Response to Referee #2 (our replied are in bold)

The high latitude region of the Southern Hemisphere which include Antarctic ice sheet and Southern Ocean is thought to play an important role in climate system, especially in long-climate change. Hence, it is important to investigate paleoclimate change the region to better understand Earth's climate. However, due to limited application of environmental proxies in the region, significant portions of Earth history, environmental records in the high latitude region are less developed than that of low and mid latitudes. Lower and higher molecular fatty acids that are produced by varieties of organisms in the ocean environment are ubiquitous in ocean sediments. Thus, fatty acids may have a potential as paleoenvironmental proxy. This study explores paleoclimatic utility of fatty acids in Southern Ocean sediments and suggests that stable carbon isotope ratio of the low (C18) and mid (C24) chain fatty acids could be used as productivity proxy in the sea ice area. Although further studies are needed to confirm robustness of the proxy, this study contributes development of biogeochemical proxy which has a potential to apply to high latitude ocean sediment. Hence, this study fits scope of Biogeosciences and suitable for publication in the journal. I have some comments on the article as below.

1. I would suggest to include some explanations that application of biomarker proxy is limited in polar regions into the introduction section (e.g. a powerful proxy such alkenone is not applicable in this region. HBI compounds, that are useful proxy of sea ice, are labile and cannot be applied to geological deep past. On the other hand, fatty acids are ubiquitous and abundantly detected even in old sediment and has a potential but its utility has not been investigated well). Such explanations highlight importance of this work.

We thank the reviewer for this excellent suggestion and in our final submission will include an additional few sentences in the introduction section highlighting the utility of fatty acids as a proxy in this region.

2. Although a number of fatty acids including C16 to C26 were abundantly detected in the studied samples (Figure S2), the authors show and discuss d13C results of C18 and C24 fatty acids only. I wonder why the authors focus the two compounds only. I suppose that aim of this paper is to investigate paleoclimatic utility of fatty acids in marine sediments. Hence, it is worth to also include results of the other compounds into the manuscript. I think many people are interested in results of other compounds and know how d13C profiles of other compounds look like. Including this significantly contributes to develop application of fatty acids in marine sediments to paleoclimate study.

The C18 and C24 δ^{13}C results were discussed in the paper as a representative of the short- and long-chain fatty acids groups respectively, as they appear to have different producers and thus offer a different signal. Both compounds yielded the highest quality isotope measurements whereas most other compounds had lower concentrations and therefore isotope measurements were of a poorer quality and not appropriate for publication. While we did obtain some isotope data on the C16 fatty acid, the peaks were not as clean (i.e. there was some coelution) and the data had higher error levels meaning we did not view the data as being as trustworthy or suitable for publication compared to the C18 and C24. We will, however, provide a spreadsheet of the concentration (all fatty acids) and δ^{13}C (C18 and C24 fatty acids) data as part of the supplement. We refer the reviewer to

In lines 148 – 152 we do state the reason for focusing on these two compounds as follows: "The C18 and C24 FAs are the most abundant compounds within the SCFA and LCFA groups, respectively, and also the least correlated with each other both in the whole core (R2 = 0.5) and below 25 cm (R2 = 0.07), which suggests they are the most likely to be produced by different

organisms. Furthermore, these two compounds yielded the highest quality isotope measurements, due to their greater concentrations, clean baseline and minimal coeluting peaks (Fig. S2). Thus, these two compounds (C18 and C24) will be the focus of analysis and discussion."

3. As for pCO2 effect on plankton d13C, important literature is missing in the manuscript (Pop et al., 1999, vol 13, 827-843, GBC). They measured d13C of POC along the north-south transect of the Southern Ocean and show significant negative correlation between dissolved CO2 and d13C of POC, suggesting strong control of pCO2 on d13C of phytoplankton. There needs to take into consideration the result for discussion.

We thank the reviewer for pointing out this important study. In our final submission we will include discussion of Popp et al., 1999 to Section 4.2. Their findings are consistent with our data in which CO_2 plays a key role in driving carbon isotope compositions of marine sterol biomarkers.

4. 4.2.3. Productivity section: The authors argue that changes in productivity is the most plausible driver for variability of fatty acid d13C recorded in the sediment core based on the results of previous studies conducted in the Southern Ocean (Villinski et al., 2008; Arrigo et al., 2015; Zhang et al., 2014). I basically agree that significant increase in productivity results in remarkable higher values of phytoplankton d13C in the polynya environment. However, those papers (Villinski et al., 2008; Arrigo et al., 2015; Zhang et al., 2014) all argue that observed increases in productivity in the regions are caused by meltwater input which promote surface stratification in summer time with reducing vertical mixing and supplying Fe, providing ideal condition for algal growth. Shadwick et al., GRL (2013) and Jack Pan et al., PlosOne (2019) also clearly show a significant correlation between meltwater fraction, chlorophyll concentration and surface water pCO2 drawdown. Especially, Shadwick et al., GRL (2013) investigates glacial meltwater impact on biological carbon drawdown in the studied region. Indeed, those paper shows lowering surface pCO2 happened in the regions where meltwater plume intruded. Regardless of sea ice fluctuations, plankton production takes place in summer when ice sheet melts. This suggests variability of meltwater input rather significantly affects productivity. Therefore, I would suggest to consider possible link between meltwater and productivity in the manuscript. Indeed, the observed resent increase in d13C of C16 fatty acid in sediment core is consistent with the fact of significant melting of Antarctic ice sheet for the past decades.

In our final submission, we will add in a few sentences in the introduction section discussing what is known about the drivers of productivity in this region. Various papers have shown that *Phaeocystis antarctica* for instance seems to predominate in more deeply mixed waters (e.g. Arrigo et al., 1999 and several other papers), as opposed to surface stratification being the main factor increasing primary productivity, even if meltwater and nutrient (e.g. Fe) transport plays a role on their production.

However, we feel that to include an interpretation of the drivers of productivity in our record is beyond the scope of this paper. We are working on a follow up paper which draws on other proxy data in which we can make more interpretations about the role of environmental factors such as sea ice and meltwater in driving productivity.

5. F. cylindrus% and F. rhombica% records are shown in Figures 6 and 7, but the authors do not mention anything about those records in the manuscript. I wonder why those data are shown in the figures.

We thank the reviewer for pointing out this oversight. We included relative abundances of these two diatoms in Fig. 6 (but not in Fig. 7 as the reviewer suggests) along with F. *kerguelensis*, F. *curta*

and CRS as representatives of the main diatom groups, to show that shifts in fatty acid $\delta^{13}C$ are most strongly covariant with *F. kerguensis* and not these other groups. We will add a few sentences explaining the reason for including these diatoms in our final submission.