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The composition and distribution of labile dissolved organic matter across the south west Pacific

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Abstract

The distribution and dynamics of dissolved organic carbon (DOC) and dissolved combined neutral sugars (DCNS) were studied across an increasing oligotrophic gradient (-18 to -22°N latitude) spanning from the Melanesian Archipelago (MA) area to the western part of the south Pacific gyre (WGY), in austral summer, as a part of the OUTPACE project. Our results showed DOC and DCNS concentrations exhibited little differences among the MA and WGY areas (0-200m: 55-78 µMC for DOC and 1.5-2 µMC for DCNS), however, a deeper penetration of DOC was noticeable at 150 m depth at the WGY area. This finding was also reflected to the DOC and semi-labile DOC (DOC_{SL}) stocks values (integration 0-200m) for which we found higher values in the WGY than the MA area. The high excess DOC_{SL} measured in WGY was characterized by a high residence time (130 ± 31 days (n = 3)) about three times higher than the MA region (T_r = 40 ± 7 days (n = 8)) suggesting an accumulation of the semi-labile DOM in the surface waters of WGY. DCNS yields (DCNS-C x DOC^{-1} %) also followed this pattern with higher values recorded in the WGY (3.2 ± 1.3%) than MA (2.8 ± 0.8%) highlighting the presence of semi-labile dissolved organic material (DOM) in the form of polysaccharides. These polysaccharides also exhibited a higher residence time in WGY (T_r = 8 ± 4 days, n = 3) than in MA (T_r = 3 ± 1days, n=8) suggesting that this DCNS pool persists longer in the surface waters of the WGY. The accumulation of DOC_{SL} in the surface waters of WGY is probably due to the very slow bacterial degradation due to nutrient limitation indicating that biologically produced DOC can be stored in the euphotic layer for a very long period.

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1. Introduction

Gyres are oceanic deserts similar to those found in continental landscapes spanning an area of several thousands of Km and are characterized by low nutrient content and limited life (Raimbault et al., 2008; D'Hondt et al., 2009; Bender et al., 2016; de Verneil et al., 2017a, b). Moreover, gyres are now considered as the worlds plastic dumps (Law et al., 2010; Eriksen et al., 2013; Cozar et al., 2014) whereas their study may help to understand future climate changes (Di Lorenzo et al., 2008; Zhang et al., 2014) and marine ecosystem functioning (Sibert et al., 2016; Browing et al., 2017). Among the five well-known oceanic gyres the South Pacific subtropical gyre, although the world's largest, has been less studied mainly due to its remoteness from the main landmasses. Nonetheless, earlier studies indicated that the western part of gyre (western tropical south pacific; WTSP) is a hot spot of N_2 fixation (Bonnet et al., 2013; Bonnet et al., 2017; Caffin et al., 2017) and recent studies have shown that there is a gradient of increasing oligotrophy from WTSP to the south Pacific Gyre (GY) (Moutin et al., 2018). Flowing from the east of the GY, oligotrophy decreases toward the Chilean coast (Claustre et al., 2008) with high residual phosphate concentrations in the center of the GY (Moutin et al., 2008).

Recent studies indicated an efficient DOC export in the subtropical gyres is related with the inhibition of DOC utilization under low-nutrient conditions (Letscher et al., 2015; Roshan and DeVries, 2017). Similar observations have also been made for the oligotrophic Mediterranean Sea (Guyennon et al., 2015). However, little information exists regarding dissolved organic matter (DOM) dynamics in GY particularly for its labile component (accumulation, export, fate), which is mainly represented by carbohydrates (Sempéré et al., 2008; Goldberg et al., 2011).

Among the three well-identified chemical families (amino acids, lipids and carbohydrates) in

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seawater, carbohydrates are the major components of organic matter in surface and deep waters accounting 5-10% and < 5% of dissolved organic carbon (DOC), respectively as shown by liquid chromatography (Benner, 2002; Panagiotopoulos and Sempéré, 2005 and references therein). The carbohydrate pool of DOC consists of free monosaccharides (i.e. free monomers) and polysaccharides (i.e. dissolved combined neutral sugars or DCNS), which are generally measured as their monosaccharide constituents (sum of fucose, rhamnose, arabinose, galactose, glucose, mannose and xylose) after acid hydrolysis (Aluwihare et al., 1997; Skoog and Benner, 1997; Kirchman et al., 2001; Panagiotopoulos and Sempéré, 2005). Free monosaccharide concentrations range from 10 to100 nM, they account < 10% of total dissolved neutral sugars (TDNS) and experiments have shown that are rapidly utilized (minutes to hours) by bacterioplankton and as such they are considered as ultra labile organic matter (Rich et al., 1996; Skoog et al., 1999; Kirchman et al., 2001). Polysaccharide or dissolved combined neutral sugars (DCNS) concentrations range from 200-800 nM, they account 80-95% of TDNS and experiments have shown that they disappear within time scales of days to months and, as such, they are considered as labile and semi-labile organic matter (Aluwihare and Repeta, 1999; Carlson and Hansell, 2015 and references therein). Other studies have shown that this labile and/or semi-labile organic matter accumulates in the surface ocean and may potentially be exported to depth contributing to ocean carbon pump (Goldberg et al., 2010; Carlson and Hansell, 2015).

In the frame of the OUTPACE project we studied DOM dynamics in terms of DOC and DCNS composition in relation to N_2 fixation to evaluate the production and fate of organic matter (including carbon export) which was one of the main goals of the project. The results are presented and discussed along with heterotrophic prokaryotic production (BP) to better

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understand the bacterial cycling of dissolved organic matter (DOM) in the area.

2. Materials and Methods

2.1 Sampling

Sampling took place along a 5500 Km transect spanning from New Caledonia to French Polynesia in the Western Tropical South Pacific (WTSP) onboard the R/V *L'Atalante* during the Oligotrophy to Ultraoligotrophy Pacific Experiment (OUTPACE) cruise (19 February-5 April, 2015). Samples were taken from 18 different stations comprising three long duration stations (LDA, LDB, and LDC; about 7-8 days duration) and 15 short duration (SD1-15) stations (~8 h duration). Biogeochemical and physical characteristics of these sites as well as the adaptive strategy are described in detail elsewhere (Moutin et al., 2017). Briefly, the cruise took place between 18-20°S covering two contrasted trophic regimes with increasing oligotrophy from west to east (Fig.1).

Discrete seawater samples were collected from 12 L Niskin bottles equipped with Viton O-rings and silicon tubes to avoid chemical contamination. For DOC and DCNS analyses, samples were filtered through two precombusted (450°C for 24 h) GF/F glass fiber filters using a custom-made all-glass/Teflon filtration syringe system. Samples for DOC were collected into precombusted glass ampoules (450°C, 6h) that were sealed after acidification with H_3PO_4 (85%) and stored in the dark at 4°C. Samples for DCNS were collected in 40-mL Falcon vials (previously cleaned with 10% of HCl and Milli-Q water) and frozen at -20°C until analyses.

3. Chemical and microbiological Analyses

3.1. Dissolved organic carbon (DOC) determination

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DOC was measured by high temperature combustion on a Shimadzu TOC-L analyzer (Cauwet, 1999). Typical analytical precision was ± 0.1-0.5 µM C (SD). Consensus reference materials (http://www.rsmas.miami.edu/groups/biogeochem/CRM.html) were injected every 12 to 17 samples to insure stable operating conditions.

3.2. Dissolved combined neutral sugars (DCNS) determination

3.2.1. Carbohydrate extraction and isolation

Seawater samples were desalted using dialysis tubes with a molecular weight cut-off of 100-500 Da (Spectra/Por® Biotech cellulose ester) according to the protocol of Panagiotopoulos et al. (2014). Briefly, the dialysis tube was filled with 8 mL of the sample and the dialysis was conducted into a 1 L beaker filled with Milli-Q water at 4°C in the dark. Dialysis was achieved after 4-5 h (salinity dropped from 35 to 1-2 g L^{-1}). Samples were transferred into 40 mL plastic vials (Falcon; previously cleaned with 10% HCl and Milli-Q water), frozen at -30 °C, and freeze dried. The obtained powder was hydrolyzed with 1M HCl for 20 h at 100°C and the samples were again freeze dried to remove the HCl acid (Murrell and Hollibaugh, 2000; Engel and Handel, 2011). The dried samples were diluted in 4 mL of Milli-Q water, filtered through quartz wool, and pipetted into scintillation vials for liquid chromatographic analysis. The vials were kept at 4°C until the time of analysis (this never exceeded 24 h). The recovery yields of the whole procedure (dialysis and hydrolysis) were estimated using standard polysaccharides (laminarin, and chondroitine sulfate) and ranged from 82 to 86% (n=3).

3.2.2. Liquid Chromatography

Carbohydrate concentrations in samples were measured by liquid chromatography according

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138 to Mopper et al. (1992) and were modified by Panagiotopoulos et al. (2001, 2014). Briefly,
139 neutral monosaccharides were separated on an-anion exchange column (Carbopac PA-1,
140 Thermo) by isocratic elution (mobile phase 19 mM NaOH) and were detected by an
141 electrochemical detector set in the pulsed amperometric mode (Panagiotopoulos et al., 2014).
142 The flow rate and the column temperature were set at 0.7 mL min^{-1} and 17°C, respectively. Data
143 acquisition and processing were performed using the Dionex software Chromeleon. Repeated
144 injections (n = 6) of a dissolved sample resulted in a CV of 12-15% for the peak area, for all
145 carbohydrates. Adonitol was used as an internal standard and was recovered at a percentage of
146 80-95%; however, we have chosen not to correct our original data.
147
148 **3.3. Bacterial production**
149 Heterotrophic prokaryotic production (BP) was determined onboard with the ^{3}H-leucine
150 incorporation technique to measure protein synthesis (Smith and Azam, 1992). Additional details
151 are given in Van Wambeke et al. (2018). Briefly, 1.5 mL samples were incubated in the dark for
152 1-2 h after addition of ^{3}H leucine, at a final concentration of 20 nM, with standard deviation of
153 the triplicate measurements being on average 9%. A factor of 1.5 Kg C mol $leucine^{-1}$ was used to
154 convert leucine incorporation to carbon equivalents. To estimate bacterial carbon demand
155 (BCD) which is used to calculate semi-labile DOC residence time, we used a bacterial growth
156 efficiency (BGE) of 8% as determined experimentally during the OUTPACE cruise (Van
157 Wambeke et al., 2018). BCD was calculated by dividing BP values at each station with BGE.
158 Trapezoidal 0-200 m integrals were then computed from volumetric rates.
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4. Results

4.1 General observations

The OUTPACE cruise was conducted under strong stratification conditions (Moutin et al., 2018) during austral summer encompassing a longitudinal oligotrophic gradient starting from the Melanesian Archipelago (MA) area (stations SD1-SD13 including LDA and LDB stations) and ending in the western part of the south Pacific gyre (WGY; stations SD14-SD15 including LDC station; Fig. 1). Additional information on the hydrological conditions of the study area (*i.e* temperature, salinity) including water masses characteristics is provided elsewhere (de Verneil et al., 2017a; Moutin et al., 2018). Two different trends can be noticed in a first approach:

a. Most of the biogeochemical parameters examined in the OUTPACE cruise (chlorophyll α concentrations, primary production and heterotrophic prokaryotic production (BP) , N_2 fixation rates, and nutrient concentrations) exhibited significantly higher values in the MA area than in the WGY area (Moutin et al., 2018; Van Wambeke et al., 2018; Benavides et al., 2018; Caffin et al., 2017). These differences were also reflected by the distribution of the diazotrophic communities detected in both areas further highlighting the different dynamics across the oligotrophic gradient (Stenegren et al., 2018; Moutin et al., 2017, 2018).

b. The bulk of DOM as shown by DOC analysis did not follow the above biogeochemical pattern and showed little variations on DOC absolute concentrations although a deeper penetration of DOM was noticeable at 150 m depth at the WGY area (Fig. 2a). As such, epipelagic (0-200 m) DOC concentrations all over the OUTPACE cruise ranged from 55 to 78 µM C with highest values observed at LDB (~85 µM C) probably related to a decaying phytoplankton bloom (de Verneuil et al., 2017b; Van Wambeke et al., 2018). Mesopelagic (200-

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1000 m) DOC values varied between 45 to 55 µM C (Fig. 3a) and are in agreement with previous studies in the South Pacific Ocean (Doval and Hansell, 2000; Hansell et al., 2009; Raimbault et al. 2008).

DCNS concentrations closely followed DOC trends and fluctuated between 1.5-2 µM C (Fig. 2b) in the epipelagic zone. These values are in good agreement to those previously reported for the central and/or the eastern part of the south Pacific Gyre (1.1-3.0 µM C; Sempéré et al., 2008) that were recorded under strong stratification conditions during austral summer (Claustre et al., 2008). Compared with other oceanic provinces our epipelagic DCNS concentrations fall in the same range to those reported in the BATS station in the Sargasso Sea (1.0-2.7 µM C) also monitored under stratification conditions (Goldberg et al., 2010). Below 200 m depth DCNS concentrations ranged from 0.5 to 1 µMC (Fig. 3b) and concur with previous reported literature values (Skoog and Benner, 1997; Amon and Benner, 2003).

4.2 DCNS yields and composition

The contribution of DCNS-C to the DOC pool is referred here as DCNS yields and are presented as a percentage of DOC (*i.e* DCNS-C x DOC^{-1} %). Epipelagic (0-200 m) average DCNS yields were slightly higher in the WGY (average ± sd: 3.2 ± 1.3%) than the MA (2.8 ± 0.9%) whereas deeper than 200 m they were 2.6 ± 0.9% and 2.3 ± 0.9% for the WGY and MA, respectively. These values are in good agreement to those reported for the eastern part of the gyre (Sempéré et al., 2008) and concur well with the range of values (2-7%) recorded in the Equatorial Pacific (Rich et al., 1996; Skoog and Benner, 1997).

The molecular composition of carbohydrates revealed that glucose was the major

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monosaccharide at all depths in both the MA and WGY areas accounting for 55-75% of the DCNS. Glucose concentrations (DCGlc-C) ranged from 0.5 to 1 µMC in both areas (Fig. 2c, Fig. 3c), however, a significantly higher mol% contribution of glucose was recorded in the WGY than the MA especially at depths > 200 m (Fig. 5). Glucose was followed by xylose (9-12%), galactose (4-9%) and mannose (5-8%) whereas the other monosaccharides accounted for < 6% of DCNS (Fig. 5). The same suite of monosaccharides was also reported by Sempéré et al. (2008) although the latter author also found that arabinose was among the major monosaccharides. Finally, it is worth noting that the relative abundance of glucose increased by depth and sometimes accounted 100% of the DCNS especially in the WGY area (Fig. 5).

4.3 DOC and DCNS stocks calculation

DOC stocks (integrated values 0-200 m) were calculated in the same stations where carbohydrate (DCNS) data were available in order to have a better comparison between the MA (stations: SD3, SD4, SD5, SD6, SD7, SD9, SD11, SD13) and WGY (LDC, SD14, SD15) stations (Fig. 2a). Semi labile DOC stock (DOC_{SL}) was calculated by subtracting an average DOC value (refractory DOC) measured at 1000 m depth from the DOC pool. This DOC value was 41 µMC (40.8 ± 1.8 µMC, n = 11) and was estimated averaging all DOC values at 1000m from all stations (n = 11). DOC_{SL} stock values in the upper 200m averaged 4494 ± 520 (n = 8) and 5121± 400 (n = 3) mmol C m^{-2} accounting for 37± 2% (n = 8) and 38 ± 1% (n = 3) of DOC in the MA and WGY sites respectively. DCNS represented 9 ± 5% (n = 8) and 6 ± 4% (n = 3) of DOC_{SL} in the MA and WGY sites, respectively, further suggesting that only a small percentage of DOC_{SL} can be attributed to DCNS (polysaccharides).

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5. Discussion

5.1 DOC and DCNS stocks in relation with biological activity

In terms of absolute stocks, DOC and DOC_{SL} were respectively by 4 and 12% higher in the WGY than in the MA whereas the opposite trend was observed for DCNS (Fig. 4b). DCNS stocks were by 12% higher in the MA than in the WGY, which agrees with the high primary production rates measured at MA (Fig. 4a). As DCNS accounted only 3.2 ± 1.3% and 6 ± 4% (n =3) of DOC and DOC_{SL} in WGY site, respectively it appears that DCNS cannot explain alone these differences in organic carbon stocks and that other semi-labile compounds (*i.e* proteins and lipids) should be taken under consideration. Unfortunately, proteins (combined amino acids) were not measured in this study. However, based on concentration kinetics on single amino acids recent investigations indicated significantly lower ^{3}H leucine concentrations in the LDC (0.56 nM) than the LDA (1.80 nM) stations (Duhamel et al., 2018). This result may suggest that single amino acids and perhaps proteins are exhausted in the LDC station reflecting the ultra-oligotrophic regime of the WGY. On the other hand, DOM exhibited only slightly different C/N ratios (integrated values 0-70 m) between MA (C/N = 13) and WGY (C/N =14), which does not suggest differences on DON dynamics in relation with organic matter lability (Moutin et al., 2018). Clearly more investigations are warranted on combined and free amino acids distribution in relation with N_2 fixation.

The high excess DOC_{SL} measured in WGY was also characterized by an elevated residence time T_r calculated as the ratio of DOC_{SL} / BCD. Our results showed that T_r in the WGY was in the order of 130 ± 31 days (n = 3), i.e. about three times higher than in the MA region (T_r = 40 ± 7 days (n = 8) indicating an accumulation of the semi-labile DOM in the surface waters of WGY

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(Fig. 4c). As suggested by previous studies the accumulation of DOC in the surface waters of oligotrophic regimes may be related in biotic and/or abiotic factors.

Nutrient limitation can prevent DOC assimilation by heterotrophic bacteria and as such sources and sinks are uncoupled, allowing accumulation (Thingstad et al., 1997; Jiao et al., 2010). Biodegradation experiments (Van Wambeke et al., 2018) focusing on the determination of the BGE and the degradation of the labile DOC pool (turning over 10 days) revealed a less biodegradable DOM fraction and lower degradation rates at the LDC (2.4% labile DOC; 0.012 d^{-1}) than the LDA site (5.3% labile DOC; 0.039 d^{-1}). Other experiments, focusing on the factors limiting BP by testing the effect of different nutrient additions, showed that BP is limited in a first place by the availability of labile carbon in the WGY (as tracked with glucose addition, Van Wambeke et al., 2018). This limitation on BP by labile carbon was also the case in the center of the GY (Van Wambeke et al., 2008), while N limitation (as tracked by addition of ammonium+nitrate) was more pronounced in the MA area.

Although extensive photodegradation may transform recalcitrant organic matter into labile, the low content in chromophoric DOM recorded in the surface waters of WGY (αCDOM(350) = 0.010-0.015 m^{-1}, 0-50 m; Dupouy et al. unpublished results from the OUTPACE cruise) points toward an already photobleached and thus photodegraded organic material (Tedetti et al., 2007; Carlson and Hansel, 2015). Notably, the 10% irradiance depths for solar radiations (Z 10%) clearly showed a higher penetration of UV-R and PAR radiations in the WGY area than in MA area (Dupouy et al., 2018). These results are in agreement with previous investigations reporting an intense solar radiation in the south Pacific gyre highlighting an important decrease of chromophoric dissolved organic matter (CDOM) in the GY (Tedetti et al., 2007).

The computation of the C, N, and P budgets in the upper 0-70 m layer by Moutin et al.

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(2018) suggested that at 70 m the environmental conditions remained seasonally unchanged during the OUTPACE cruise forming an average wintertime depth of mixed layer. These authors calculated seasonal (from winter to austral summer) net DOM and POM accumulation based on such assumptions and found a dominance of DOC accumulation in the MA area (391 to 445 mmol m^{-2} over 8 months). This DOC accumulation in the MA area was 3.8 to 8.1 times higher than that of POC accumulation during the same time period whereas, only DOC accumulation was calculated at WGY, although two times lower than DOC in the MA. The accumulation of DOC and DOC_{SL} (Fig. 4b) in the WGY may have important implications to the sequestration of this organic material to the mesopelagic layers. DOC appears to be the major form of export of carbon in the WGY area and this result agrees with the general feature observed in oligotrophic regimes (Roshan and Devries, 2017).

5.2 DCNS dynamics across the south west Pacific

Previous investigations have employed the DCNS yields along with mol% of glucose to assess the diagenetically "freshness" of organic matter (Skoog and Benner, 1997; Benner, 2002; Goldberg et al. 2010). In general freshly produced DOM has DCNS yields >10% and mol% glucose between 28-71% (Biersmith and Benner, 1998; Hama and Yanagi, 2001). Elevated mol% glucose (> 25%) does not necessarily mirror fresh material because such values have also been reported for deep DOM and low molecular weight DOM that are considered as a diagenetically altered material (Skoog et al., 1997). Our results showed higher DCNS yields in the surface waters of WGY than the MA area with about a similar contribution of glucose (52± 17% , n = 8 vs 49± 3%, n= 3; Fig. 5a) to the DCNS pool, further confirming the presence of a

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higher amount of semi-labile organic material in WGY than in the MA. Despite that DCNS represent a small fraction of semi-labile DOC the higher residence time of DCNS in the WGY (T_r = 8 ± 4days, n = 3) than the MA area (T_r = 3 ± 1days, n=8) clearly shows that the DCNS pool persist longer in the surface waters of the WGY (Fig. 4c). Moreover, because carbohydrates do not absorb light these polysaccharides (DCNS) do not seem to be impacted by the high photochemistry in WGY and potentially may be exported in the Ocean interior.

As expected, DCNS yields decreased by depth but remained always higher in WGY than the MA area. Glucose accounted for 75% and 50% of DCNS in the WGY and MA areas, respectively (200 m depth), and this percentage increased considerably with depth in both areas (76% for MA and 96% for WGY at 2000 m depth) indicating a preferential removal of the other carbohydrates relative to glucose (Fig. 5b; Fig. 5c). The low DCNS yields (~1%) at 2000 m depth along with the high % mol abundance of glucose clearly suggests the presence of diagenetically altered DOM and is consistent with previous investigations (Skoog and Benner, 1997; Goldberg et al. 2010; Golberg et al., 2011).

6. Conclusions

This study showed a rather uniform distribution of DOC and DCNS concentrations in surface waters across an increasing oligotrophic gradient in the south west Pacific Ocean during the OUTPACE cruise. Nevertheless, our results showed that DOC and DOC_{SL} stocks were by 4 and 12% higher in WGY than the MA area, respectively accompanied with higher residence times in the WGY area indicating an accumulation of semi-labile material in the latter area. Although DCNS accounted a small fraction of DOC_{SL} (5 – 9%) our results showed that DCNS or

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polysaccharides also exhibited a higher residence time and higher DCNS in the WGY than in the MA area indicating that DCNS persist longer in the WGY. Glucose was the major monosaccharide in both areas (50 - 75%) and its relative abundance increased with depth along with a decrease of the DCNS yields indicating a preferential removal of the other carbohydrates relative to glucose. Clearly more investigations are warranted to better characterize this DOC_{SL} material in terms of combined and free amino acids distribution in relation with N_2 fixation.

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Figure captions:

Figure 1: Quasi-Lagrangian Surface Chlorophyll-a concentration (mg m^{-3}) during the OUTPACE cruise. The satellite data are weighted in time by each pixel's distance from the ship's position for the entire cruise. The white line shows the vessel route (data from the hull-mounted ADCP positioning system). Coral reefs and coastlines are shown in black, land is grey, and areas of no data are left white. The positions of the short (long) duration stations are shown by cross (plus) symbols. The ocean color satellite products are produced by CLS.
Figure courtesy of A. de Verneil (02/06/2017).

Figure 2: Depth profiles of (A) DOC (B) DCNS and (C) DCGlc in the upper surface layer (0-300m) of the study area. Abbreviations DCNS: Dissolved combined neutral sugars; DCGlc; Dissolved combined glucose. DCNS and DCGlc concentration is given in carbon equivalents in order to have the same unit with DOC. Long duration stations (LDA, LDB and LDC) are also indicated in each graph. In contrast to DCNS, DOC was also sampled in LDA and LDB including SD2, SD8, SD10, and SD12 stations and these results are shown in Fig. 2A and Fig. 3A.

Figure 3: Depth profiles of (A) DOC (B) DCNS and (C) DCGlc in the 0-2000 m layer of the study area. Abbreviations and comments on DOC sampling are given in Fig. 1. The white rectangles mask abnormal extrapolation due to the absence of DCNS data.

Figure 4: (A) Integrated (0-200m) BCD and PP fluxes (mmol C m^{-2} d^{-1}) (B) Carbon stock

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(mmol C m^{-2} d^{-1}) and (C) residence time (days) of semi labile DOC and DCNS-C for MA and WGY. MA comprises the SD2-SD13 stations and WGY comprises the LDC and SD14-SD15. BCD values are calculated assuming a BGE of 8% according to to VanWambeke et al. (2018) (see material and methods). Error bars correspond to standard deviation of the different stations.

Figure 5: Relative abundance (%) of dissolved monosaccharides at (A) surface, (B) 200 m and (C) 2000 m depth for MA and WGY. MA comprises the SD2-SD13 stations and WGY comprises the LDC and SD14-SD15.

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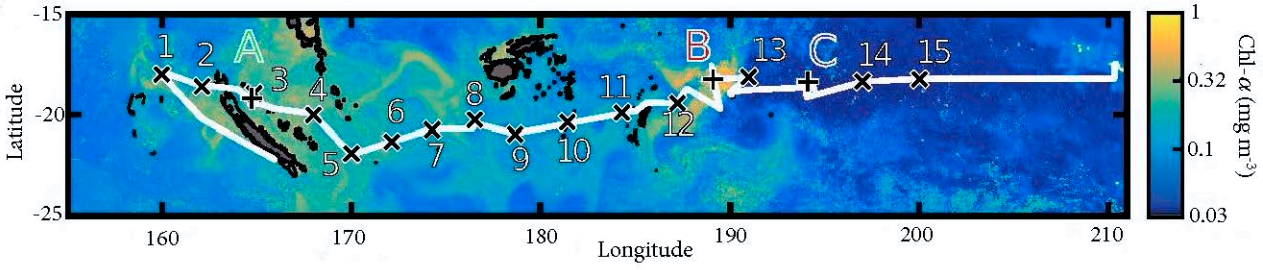

Figure 1

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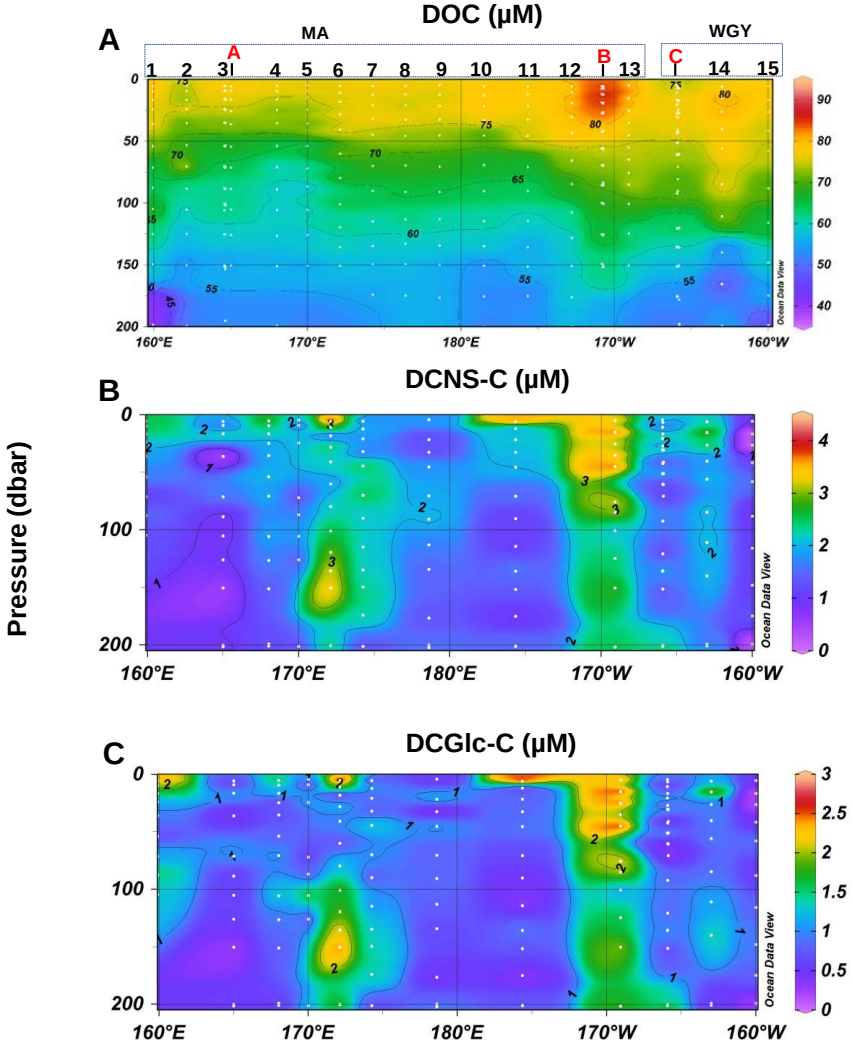

Figure 2

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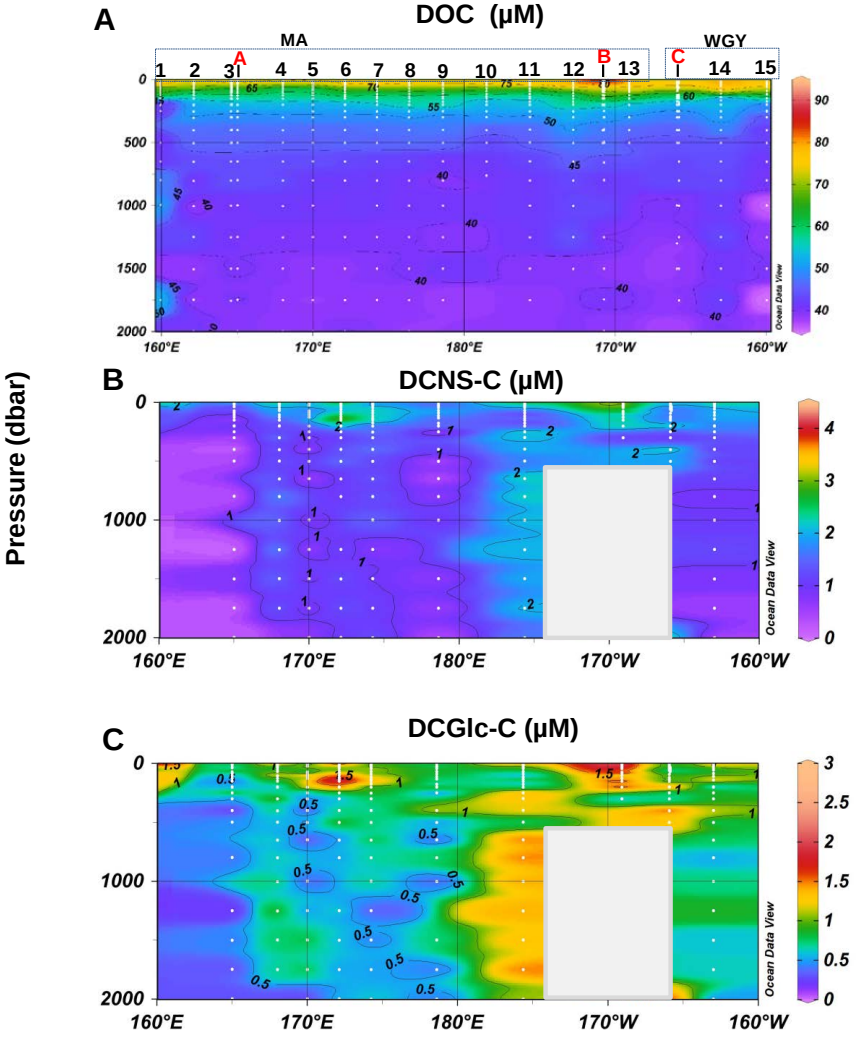

Figure 3

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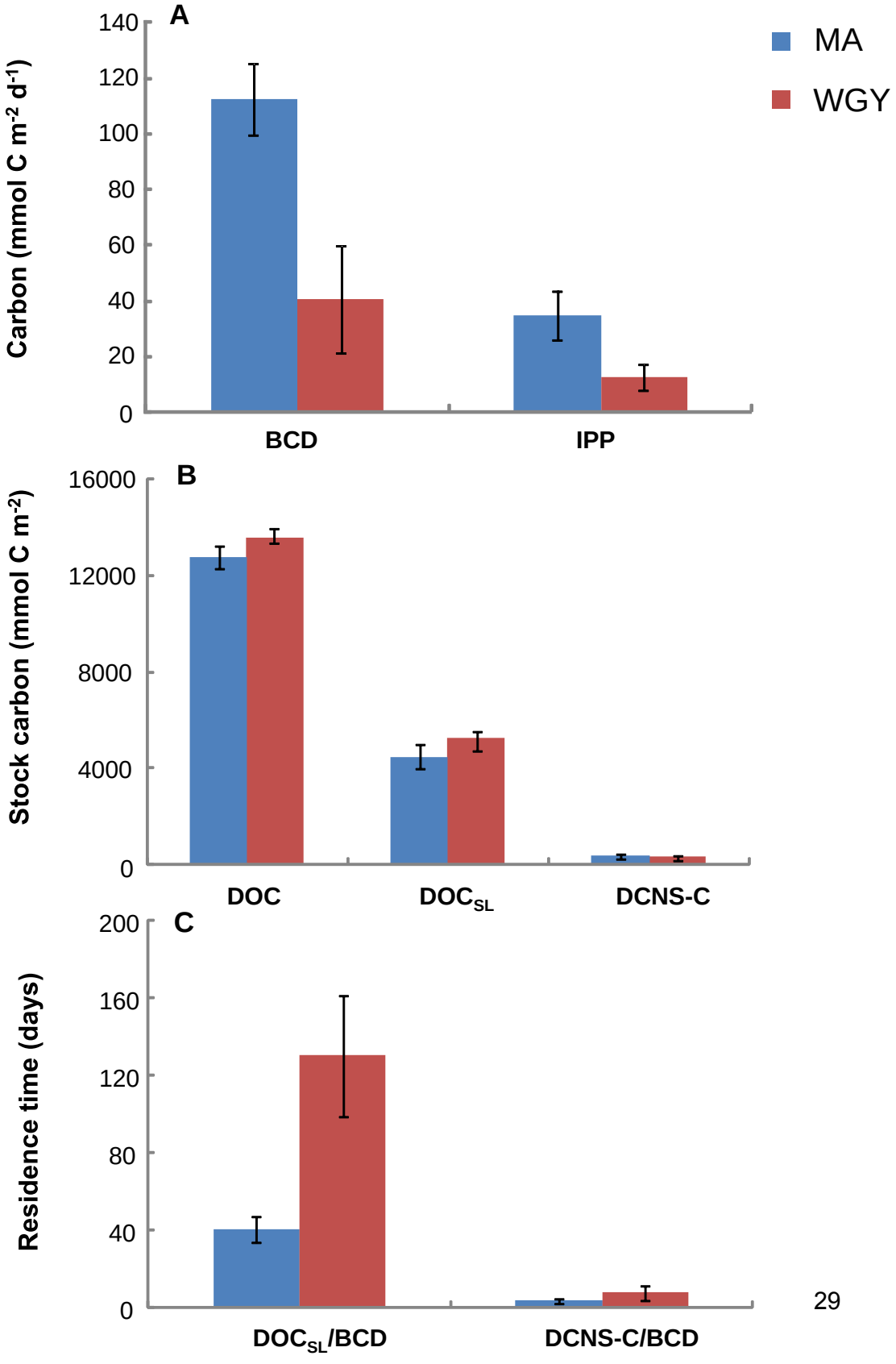

Figure 4

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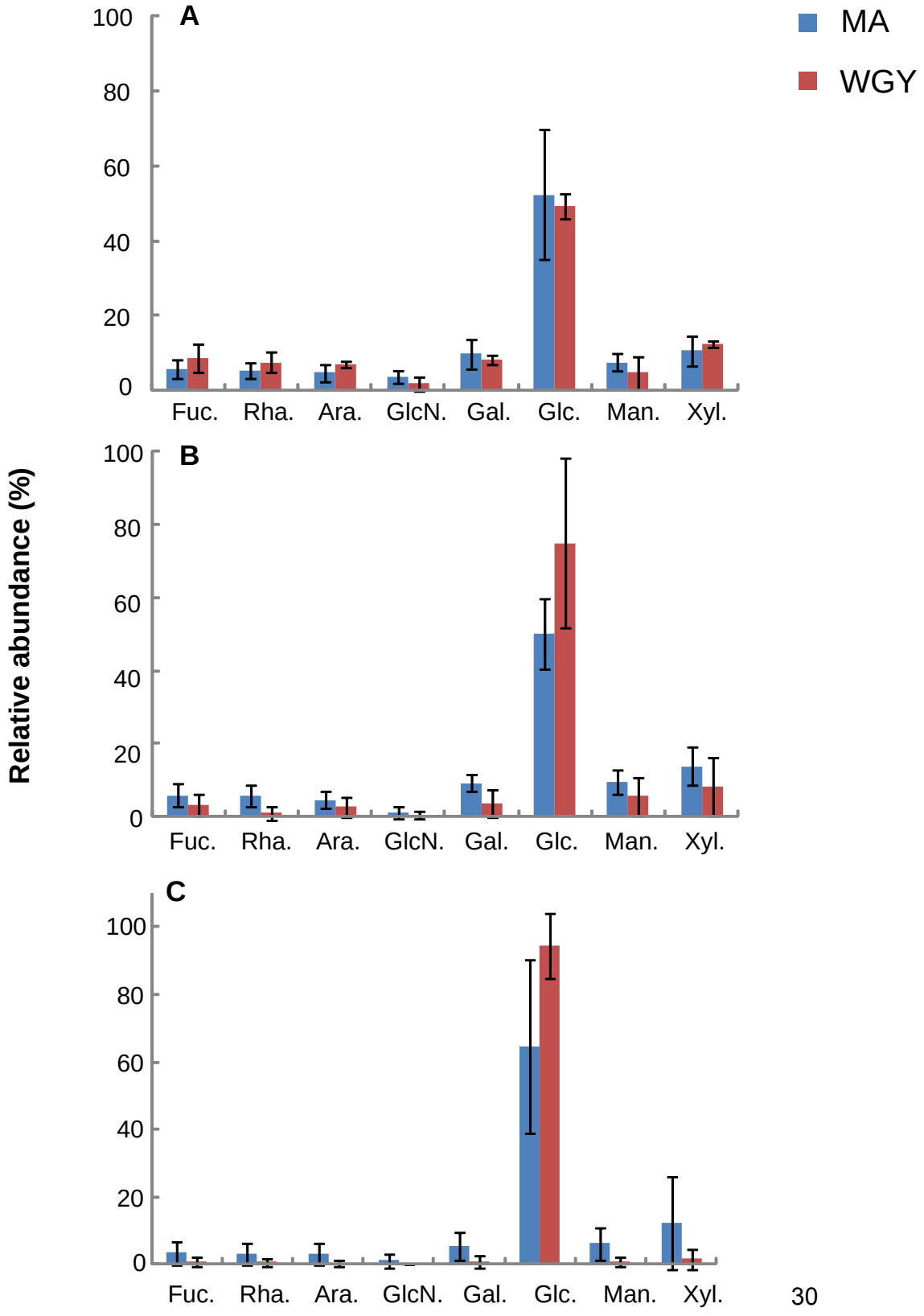

Figure 5