

Interactive comment on “Carbon dynamics in the western Arctic Ocean: insights from full-depth carbon isotope profiles of DIC, DOC, and POC” by D. R. Griffith et al.

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We appreciate the reviewers' comments (shown below). We have found them to be thoughtful and generally supportive. We have addressed each of them in turn.

B. Chen Comment: 1. "in situ DIC fixation at these depths (3-16 $\mu\text{mol C m}^{-3}$)" in line 9, page 10687. Is the unit correct? I think that it should be " $\mu\text{mol C L}^{-3}$ ", or the value is too small to be detected.

Author Response: The range in question ($3 - 16 \mu\text{mol m}^{-3}$) is that portion (4 – 22 %) of the ambient POCsusp ($72.6 \mu\text{mol m}^{-3}$; averaged between 150m and 3000m) that we estimate would derive from DIC fixation based on dual isotope mass balance cal-

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culations. We have changed the wording slightly at page 10687 (lines 1-12) to help clarify this (see below). "The source of chemical energy driving deep Arctic DIC fixation remains uncertain. One possibility is that chemoautotrophy is driven by nitrifying organisms that utilize NH_4^+ from the decomposition of suspended and sinking particulate organic matter (Karl et al., 1984). If we assume that the average vertical organic nitrogen flux between 150 - 3000 m ($2.8 \text{ mmol N m}^{-2} \text{ y}^{-1}$ (Honjo et al., 2010)) is entirely converted to NH_4^+ and nitrifiers require approximately 10 NH_4^+ molecules to fix a single molecule of CO_2 (e.g., Wuchter et al., 2006), then sinking organic nitrogen fluxes alone could support DIC fixation rates as high as $280 \mu\text{mol C m}^{-2} \text{ y}^{-1}$, which is relatively large compared to our isotope-based estimates of the fraction of POCsusp derived from in situ DIC fixation at these depths ($3 - 16 \mu\text{mol C m}^{-3}$). And while further mechanistic, genetic, and compound-specific isotope studies are clearly needed, our results provide bulk isotopic evidence that DIC fixation contributes significantly to POCsusp in the meso- and bathypelagic Arctic."

B. Chen Comment: 2. For the calculation on page 10686, if no advected POC or sorbed DOC was considered, will the picture of the in situ DIC fixation be changed a lot?

Author Response: In our model, advected POC and sorbed DOC contribute ^{14}C -depleted carbon to the POCsusp pool. There is reason to believe that both sources are likely, and removing them as a third end-member leads to an overdetermined system with results that depend strongly on which isotope (^{13}C or ^{14}C) is used for two end-member mass balance calculations. Still, both scenarios predict a slightly larger contribution from DIC fixation. An additional source of intermediate age carbon to the POCsusp pool could be derived from heterotrophic consumption of a DOC fraction that is both ^{13}C enriched (sugars, etc) and ^{14}C modern (per Repeta and Aluwihare, 2006). We failed to mention this possibility in the original manuscript and have therefore changed lines 25-27 on page 10685 to read: "One possibility is that these enriched $\text{POC}^{14}\text{Csusp}$ values reflect heterotrophic organisms that consume labile (modern) or

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semi-labile OC ($\Delta^{14}\text{C} \sim -120\text{‰}$ (Repeta and Aluwihare, 2006)) attached to otherwise refractory POC sink (e.g., White et al., 2007)."

R. Benner Comment: The authors present novel and interesting data on the isotopic compositions of the major forms of carbon in the Canada Basin. There are many potential uses for these data, and the authors highlight one particularly interesting observation - the potential for an isotopic signature of chemolithoautotrophic carbon fixation at intermediate depths in the basin. Indications of chemolithoautotrophy have been observed at intermediate depths in other ocean basins, so the authors' observations are consistent with the growing recognition of this process of carbon incorporation in the ocean interior. The low $\Delta^{14}\text{C}$ values in the deep Canada Basin are an interesting feature that the authors do not discuss. The $\Delta^{14}\text{C}$ in the deep Canada Basin is depleted (-450‰) in comparison to values for the deep North Atlantic (-390‰ Bauer 2002). It appears this could be due to aging in the Canada Basin, which is consistent with the increase in age of DIC in basin deep waters. However, the $\Delta^{13}\text{C}$ in the deep Canada Basin is also depleted (-23‰ in comparison to the deep North Atlantic (-21‰ Bauer 2002). This suggests a different source of DOC could also be impacting its $\Delta^{14}\text{C}$ content. It would be useful for the authors to expand on this and make a more quantitative comparison between the depletion of radiocarbon in DOC and DIC in the Canada Basin.

Author Response: As the reviewer points out, the constant offset between $\Delta^{14}\text{C}$ and $\Delta^{13}\text{C}$ in the deep Canada Basin does suggest aging in this isolated deep water. We have added the following paragraph at page 10683 (line 19) to address the offset between $\Delta^{14}\text{C}$ and $\Delta^{13}\text{C}$: "Canada Basin $\Delta^{14}\text{C}$ values are depleted relative to $\Delta^{13}\text{C}$ throughout the water column, and largely reflect the stratification of Atlantic and Pacific source waters in the upper 1000 m (Fig. 2). Below 1000 m, the $\Delta^{14}\text{C}$ and $\Delta^{13}\text{C}$ profiles mirror one another with an offset (380‰ at CB4; 356‰ at CB9) that is similar to other oceans (Druffel and Bauer, 2000)." We also agree with the reviewer that depleted $\Delta^{13}\text{C}$ values in the deep Canada Basin point to a source of DOC other

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than the North Atlantic water. Evidence from this study and others strongly implicates terrestrial OC as the most likely source of 13C depleted DOC to the deep Arctic. We have changed the sentence at page 10683 (line 4-6) and added the paragraph below at page 10683 (line 6) to explain and quantify this contribution: "Previous measurements of lignin phenols and 13C isotope signatures pointed to relatively minor contributions from terrestrial OC to the deep Canada Basin DOC pool (Anderson, 2002; Opsahl et al., 1999)." "Yet, the DOC isotope profiles presented here (Fig. 2) suggest that terrestrial OC has a large influence on deep Canada Basin waters. The fact that deep Arctic $\Delta^{13}\text{C}$ ($\delta^{13}\text{C} \sim -23\text{‰}$) is more depleted than deep North Atlantic $\Delta^{13}\text{C}$ ($\delta^{13}\text{C} \sim -21\text{‰}$ (Bauer, 2002)) is most likely due to relatively large terrestrial OC contributions to the Arctic Ocean. An obvious source is OC from Arctic rivers ($\delta^{13}\text{C} \sim -26$ to -29‰ (Goni et al., 2005; Guo et al., 2007; Naidu et al., 2000; Raymond et al., 2007)). While riverine DOC is largely confined to fresh arctic surface waters where it can be degraded or exported to the North Atlantic Ocean (Benner et al., 2005; Opsahl et al., 1999), riverine POC clearly has the potential to reach deep basins directly or following deposition in shelf sediments and subsequent resuspension and lateral transport by currents and eddies (Hwang et al., 2008; O'Brien et al., 2011). Moreover, Arctic riverine DOC is unlikely to be a major source of terrestrial OC to the deep Canada Basin because its characteristically enriched 14C values ($\Delta^{14}\text{C} \sim 50\text{‰}$ (Raymond et al., 2007)) are not consistent with depleted deep Arctic $\Delta^{14}\text{C}$ measurements. Arctic riverine POC, on the other hand, is depleted in both 13C and 14C ($\delta^{13}\text{C} \sim -27\text{‰}$, $\Delta^{14}\text{C} \sim -600\text{‰}$ (Goni et al., 2005; Guo et al., 2007)), and some portion could be converted to DOC on Arctic margins, in shelf sediments, or after transport to the deep basin. On this basis, dual isotope mass balance calculations suggest that ~ 30 % of deep Canada Basin DOC could be derived from terrestrial POC sources, and aged North Atlantic DOC ($\delta^{13}\text{C} \sim -21\text{‰}$, $\Delta^{14}\text{C} \sim -390\text{‰}$ (Bauer, 2002)) makes up the balance."

R. Benner Specific Comment: Pg 10687, line 9 - the rate of carbon fixation should include the unit of time (3-16 $\mu\text{mol C m}^{-3} \text{y}^{-1}$)

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Author Response: See response to reviewer B. Chen above.

R.L. Hansman Comment: This paper contributes a complete data set of concentrations, $\delta^{13}\text{C}$, and $\Delta^{14}\text{C}$ for DIC, DOC, and suspended POC depth profiles from two sites in the Arctic. These data are an interesting complement to existing profiles from other major ocean basins. The unique inputs and conditions of the Arctic Ocean as compared to more open ocean sites make this a necessary contribution to understanding the global marine carbon cycle. A notable highlight is the isotopic signature of suspended POC, of which the Canada Basin has extremely low concentrations. The ^{14}C -enriched signature of suspended POC relative to sinking POC potentially indicates significant DIC fixation by chemoautotrophs, particularly at intermediate depths. These observations are consistent with the growing evidence supporting chemoautotrophy in the deep ocean, and provide additional geochemical support to many existing microbial observations. The collection of sorbed DOC which served as a 'blank' for suspended POC appears fortuitous in this case due to an in situ pump failing to start. As it resulted in up to 19% of total organic carbon for suspended POC samples (albeit in an area of very low concentrations), future sample collection should include such a characterization of DOC sorption.

Author Response: We agree with the reviewer.

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