reanalysis (NCEP-CFSR) for wind

120 stress, heat and freshwater fluxes. For the open boundary conditions and initial conditions of the

121 parent domain, a monthly climatology computed from the Simple Ocean Data Assimilation (SODA)

122 reanalysis (Carton and Giese, 2008) was used for the dynamical variables (temperature, salinity and

123 velocity fields). The NCEP-CFSR products do no cover the period of our mesocosm experiments

124 (November 2013 and June 2014). The simulations were thus performed over another period when

125 the atmospheric forcing was available. We choose the 3 years period of 1998-2000, using 1998 and

126 1999 as a spin-up and the last year 2000 to analyze the thermal structure and circulation field. Model

127 outputs were stored as daily averages. The configurations were run without and with a deep

128 seawater discharge mimicking the OTEC functioning. The deep seawater discharge was initiated on

129 January 1st 2000. Eight cases of horizontal discharge settings were simulated at different depths: 1)

130 the DCM (45 m), 2) the BEL (80 m), that were estimated on June 12th 2014, and 3) six depths below

131 the euphotic zone (110 m, 140 m, 170 m, 250 m, 350 m and 500 m). In the OTEC plant, deep water

132 will be pumped at 1100 m where temperature is around 5 °C and salinity 35. Circulation of this water

133 through the plant system will warm it up until 8 °C prior to its release in the upper ocean. We thus

134   applied at the location of the OTEC plant (61°13'0'' W, 14°35'48'' N), a cold water discharge

135   (temperature 8 °C, salinity 35) at a flow rate of 28 m^3 s^{-1} and with a northward orientation. The

136   thermal impact of the cold-water source was assessed documenting the differences between

137   simulations without and with the modelled OTEC plant functioning over the full year 2000.

138   **2.2. Field observations and *in situ* experiments**

139   **2.2.1.   Sampling and analytical methods**

140   Temperature, salinity, and fluorescence profiles were performed using Seabird SBE19+ probe

141   with *in situ* Fluorimeter Chelsea AQUAtracka III.

142   Seawater was collected in the water column in ultra-clean conditions (Giraud et al., 2016) to

143   measure *in situ* parameters and to prepare the microcosms. Seawater and microcosms were sampled

144   similarly in a land laboratory a few hours after collection.

145   Nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}) and silicate ($Si(OH)_4$) concentrations were

146   determined in filtered waters (<0.6 μm PC membrane) stored at -20 °C until analysis using a Bran +

147   Luebbe AAIII auto-analyzer (Aminot and Kérouel, 2007).

148   Filtered samples (0.2 μm; 300AC-Sartobran™ capsules) for dissolved trace metals

149   determination were collected under pure-N_2 pressure (0.7 atm) in acid cleaned low density

150   polyethylene bottles, acidified with ultrapure HCl (pH < 2) and stored in two plastic bags in dark at

151   ambient temperature. Concentrations of dissolved trace metals (cadmium, Cd; lead, Pb; iron, Fe;

152   zinc, Zn; manganese, Mn; cobalt, Co; nickel, Ni; and copper, Cu) were determined in UV-digested

153   samples by ID-ICP-MS (Milne et al., 2010) after preconcentration on a WAKO resin (Kagaya et al.,

154   2009) using an Element XR ICP-MS. Blanks, limits of detection, accuracy and precision (assessed

155   using reference samples) of the ID-ICP-MS method are reported in Table 1. The values determined

156   by ID-ICP-MS were in excellent agreement with the consensus values, apart for Cd that yielded

157   higher concentration in S-SAFE reference sample than the consensus value (Table 1).

158   The pH was determined using a pH ultra-electrode (pHC28) mounted on a HQ40d multi pH-

159   meter (HACH) with an accuracy of ± 0.002 pH unit in samples preserved with saturated $HgCl_2$ in

160   glass bottles hermetically closed with Apiezon grease, sealed with Parafilm® and stored in the dark

161   at ambient temperature.

162   Three complementary methods were used to analyze the phytoplankton community. Pigment

163   signatures were measured by HPLC (using an Agilent Technologies 1100-series) on polysulfone

164   filters (0.22 μm pore-size) frozen at -20 °C and stored in liquid nitrogen, after internal standard

165   addition (vitamin E acetate) and extraction in a 100 % methanol solution (Hooker et al., 2012). Fifty

166   pigments were identified and associated to phytoplankton groups (Uitz et al., 2010). Identification

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167 and enumeration of pico-phytoplankton were realized by flow-cytometry using a BD-FACSVerse™

168 (Marie et al.,1999) in samples preserved in cryotube with addition of 0.25 % glutaraldehyde frozen at

169 -20 °C and stored in liquid nitrogen. Four groups of pico-phytoplankton were identified:

170 *Prochlorococcus*, picoeukaryotes (< 10 µm), and 2 groups of *Synechococcus* discriminated,

171 respectively, by their low and high phycourobilin (PUB) to phycoerythrobilin (PEB) ratios. Taxonomic

172 identification and enumeration of micro-phytoplankton (20-200 µm) and a part of nano-

173 phytoplankton (2-20 µm) (Dussart, 1966) were carried out using an inverted microscope (Wild M40)

174 in samples preserved with neutral lugol solution. Utermöhl settling chambers (Hasle, 1988) were used

175 for micro-phytoplankton analyses, and a smaller sedimentation chamber (2.97 mL) for the analyses of

176 nano-phytoplankton. When possible, phytoplankton was identified to the lowest possible taxonomic

177 level (species, genus or group). Biovolume of each species was also estimated from these

178 microscope analyses (Hillebrand et al., 1999).

179 ### 2.2.2. *In situ* microcosm experiments

180 The potential impact of deep seawater discharge on the phytoplankton community was simulated

181 by *in situ* microcosm incubations of various deep and surface seawater mixing (Giraud et al., 2016).

182 The experiments were conducted from 12th (D0) to 19th (D7) of June 2014. The deep and surface

183 seawaters were collected at the site of the future OTEC pilot plant (61°11'52'' W-14°37'57'' N; Fig.

184 1). Microcosms bottles were incubated on two stainless steel structures set at the depths of deep

185 chlorophyll-*a* maximum (DCM) and at the bottom of the euphotic layer (BEL) on a mooring chain

186 located, for practical reasons, closer to the coast (61°10'9'' W-14°39'8'' N, seafloor at 220 m depth)

187 during 6 days (Giraud et al., 2016).

188 Seawater was collected at D0 at the depths of DCM (45 m depth) and BEL (80 m depth)

189 identified on the future OTEC site from the fluorescence profile, and close to the bottom (1100 m

190 depth corresponding to the pumping depth of the future OTEC plant) in ultra-clean conditions.

191 Deep seawater was mixed in three proportions (0 % as a control hereafter referred to as "Control", 2

192 % as a low input called "2 % of deep seawater", and 10 % as a large input called "10 % of deep

193 seawater") with DCM and BEL waters. Each resulting mixture was distributed in 2.3 L polycarbonate

194 bottles filled up to overflow level, of which four replicates per mixing condition per depth were

195 immersed at their respective sampling-depth for 6 days; duplicates per mixing condition per depth

196 were kept in dark at 25 °C for a few hours until sampling for later characterization of phytoplankton

197 assemblage and biogeochemical properties at D0 (called "Surrounding waters D0"); and duplicates

198 per mixing condition per depth were used to estimate carbon and NO_3^- uptakes at D0 (called

199 "Surrounding waters D0") as described below.

200 Same sampling and mixtures were realized at day 6 (D6, June 18th) just to evaluate the temporal

201 evolution in the natural environment, resting on duplicate bottles per mixing condition per depth for

202 phytoplankton and biogeochemical characterizations at D6 (called "Surrounding waters D6") and

203 using other duplicates to estimate carbon and NO_3^- uptakes at D6 (called "Surrounding waters D6").

204 After the 6 days incubation, all the incubated microcosm bottles on the mooring (called

205 "Microcosm D6") were brought on board. A quarter of each four replicates per condition was put in

206 a new 2.3 L clean bottle and used to estimate carbon and NO_3^- uptakes after 6 days of incubation

207 (called "Microcosm D6"). The remaining microcosm contents were kept for sampling and analysis.

2.2.3. Carbon and nitrate uptakes

209 Carbon (primary production) and NO_3^- uptake rates were estimated in the same sample using the

210 dual $^{13}C/^{15}N$ isotopic label technique (Slawyk et al., 1977). Immediately after sampling, ^{13}C tracer

211 ($NaH^{13}CO_3$, 99 atom%, Eurisotop, 0.25 mmol^{13}C mL^{-1}) and ^{15}N tracer ($Na^{15}NO_3$, 99 atom%, Eurisotop,

212 1 µmol^{15}N mL^{-1}) were added to seawater mixtures at 10^{-3}:1 v/v ratio. The initial enrichment was 10

213 atom% excess of ^{13}C for the bicarbonate pool and 16-95 atom% excess of ^{15}N for the NO_3^- pool

214 depending on the ambient NO_3^- concentration. The $^{13}C/^{15}N$ amended bottles were incubated for 24

215 h on the mooring line at the DCM and BEL depths, after which 1 L samples were filtered onto pre-

216 combusted (450 °C, 4 h) glass fiber filters (Whatman). Filters were stored at -20 °C and oven dried

217 (60 °C, 24 h) prior to analysis. Concentrations of carbon (POC), nitrogen (PON) as well as ^{13}C and ^{15}N

218 enrichments in particulate matter were measured with a mass spectrometer (Delta plus,

219 ThermoFisher Scientific) coupled to a C/N analyzer (Flash EA, ThermoFisher Scientific). Standard

220 deviations were 0.009 µM and 0.004 µM for POC and PON, and 0.0002 atom% and 0.0001 atom%

221 for ^{13}C- and ^{15}N-enrichments, respectively.

222 The absolute uptake rates (ρ, in µmol L^{-1} h^{-1}) were calculated for nitrogen (Dugdale and Wilkerson,

223 1986) and carbon (Fernández et al., 2005) using the particulate organic concentrations measured

224 after 24 h of incubation. These rates were converted into biomass specific uptake rates (V, in µmol

225 µmol POC or PON^{-1} h^{-1}) by dividing ρ by POC or PON. The addition of ^{15}N tracer would cause a

226 substantial increase in dissolved inorganic nitrogen concentrations especially in the surface waters

227 and, in turn, an overestimation of uptake rates (Dugdale and Wilkerson, 1986; Harrison et al., 1996).

228 The NO_3^- uptake rates were corrected for this perturbation (Dugdale and Wilkerson, 1986) using a

229 half-saturation constant of 0.05 µmol.L^{-1} characteristic for nitrogen-poor oceanic waters (Harrison et

230 al., 1996) and the measured NO_3^- concentration. Overestimation was low (< 5 %) in samples with an

231 addition of deep seawater but it was of about 50 % in samples without deep seawater addition. The

232 uptake rates measured in these samples represented therefore estimations rather than actual values.

2.2.4. Statistical analyses

233

234   Kruskal-Wallis test was applied on the set of pigments concentrations, pico-phytoplankton

235   abundances and macronutrients concentrations. If significant differences ($p < 0.05$) were found,

236   Mann-Whitney test was run to identify the samples significantly different. Statistical analyses were

237   performed using Statgraphics Centurion XVI software.

238   ## 3. Results

239   ## 3.1. Modeling of the deep seawater discharge

240   ### 3.1.1. Model evaluation

241   We compared modeled daily profiles (temperature, salinity) of June and November 2000 with *in*

242   *situ* CTD data at OTEC station we recorded in June 2014 and November 2013 (Fig. 2 a-b).

243   In June, the modeled and observed vertical profiles of temperature were quite in agreement with

244   a well mimicked thermocline depth. However, a warm bias of ~1.5 °C was simulated by the model in

245   the top 50 m. Between 300 and 500 m depth, a cold bias of ~1.5 °C depth was also observed. The

246   modeled and experimental salinity profiles presented a similar pattern. However, the salinity was

247   largely overestimated by the model in the top-120 m, especially in the upper 60 m (by ~2 units), as

248   compared to field observations. Between 120 m and 150 m, the model slightly underestimated the

249   salinity.

250   In November, the thermocline and halocline were well reproduced with modeled vertical profiles

251   of temperature and salinity, in good agreement with observations. However, temperature was

252   slightly overestimated by the model, with warm bias of ~0.8 °C. At deeper depths, the modeled and

253   observed temperatures were in excellent agreement. Salinity was underestimated by the model

254   within the top 50 m by ~1 unit, and between 70 and 200 m depths by at maximum 0.3 units. Below

255   200 m depth, modeled and observed salinities exhibited similar profiles.

256   ADCP measurements (horizontal velocity and direction of currents) were made by our DCNS

257   partner at the study site for a feasibility study, but in June 2011 (between 40 m and 800 m depths).

258   ADCP data were compared to model outputs for June 2000 (Fig. 3). Current directions were quite

259   similar between model outputs and ADCP data with a mean direction toward the South/South-East.

260   The horizontal velocity norm was also quite close between both data sets with larger velocity close

261   to the surface at ~50 m depth. Larger difference appeared in subsurface in ADCP data but similar

262   trends were observed and values were relatively close.

263   Modeled physical properties (temperature, salinity, currents) were therefore quite similar to those

264   directly observed at the study site. The small differences observed between model and field data are

265 likely due to inter-annual variability since years examined were indeed different for the model

266 simulation (2000) and the field data (2011, 2013 and 2014).

3.1.2. Impact of the deep seawater discharge on the thermal structure in surface

268 In order to assess the deep seawater discharge impact on the thermal structure of the upper 150

269 m of the water column, the dispersion of temperature differences (ΔT in °C) obtained without and

270 with the deep seawater discharge in the model outputs was examined on two vertical sections. A

271 section of 124 km for the large domain (corresponding to the child domain) and another section of

272 10 km for the near-OTEC domain (defined from 61.24° W to 61.17° W and 14.60° N to 14.67° N)

273 were defined, both centered on the OTEC site and parallel to the coast (Fig. 1). Presently, there are

274 no environmental standards defining threshold levels for temperature difference that will be induced

275 by an OTEC deep seawater discharge. So, the study relied on the World Bank Group prescriptions

276 for liquefied natural gas facilities which set at 3 °C the temperature difference limit at the edges of

277 the zone where initial mixing and dilution take place (IFC, 2007).

278 We thus considered for each discharge depth the cooling and warming outputs from the model,

279 which exhibit a $|\Delta T| \geq 3$ °C. Areas (in % of the considered domain) impacted by these cooling and

280 warming effects were added (absolute values) in order to compare the potential impact of each

281 discharge depth configuration. None of the discharge depth configurations could produce a

282 modification of the thermal structure of the top 150 m of the water column, higher than or equal to

283 the considered temperature threshold ($|\Delta T| \geq 3$ °C), for both domains sections.

284 Then, a lower temperature difference of 0.3 °C (absolute value) was considered. This temperature

285 difference represented a low threshold as compared to the World Bank Group prescriptions (IFC,

286 2007) that instead represent a high threshold. The areas exhibiting a $|\Delta T| \geq 0.3$ °C in the top 150 m

287 (Table 2) were extremely small (< 1 km²) and were not significantly different in both sections and at

288 the different discharge depths, on an annual average and in June (our experimental period).

3.2. Biogeochemical properties and phytoplankton community

3.2.1. Expected biogeochemical properties of the resulting mixed waters

291 The pH was very similar at the DCM and BEL at the OTEC site on D6 (8.24 and 8.25,

292 respectively), whereas deep seawater-pH showed lower value (7.81). The addition of 2 % and 10 %

293 deep seawater to surface waters could thus induce a pH-decrease of respectively, 0.01 and 0.07 unit.

294 Hence, the effect on pH could be rather limited compared to the 0.1 pH decrease (from 8.2 to 8.1)

295 between the pre-industrial time and the 1990's[39].

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296   NO_3^- and PO_4^{3-} concentrations (Table 3) were below the detection limit (< 0.02 μM) at the DCM

297   (55 m) and BEL (80 m) at the OTEC site on observational D4 (June 16th 2014), whereas $Si(OH)_4$

298   concentrations were above detection limit (> 0.08 μM), particularly at the DCM (2.4 μM). NO_2^-

299   concentrations showed the highest values at the BEL whereas they were negligible at the DCM

300   (<0.02 μM). In deep seawater, as commonly observed, NO_3^-, PO_4^{3-} and $Si(OH)_4$ concentrations were

301   largely higher compared to the surface (Table 3). The 2 % and 10 % deep water additions

302   represented a large input for NO_3^- (from <0.02 μM to 0.54 and 2.71 μM, respectively). If the 10 %

303   ratio also induced a large input of PO_4^{3-} (from <0.02 to 0.19 μM), the input of 2 % deep water was

304   more limited (0.04 μM). The effect of 2 % or 10 % deep seawater addition was more limited for

305    $Si(OH)_4$ relatively to NO_3^- and PO_4^{3-} input, yet it accounted for 50-63 % increase for 10 % deep

306   seawater addition (Table 3). Finally, because deep and DCM waters were NO_2^- depleted, the deep

307   seawater input did not modify the NO_2^- concentration at the DCM. At the BEL, NO_2^- concentration

308   was higher and the 10 % addition slightly diluted NO_2^- at this depth.

309   Mn showed maximum concentrations in the surface layer on D4 at the OTEC site (Table 4)

310   decreasing with depth as observed close to the Lesser Antilles in the Atlantic Ocean (Mawji et al.,

311   2015), but the measured surface concentrations were particularly high, especially at the DCM. Fe

312   that commonly dispatches hybrid distribution combining a nutrient-type profile in surface waters and

313   a scavenged-type distribution in deep waters (Bruland, 2003) also exhibited high surface values,

314   particularly at the DCM (Table 4). Cd, Zn, Co, Ni, and Cu dispatched nutrient-type profiles, whereas

315   Pb exhibited scavenged-type profile (Nozaki, 1997; Gruber, 2008), but like for dissolved Fe and Mn,

316   their concentrations in the upper waters were particularly high (Table 4). For all trace metals at both

317   depths, the 2 % deep seawater addition will not induce significant changes in their surface

318   concentrations (Table 4). The 10 % deep seawater addition could increase Cd, Ni and Zn

319   concentrations in surface waters (Table 4), whereas it would not constitute an input of Pb, Cu, Co,

320   and Fe, and it can even dilute Mn (Table 4).

321   The surface waters can thus be enriched in macronutrients (NO_3^-, PO_4^{3-}) when submitted to a

322   deep seawater discharge (particularly with 10 % deep seawater addition) in proportion depending

323   on the depth. The same scheme can be applied in some of the dissolved trace metals (Cd, Ni, Zn)

324   when a large ratio of deep seawater (10 %) is discharged.

325   ### 3.2.2. Phytoplankton community in the natural environment

326   A set of seven accessory pigments identified as biomarkers of specific taxa (Uitz et al., 2010;

327   Table 5) were analyzed at OTEC station at D0, D4 and D6 in surrounding surface waters (Fig. 4), as

328   well as population abundance and their biovolume using light microscopy (Fig. 5).

329   The total chlorophyll *a* (TChl *a* defined as the sum of chlorophyll *a* and divinyl chlorophyll *a*), a

330   proxy of the phytoplankton biomass, was higher at DCM than at BEL, as usually observed, by about

331   two-folds. The fucoxanthin (biomarker of diatoms) concentrations were similar at the DCM and BEL

332   on D0 (Fig. 4), like the total abundance of diatoms (Fig. 5). Fucoxanthin concentration increased by

333   D4 and then by D6 at the DCM, corresponding to increases of cumulated diatoms biovolume on D4

334   (Fig. 5) and of diatoms abundance on D6 (Fig. 5). Peridinin, a biomarker of dinoflagellates, was

335   detected at the DCM unlike at the BEL, with relatively high abundance and biovolume of

336   dinoflagellates (Fig. 5). The 19'-hexanoyloxyfucoxanthin (biomarker of haptophytes) concentration

337   (Fig. 4) and the prymmnesiophytes (haptophyte) abundance and biovolume (Fig. 5) showed higher

338   values at the DCM than at the BEL only at D4.

339   At the DCM, dinoflagellates largely dominated the nano- and micro-phytoplankton assemblage

340   with the largest abundance and biovolume. Whereas prymnesiophytes showed the second highest

341   abundance, its biovolume was very low, on the contrary to diatoms that dispatched lower abundance

342   but higher biovolume (Fig. 5). At the BEL, dinoflagellates, prymnesiophytes and diatoms showed

343   similar abundance, dinoflagellates and the diatoms occupied the major part of the total biovolume.

344   Three groups of dinoflagellates were observed by light microscopy but they could not be identified

345   at species level. However, their small size and the lack of colored starch (using lugol) in the

346   cytoplasm suggested they were mixotrophic or heterotrophic population. Furthermore, the low

347   concentrations of peridinin in samples supported this assumption.

348   At both depths, light microscopy analyses suggested that the large cyanobacteria, mainly

349   *Trichodesmium sp.*, were low in abundance and biovolume. Flow cytometry identification and

350   count indicated that the small cyanobacteria *Prochlorococcus* dominated the pico-

351   phytoplankton assemblage, but they showed a significant decrease from D0 to D6 (Fig. 6). A

352   significant portion of *Synechococcus* was also observed while picoeukaryotes were poorly

353   represented. Both *Prochlorococcus* and *Synechococcus* showed higher abundance at the

354   DCM than at the BEL (by 65 % and 86 %, respectively), in line with the pigments analyses of

355   zeaxanthin (biomarker of cyanobacteria) and total chlorophyll *b* concentrations

356   (prochlorophytes).

3.2.3. Primary production and nitrate uptake in the natural environment

358   The phytoplankton distribution and assemblage can partly drive the intensity of primary

359   production, so the specific uptake rate of carbon (V_C; Fig. 7) and NO_3^- ($V_{NO_3^-}$) were estimated at D0

360   and D6.

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361   V_C in surrounding surface waters was relatively low at D0 (Fig. 7) indicating low primary

362   production in these poor-nutrients waters. Yet, V_C was approximately four-times higher at the DCM

363   (2.10^{-3} h^{-1}) than at the BEL (5.10^{-4} h^{-1}) at D0, but drastically decreasing on D6 at the DCM (to ~6.10^{-4}

364   h^{-1}). V_{NO3-} were also very low at D0 (1.10^{-3} h^{-1} at DCM, 4.10^{-3} h^{-1} at BEL) and drastically decreased at

365   D6, below the detection limit (data not shown).

366   **3.3. Impacts on the phytoplankton community of the deep seawater discharge**

367   **3.3.1.   Changes in the phytoplankton assemblage**

368   At the DCM, TChl *a* was similar in all treatments (p < 0.05) after 6 days of incubation in

369   microcosms (Fig. 8). Only fucoxanthin and 19'-butanoyloxyfucoxanthin showed significant (p < 0.05)

370   higher concentrations in 10 % enrichments as compared to controls, indicating higher abundance

371   and/or biovolume of diatoms and haptophytes. The other diagnostic pigments did not show any

372   significant difference between enriched microcosms and controls. Picoeukaryotes and

373   *Synechococcus* abundances did not show significant variations between the treatments (Fig. 9a).

374   Reversely, *Prochlorococcus* population showed higher (p < 0.05) abundance both in 2 % and 10 %

375   enriched microcosms as compared to controls (Fig. 9a).

376   At the BEL, after the 6 days incubation period, pigments concentrations were below the

377   detection limit indicating very low abundance of phytoplankton. Pico-phytoplankton did not show

378   significant variations between the treatments and the controls (Fig. 9b). Pico-phytoplankton were

379   clearly much less abundant at the BEL (< 1000 cells mL^{-1}) than at DCM (Fig. 9b), 20-times even lower

380   than that observed in surrounding waters at this depth on D6. For comparison, total abundance at

381   the DCM was ~5-times lower in incubated microcosms on D6 compared to surrounding surface

382   waters.

383   **3.3.2.   Changes in the primary production and nitrate uptake**

384   Deep water inputs (2 % and 10 %) to surrounding waters collected at the DCM on D0 led to

385   an increase of V_C within 24 h compared to the controls (by 43 % and 48 %, respectively; Fig. 7); but

386   they had no effect on D6 despite very low value in natural waters at this depth (6.10^{-4} h^{-1}). The 6 days

387   incubated microcosms showed very low V_C in all treatments (Fig.7). At the BEL, V_C were quite similar

388   on D0 and D6 and after 6 days of incubation, without significant differences between the treatments

389   (Fig. 7). V_{NO3-} measured in microcosms after a 6-days *in situ* incubation were below the detection

390   limit (data not shown).

391

392

4. Discussion

4.1. Natural variabilities in the oligotrophic area

4.1.1. Modeling of the deep seawater discharge

Salinity field data showed large seasonal variations, with low values in June 2014 (34.6 on the top 50 m) and much higher values in November 2013 (35.5 on the top 50 m). The model run for year 2000 did not fully reproduce these variations. Indeed, salinity was overestimated by the model in June whereas it was underestimated in November. The observations we made at the OTEC station showed that the low salinity observed in June was associated with high $Si(OH)_4$ concentrations. High $Si(OH)_4$ levels in fresher seawater have been already reported in surface waters in the Caribbean Sea and they were attributed to Amazon and Orinoco fresh rivers inputs (Steven and Brooks, 1972; Moore et al., 1986; Muller-Karger et al., 1995; Hu et al., 2004). Fresh surface waters enriched in $Si(OH)_4$ (Moore et al., 1986; Edmond et al., 1981) can be transported from the Amazon and Orinoco rivers towards the Caribbean Sea by the North Brazil Current and the Guiana Current (Muller-Karger et al., 1988, 1995; Osborne et al., 2014, 2015). It is likely that the rivers discharges and thus its inputs in the Caribbean Sea were quite different between 2000 (modeled year) and 2014 (*in situ* observations), thus explaining the discrepancy between modeled and observed salinities. Meso- and submeso-scale features resulting from the rivers flows could also induce short-term variability in the area and then could explain the observed differences.

4.1.2. Biogeochemistry and phytoplankton community structure

The very low PO_4^{3-} and NO_3^- concentrations recorded in the oligotrophic surrounding surface waters were likely favorable to the development of small phytoplankton, especially to the cyanobacteria as shown with the significant occurrence of *Prochlorococcus* in these waters, which are typical of poor nutrient waters (Partensky et al., 1999). In line with the very low V_{NO3-} measured here, it has been shown that V_{NO3-} by *Prochlorococcus* represents indeed only 5-10 % of its nitrogen uptake whereas reduced nitrogen substrates (NO_2^-, ammonium, and urea) uptake accounts for more than 90-95 % (Casey et al., 2007). By contrast, the development of larger phytoplankton taxa (particularly diatoms), which have higher NO_3^- and PO_4^{3-} requirements for their growth, were probably limited by these elements. Actually, NO_3^- and PO_4^{3-} concentrations in surrounding waters at the DCM were both lower than the detection limit (< 0.02 µM at D4) which is much lower than the average values of half-saturation constants for diatoms (1.6 ± 1.9 µM for NO_3^- and 0.24 ± 0.29 µM for PO_4^{3-}; Sarthou et al., 2005). For $Si(OH)_4$, surrounding surface concentrations at DCM (2.39 µM) were in the range of diatoms half-saturation constants (3.9 ± 5.0 µM; Sarthou et al., 2005), hence the

425   diatoms development was probably not limited by $Si(OH)_4$. Furthermore, diatoms showed low

426   abundance in spite of relatively high $Si(OH)_4$ and dissolved trace metals (in particular Fe)

427   concentrations in surface waters. The potential of Fe limitation on phytoplankton community has

428   been reported previously in upwelling systems, with an apparent half-saturation constant for diatoms

429   growth of 0.26 nM Fe in the Peru Upwelling system (Hutchins et al., 2002). This constant is far lower

430   than the concentration of Fe measured in surrounding waters at DCM (1.08 ± 0.03 µM at D4),

431   suggesting that diatoms were probably not limited by Fe. This further supports growth limitation of

432   diatoms by NO_3^- and/or PO_4^{3-}.

433   Advection of waters from Amazon and Orinoco rivers can explain the relatively high $Si(OH)_4$

434   observed in the Caribbean Sea. However, little information is available on the input of trace metals

435   by these waters into the Caribbean Sea. Amazon river can be a source of dissolved Fe, Cu, Ni, Pb

436   and Co for the western-subtropical North Atlantic (Tovar-Sanchez and Sañudo-Wilhelmy, 2011), but

437   this input can decrease rapidly away from its source like it has been shown for Co in the Western

438   Atlantic (Dulaquais et al., 2014). Those inputs into the Caribbean Sea will have to be further

439   examined, especially for Fe, Cd, Ni, Zn, Mn whose relatively high concentrations were detected in

440   the $Si(OH)_4$-enriched surface waters of this study. Additionally, other inputs of trace metals such as

441   atmospheric deposition can also increase surface concentrations, and those inputs can be substantial

442   (Shelley et al., 2012).

4.1.3. Primary production

444   Despite low V_C on D0 and D6 at the DCM, primary production still indicated much higher value

445   on D0 compared to D6 that was associated with higher TChl *a* (Fig. 4a). The decrease of divinyl-

446   chlorophyll *a* (*Prochlorococcus*) concentration [58] over the 6 days of observation can account for the

447   decrease of TChl *a*, whereas chlorophyll *a* concentrations did not vary significantly during this period.

448   The *Prochlorococcus* abundance was also lower by two-times on D6 compared to D0 (Fig. 6a). On

449   the contrary, fucoxanthin (diatoms) increased by four-times over the 6 days (Fig. 4 a), as well as the

450   diatoms abundance (by three-times; Fig. 5a). In turn, the increase in diatoms abundance was not

451   associated with an increase in primary production. Instead, the observed decrease in primary

452   production can be due to the decrease in *Prochlorococcus* abundance. In tropical and subtropical

453   waters, pico-phytoplankton can indeed contribute to more than 80 % of the primary production

454   (Platt et al., 1983; Goericke and Welschmeyer, 1993). The development of diatoms population likely

455   did not compensate the large decrease in *Prochlorococcus* abundance (from 141 to 63 10^3 cells mL$^-$

456   ^{1}).

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4.2. Impact of deep seawater discharge

4.2.1. Temperature effects

The numerical simulation showed that the area impacted in the top-150 m by a temperature difference larger than or equal to 0.3 °C (absolute value) was lower than 1 km² (~2-3 % of the considered domain) and was insensitive to the injection depth or to the size of the tested domain (Table 2). This suggests that temperature difference might rather be linked to internal variability of the system. Since the effect of the discharge appears undetectable within 2-3 % variation of the model, it can be deduced that in a worst-case scenario, only 3 % of the small domain (300 m along the section, down to the 150 m depth) would be impacted by a temperature difference larger than or equal to 0.3 °C (absolute value). The impact of a 0.3 °C temperature variation on the growth of diatoms, notably on *Pseudonitzschia pseudodelicatissima* species that were observed in our study area, is limited to a change in the growth rate of 0.03 d^{-1} [61]. For *Synechococcus,* a 0.3 °C variation of the temperature would also have a limited impact on the growth, with a variation of only 0.02 d^{-1} (Boyd et al., 2013), like for *Emiliania huxleyi* (coccolithophyceae) for which the induced variation of maximum growth rate will be lower than 0.01 d^{-1} (Fielding, 2013). The thermal effect on the phytoplankton assemblage could thus be considered negligible.

4.2.2. Impact on the phytoplankton community

Microcosms enrichment of DCM waters with 10 % of deep seawater led after 6 days to a significant increase ($p < 0.05$) of fucoxanthin (diatoms) and 19'-butanoyloxyfucoxanthin (haptophytes) by 71 % and 77 %, respectively, as compared to the controls. If the 2 % enrichment also showed similar trends, the differences of diagnostic pigments concentrations were not significant. NO_3^- and PO_4^{3-} concentrations induced by 10 % deep-water input on D0 (2.57 ± 0.13 µM and 0.14 ± 0.2 µM, respectively; Giraud et al., 2016) were close to NO_3^- and PO_4^{3-} half-saturation constants of diatoms (1.6 ± 1.9 µM and 0.24 ± 0.29 µM, respectively; Sarthou et al., 2005). The 10 % enrichment could thus support a development of diatoms. On the contrary, NO_3^- and PO_4^{3-} enrichments induced by 2 % addition of deep-water were too low (0.57 ± 0.02 µM and 0.04 ± 0.00 µM, respectively; Giraud et al., 2016) compared to these half-saturation constants to support the diatoms development. Therefore, the diagnostic pigments suggested a significant response proportionally to the amount of added deep seawater.

Prochlorococcus were also more abundant ($p < 0.05$) in 2 % and 10 % treatments as compared to the controls. This lack of further *Prochlorococcus* population increase in 10 % treatments could be

490   attributed to a higher grazing pressure by haptophytes and/or to NO_3^- and PO_4^{3-} too rich conditions

491   (Giraud et al., 2016).

492   Phytoplankton assemblage widely evolved in surrounding waters, from a predominance of pico-

493   phytoplankton (*Prochlorococcus*) on D0 towards a higher abundance of micro-phytoplankton

494   (diatoms) on D6. In order to assess if the impact on the phytoplankton assemblage due to 10 %

495   deep seawater addition (with a shift towards the diatoms) was in the range of the natural variation

496   observed in the surrounding surface waters, 10 % deep seawater microcosms phytoplankton

497   assemblage was compared to the natural phytoplankton assemblage.

498   Whereas microcosm controls showed a lower *Prochlorococcus* abundance (Fig. 9a) than

499   surrounding surface waters on D6 ($p < 0.05$), the 10 % microcosms additionally showed, higher

500   fucoxanthin (diatoms) and 19'-butanoyloxyfucoxanthin (haptophytes) by about 142 % and 317 %

501   (Fig. 8), respectively, as compared to natural waters at D6. Furthermore, 10 % enrichments showed a

502   fucoxanthin increase over the 6 days period by 3-times higher than in surrounding waters, whereas

503   controls only showed an increase by 1.5-times higher than in surrounding waters. Therefore, it can

504   be concluded that the 10 % deep seawater enrichment induced higher variations of the

505   phytoplankton assemblage than those observed from D0 to D6 in surrounding surface waters.

506   V_C were higher ($p < 0.05$) both in 2 % and 10 % enrichments on D0 as compared to controls,

507   suggesting a positive response of phytoplankton to the deep seawater addition. Conversely, there

508   was no carbon-uptake rate difference ($p < 0.05$) between controls and enriched waters (with 2 % and

509   10 % of deep seawater) at D6 with the 6 days incubated microcosms, suggesting that the observed

510   community modifications did not change the primary production. Indeed, the phytoplankton

511   community was quite similar in surrounding surface waters on D6 and in 6 days-incubated microcosm

512   controls. Thus, only the initial phytoplankton assemblage and initial primary production in

513   surrounding surface waters would influence the response of the phytoplankton community and its

514   production.

515   At the BEL, after 6 days of incubation, deep seawater addition experiments clearly showed lower

516   effects on the phytoplankton community than at the DCM. Indeed, whereas significant differences

517   ($p < 0.05$) between 10 % enrichments and controls were observed in diagnostic pigments

518   concentrations at the DCM, pigments concentrations were too low at the BEL to be quantified. It

519   can be suggested that the lower population and lower carbon uptake could be related to the lowest

520   light availability.

521   Overall, the phytoplankton response was proportional to the amount of added deep seawater. If

522   the phytoplankton assemblage significantly varied over time in the environment, the 10 % deep

523   seawater enrichment showed larger variations (for diatoms and haptophytes) than those observed in

524 the natural environment. The DCM should be more impacted than the BEL by the deep seawater

525 discharge even with a large deep seawater input. On the other hand, the impact on the primary

526 production largely depended on the initial phytoplankton assemblage, which was quite variable over

527 time. The modification of the phytoplankton community to a deep seawater input could also be

528 depending on the initial phytoplankton community. For that, the microcosm experiments did not

529 allow drawing a scenario over the long term of the potential modifications of the primary production

530 and the phytoplankton community associated to the deep seawater discharge by an OTEC.

531 Light microscopy analyses showed a large abundance of dinoflagellates at the DCM (between

532 9,240 and 20,400 cells mL^{-1} on D6 and D4; Fig. 5 a) which could be mixotrophic or heterotrophic and

533 thus probably exert a grazing pressure on the phytoplankton, particularly on the pico-phytoplankton

534 (Liu et al., 2002). However, in this study, the zooplankton larger than 200 µm and its potential control

535 on the phytoplankton community were not considered and should be examined in future studies.

5. Conclusion

537 Two complementary approaches were applied to study the potential effects of the deep

538 seawater discharge of the planned OTEC plant on the phytoplankton community off Martinique.

539 Because the distribution and the development of phytoplankton are directly linked to the surface

540 stratification, it is important to assess the thermal effect of deep seawater by an OTEC plant.

541 Modelling of the deep seawater discharge showed that the thermal structure of the top 150 m of the

542 water column on large and near-OTEC sections should be very slightly impacted for the lowest

543 considered temperature differences |ΔT| ≥ 0.3 °C. If World Bank Group prescriptions of not

544 exceeding a higher temperature difference of 3 °C are followed, the environmental perturbations

545 potentially caused by the operation of the OTEC should be considered negligible. The area where

546 the 150 m-depth waters are impacted by the lowest considered temperature differences |ΔT| ≥ 0.3

547 °C would not exceed 1 km^2 in a worst-case scenario.

548 The phytoplankton community and its production could be impacted by a large deep seawater

549 input. Whereas pico-phytoplankton currently largely dominates the phytoplankton assemblage, a

550 ratio of 10 % of deep seawater in DCM waters could induce a shift toward the diatoms and micro-

551 phytoplankton. The ratio of 2 % of deep seawater in DCM waters only showed significant higher

552 *Prochlorococcus* abundance than controls, but the assemblage and the primary production were not

553 modified by this lower input. The stimulation of *Prochlorococcus* could be due to one or some of the

554 following causes: NO_3^- and/or PO_4^{3-} supply, trace metal supply, lowered pH (higher availability of

555 dissolved inorganic carbon).

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556   Although significant, these results would have to be extended to larger temporal scale, and the

557   phytoplankton interactions with higher trophic levels (such as zooplankton) must be studied.

558   Because no environment standards on the deep seawater discharge effects are available yet, a

559   rigorous monitoring of the phytoplankton community, biogeochemical parameters distribution and

560   of the water column stratification must be established as soon as the OTEC is implemented and

561   during its continuous functioning.

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Biogeosciences Open Access

Discussions

EGU

740   **Tables**

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742   **Table 1-** Comparison of analyses of SAFe (Sampling and Analysis of iron) S and D2 reference
743   samples (http://www.geotraces.org/science/intercalibration) between ID-ICPMS values (this study)
744   and the consensus values. Our mean reagent blanks (based on all blank determinations) for dissolved
745   Cd, Pb, Fe, Ni, Cu, Zn, Mn and Co, and detection limits of ID-ICPMS estimated as three times the
746   standard deviation of the mean reagent blanks are also shown.

747

	Cd (pM)	Pb (pM)	Fe (nM)	Ni (nM)	Cu (nM)	Zn (nM)	Mn (nM)	Co (pM)
SAFe D2								
This study	948.83 ± 65.95	28.86 ± 4.44	0.898 ± 0.098	8.60 ± 0.36	2.15 ± 0.16	7.29 ± 0.27	0.40 ± 0.05	40.12 ± 3.88
Consensus values	986.00 ± 23.00	27.70 ± 1.50	0.933 ± 0.023	8.63 ± 0.25	2.28 ± 0.15	7.43 ± 0.25	0.35 ± 0.05	45.70 ± 2.90
n=	20	20	18	19	22	13	23	23
SAFe S								
This study	7.24 ± 1.57	48.42 ± 6.08	0.087 ± 0.025	2.56 ± 0.55	0.55 ± 0.06	0.07 ± 0.06	0.75 ± 0.05	2.85 ± 0.81
Consensus values	1.10 ± 0.30	48.00 ± 2.20	0.093 ± 0.008	2.28 ± 0.09	0.52 ± 0.05	0.07 ± 0.01	0.79 ± 0.06	4.80 ± 1.20
n=	25	27	15	25	30	10	27	28
Detection Limit	0.996	0.613	0.032	0.096	0.011	0.129	0.001	0.07
Blanks	0.716	1.809	0.061	0.040	0.019	0.129	0.003	0.32

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750   **Table 2-** Area (km^2) impacted in the top-150 m by a temperature difference $|\Delta T| \geq 0.3$ °C on two
751   vertical sections centered on the OTEC, considering eight depths of deep seawater discharge (45,
752   80, 110, 140, 170, 250, 350, 500 m), average and root mean square for the year 2000 (from the
753   monthly data) and for June 2000.

754

Depth of deep water discharge	Mean Year 2000		June 2000	
	Large domain	Near-OTEC domain	Large domain	Near-OTEC domain
45 m	0.4 ± 0.4	0.0 ± 0.1	0.0	0.0
80 m	0.6 ± 0.7	0.1 ± 0.1	0.4	0.0
110 m	0.6 ± 0.5	0.0 ± 0.1	0.9	0.0
140 m	0.4 ± 0.5	0.1 ± 0.1	0.1	0.0
170 m	0.5 ± 0.8	0.0 ± 0.1	0.5	0.0
250 m	0.5 ± 0.7	0.1 ± 0.1	0.1	0.0
350 m	0.5 ± 0.5	0.1 ± 0.1	0.0	0.0
500 m	0.5 ± 0.5	0.1 ± 0.1	0.3	0.0

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768 **Table 3-** Nitrate, silicate, phosphate and nitrite concentrations on June 16th 2014 (D4) at the deep
769 chlorophyll maximum (DCM), at the bottom of the euphotic layer (BEL), and at the deep seawater
770 pumping depth. Concentrations were measured at the OTEC site (0 % addition of deep waters) and
771 calculated for 2 % and 10 % deep seawater additions.
772

Depth (m)	Deep seawater ratio	$[NO_3^-]$ (µM)	$[Si(OH)_4]$ (µM)	$[PO_4^{3-}]$ (µM)	$[NO_2^-]$ (µM)
DCM	0 %	< 0.02	2.39	< 0.02	0.02
	2 %	0.54	2.88	0.04	0.02
	10 %	2.71	4.82	0.19	0.02
BEL	0 %	< 0.02	1.46	< 0.02	0.32
	2 %	0.54	1.96	0.04	0.32
	10 %	2.71	3.98	0.19	0.29
1100	100 %	27.11	26.69	1.87	<0.02

773

774

775 **Table 4-** Concentrations of dissolved trace metals (in nM): Mn, Fe, Cd, Zn, Co, Ni, Cu, Pb measured
776 on June 16th 2014 (D4) at the OTEC site at the DCM, BEL and 1100 m (0 % addition of deep waters),
777 and their calculated concentrations in the mixtures with 2 % and 10 % addition of deep water.
778

Depth (m)	Deep seawater ratio	Mn (nM)	Fe (nM)	Cd (nM)	Zn (nM)	Co (nM)	Ni (nM)	Cu (nM)	Pb (nM)
DCM	0 %	2.97 ± 0.17	1.08 ± 0.03	0.03 ± 0.01	1.54 ± 0.04	0.05 ± 0.00	2.22 ± 0.10	1.70 ± 0.18	0.03 ± 0.00
	2 %	2.92	1.08	0.04	1.56	0.05	2.29	1.70	0.03
	10 %	2.71	1.09	0.07	1.63	0.05	2.60	1.71	0.03
BEL	0 %	1.65 ± 0.04	0.68 ± 0.03	0.03 ± 0.00	0.65 ± 0.03	0.03 ± 0.00	2.26 ± 0.17	1.14 ± 0.10	0.03 ± 0.00
	2 %	1.63	0.69	0.04	0.68	0.03	2.34	1.15	0.03
	10 %	1.52	0.73	0.08	0.82	0.03	2.64	1.21	0.03
1100	100 %	0.34 ± 0.02	1.22 ± 0.05	0.45 ± 0.01	2.39 ± 0.07	0.06 ± 0.00	6.00 ± 0.13	1.80 ± 0.08	0.02 ± 0.00

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781 **Table 5-** Definition of the diagnostic pigments used as phytoplankton biomarkers (taxonomic
782 significance) and associated phytoplankton size class (Uitz et al., 2010).
783

Diagnostic Pigments	Abbreviations	Taxonomic Significance	Phytoplankton Size Class
Fucoxanthin	Fuco	Diatoms	microplankton
Peridinin	Perid	Dinoflagellates	microplankton
19'-hexanoyloxyfucoxanthin	Hex-fuco	Haptophytes	nanoplankton
19'-butanoyloxyfucoxanthin	But-fuco	Pelagophytes and Haptophytes	nanoplankton
Alloxanthin	Allo	Cryptophytes	nanoplankton
chlorophyll *b* + divinyl chlorophyll *b*	TChlb	Cyanobacteria, Prochlorophytes	picoplankton
Zeaxanthin	Zea	Chlorophytes, Prochlorophytes	picoplankton

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787 **Figure captions**

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789 **Figure 1-** Bathymetry of the parent and child (grey rectangle) domains interpolated from the GINA
790 data base with a zoom on the near domain (black rectangle); the oblique white and black lines
791 represent the large and small sections, respectively, used for numerical simulations.
792
793 **Figure 2-** Comparison of temperature and salinity between model outputs and field data at the
794 OTEC station (a) on June 16th 2000 and 2014, respectively and (b) on November 28th 2000 and 2013,
795 respectively.
796
797 **Figure 3-** Comparison of mean current direction and horizontal velocity norm between model
798 outputs from June 2000 and ADCP data from June 2011.
799
800 **Figure 4-** Pigment concentrations (from HPLC analysis) at the OTEC site at the DCM (a) and at the
801 BEL (b), on June 12th (D0), 16th (D4), 18th (D6) 2014 (bars represent the standard deviation).
802
803 **Figure 5-** Abundance and biovolume of micro- and part of nano-phytoplankton at the OTEC site on
804 June 12th (D0), 16th (D4), 18th (D6) 2014, at the DCM (a and c, respectively) and at the BEL (b and d,
805 respectively) (bars represent the standard deviation).
806
807 **Figure 6-** Abundance of pico-phytoplankton at the DCM (a) and at the BEL (b), on June 12th (D0),
808 16th (D4), 18th (D6) 2014 (bars represent the standard deviation).
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810 **Figure 7-** Specific carbon uptake rate (h^{-1}) at the DCM (a) and BEL (b) depths, on June 12th (D0), and
811 18th (D6), and in 6 days incubated microcosms (D6), for the three mixing conditions (0 %, 2 % and 10
812 % of deep seawater additions) (for surrounding waters bars represent the standard deviation for 3
813 replicates).
814
815 **Figure 8-** Diagnostic pigment concentrations in surrounding surface waters on D0 and D6, and in
816 controls and deep water-enriched (2 % and 10 %) microcosms after 6 days of incubation at the DCM
817 (bars represent the standard deviation). Similar letters (a, b or c) attributed to 2 or more treatments
818 indicate no significant differences ($p < 0.05$) between these treatments.
819
820 **Figure 9-** Abundance of picophytoplankton in surrounding surface waters on day 0 and 6, and in
821 controls and deep water-enriched (2 % and 10 %) microcosms after 6 days of incubation at 45 m
822 depth (a) and 80 m depth (b) (bars represent the standard deviation). Similar letters (a, b or c)
823 attributed to 2 or more treatments indicate no significant differences ($p < 0.05$) between these
824 treatments.
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827   **Figure 1**

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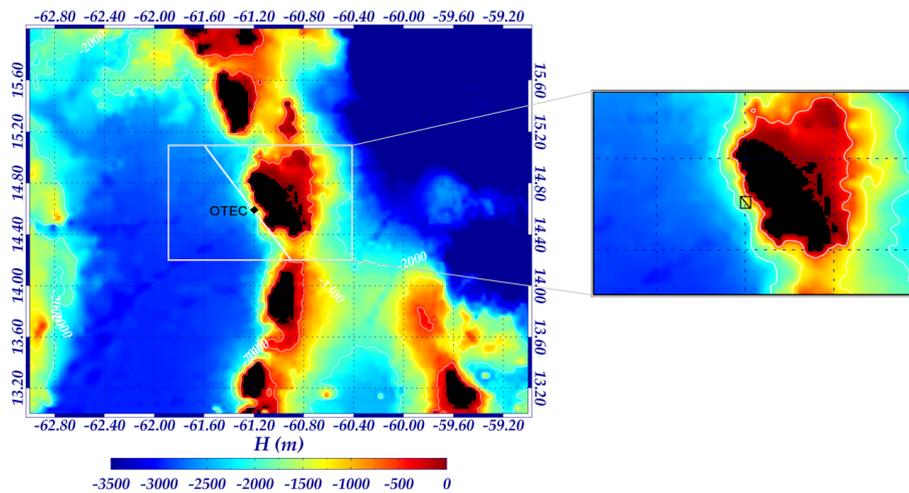
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833   **Figure 2**

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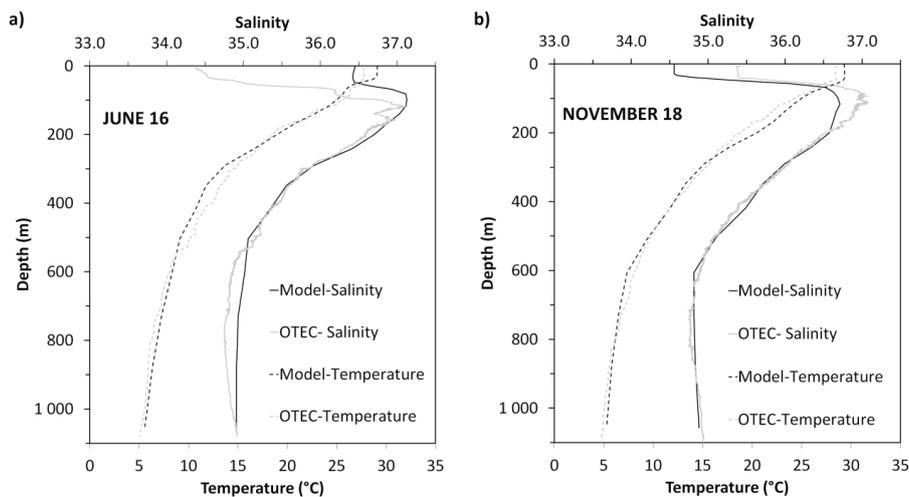
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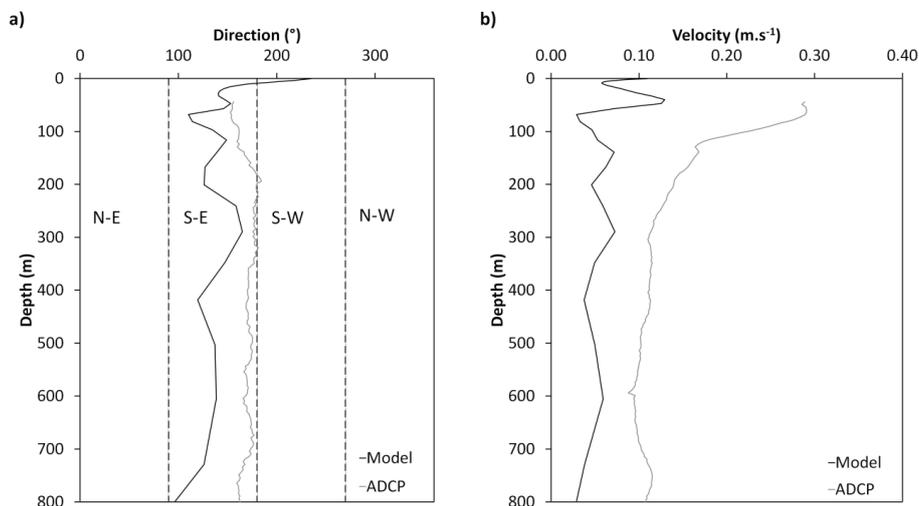
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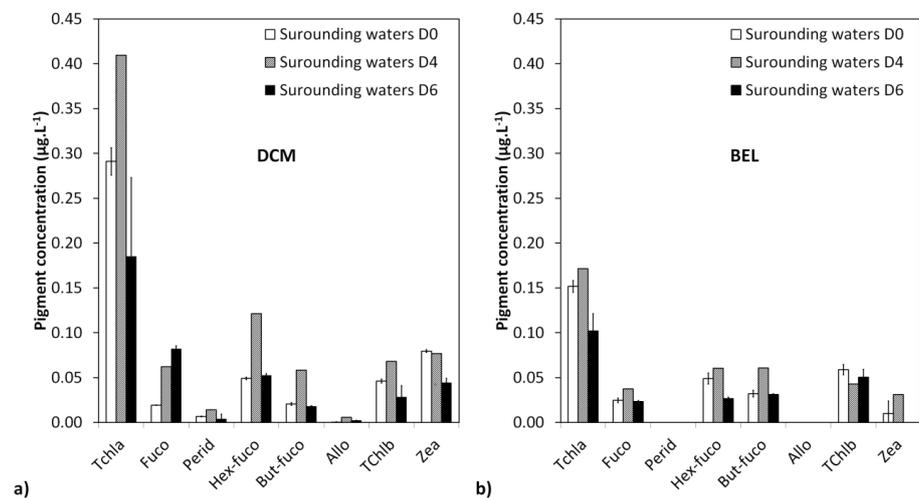
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860   **Figure 5**

a)   b)

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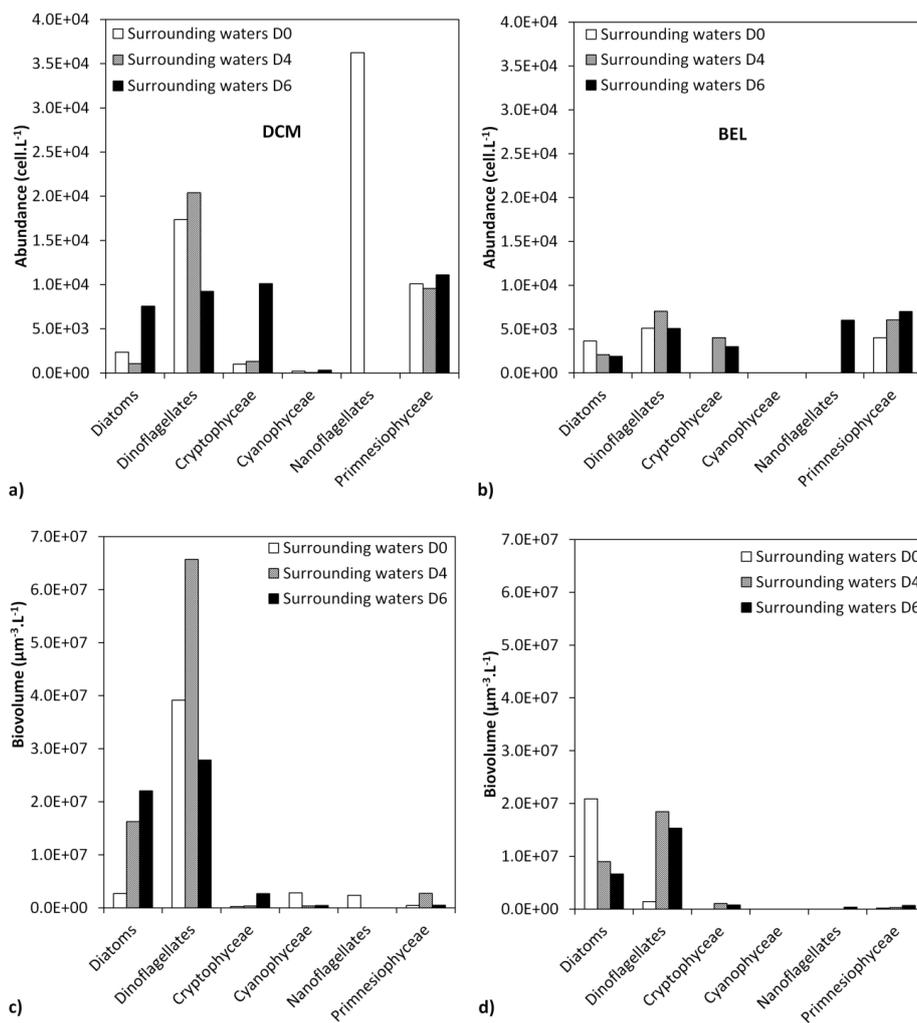
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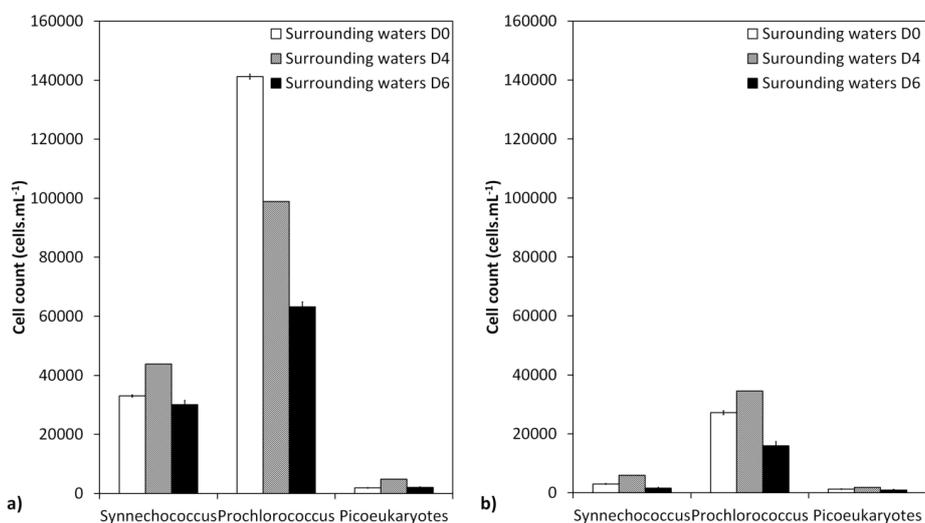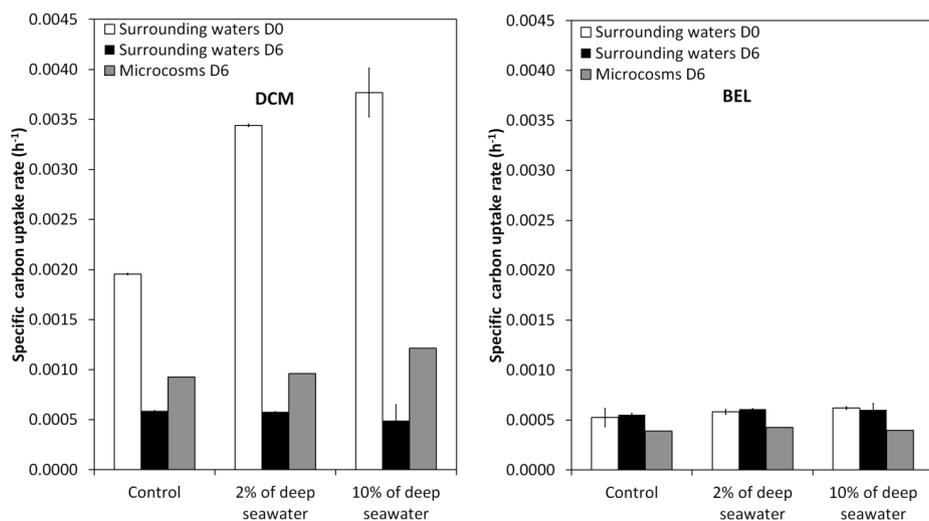
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