Anonymous Referee #2

Liang Su and Co-Authors present a new proxy downcore record from the Chukchi Sea covering the past 200 years combined with results from surface sediments. The aim is to investigate different sources (pelagic/sympagic) of organic carbon in the study area. With their record they show the relationship between sea ice and organic matter input to better the understanding of the mechanisms driving the marine carbon cycle in the Arctic Ocean. This study is relevant due to the ongoing and expected climate changes in the Arctic Ocean especially regarding the fate of organic carbon produced, delivered in the Chukchi Sea, an area of dramatic sea-ice loss in the recent years.

The manuscript is well written and the presented work is of importance to the scientific community. However, some points need clarification and/or correction before publication.

Apologies, in case I have misinterpreted anything.

We greatly appreciate the referee in reviewing our manuscript. Please refer to the one-to-one response below in blue for specific modifications and clarifications.

General comments:

The interpretation of the IP_{25}/PIP_{25} record needs some attention. I think the biggest weakness is, that you do not use your IP_{25} record from surface sediments to verify the interpretation of your down core record, e.g., to validate the PIP_{25} index and its environmental signal.

This is a good point. We have made sensitivity test on *c*-factor based on the surface sediments from the study region. See the detailed answers to specific comments below.

Further an age control of surface sediments should at least be discussed. Surface sediments may not always represent modern conditions or a mix of several hundred to thousand years, which makes the comparison with satellite data from a very specific time interval difficult. Further details on this are given in the Specific Comments.

Limitation linked to the age of the surface sediments is indeed an issue and we have added a discussion on this in the revised manuscript. For a detailed explanation see the responses to specific comments below.

In the figures, the time on the x-axis is displayed from left/old to right/young. In my understanding, it is common to show old ages on the right and young ages on the left in the palaeoceanographic community. This may also be the reason for some inconsistencies in the order results are described, see comment below.

The PAGES2k community working on the Common Era climate (last 2000 years) has agreed to have Present on the right, while paleoceanographers working on more ancient climate have it on the left (cf papers of Pages2k network; PAGES2k, 2013, 2019).

PAGES2k Consortium. 2013. Continental-scale temperature variability during the past two millennia. Nature Geoscience, 6, 339–346.

PAGES2k Consortium. 2019. Consistent multidecadal variability in global temperature reconstructions and simulations over the Common Era. Nature Geoscience, 12, 643-649.

Specific Comments

Introduction

L79 Belt et al., 2007, de Vernal et al., 2013 seem rather old and rather specific proxy studies. Further there have been updates on the given references and many other studies regarding this topic.

We updated the references and selected review articles (Belt, 2018; de Vernal et al., 2013) for their broader coverage.

Belt, S. T.: Source-specific biomarkers as proxies for Arctic and Antarctic sea ice, Org. Geochem., 125, 277–298, https://doi.org/10.1016/j.orggeochem.2018.10.002, 2018.

de Vernal, A., Gersonde, R., Goosse, H., Seidenkrantz, M.-S., and Wolff, E. W.: Sea ice in the paleoclimate system: the challenge of reconstructing sea ice from proxies – an introduction, Quat. Sci. Rev., 79, 1–8, https://doi.org/10.1016/j.quascirev.2013.08.009, 2013.

Fig 1 The blue dots are barely visible, please change the color. The black pentagram is too small. What is the source of the sea ice margins, please add a reference.

We changed the blue dots to red ones and enlarged the star now in red to make it more visible. References of the sea ice margins were added in the figure caption (https://nsidc.org, Cavalieri et al., 1996).

Cavalieri D J, Parkinson C L, Gloersen P, Zwally H J. Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data, Version 1. Boulder, Colorado USA: NASA National Snow and Ice Data Center Distributed Active Archive Center (Digital media, updated yearly), 1996.

Oceanographic Setting

L123-125 What is the time interval of the sea-ice dataset you used?

We have used satellite sea ice concentration data from 1979 to 2020 for seasonal of sea ice. This is now indicated in the revised manuscript.

Results

L231-235 One time you describe your records from old to young, the other time, from young to old. Please be consistent.

We have carefully checked the description of the results and harmonized it.

L238 IP_{25} concentrations span

Done.

Material & Methods

L128 In what year where the surface sediments taken? Have they all been measured to represent modern sediments? This is relatively important when comparing them to modern sea-ice concentrations.

This has been the approach taken by paleoceanographer for years, without even using box cores but core-tops that most the time were not modern. We are fully aware of the limitation of this approach and added a sentence in the revised manuscript (see 5.2.1). Nevertheless, distinct end-numbers were resolved from the ternary model diagram. Therefore, we believe that our method is still reliable.

L196-199 Why do you exclude other surface records, e.g., Wegner-Koch et al., 2020.

Koch et al. (2020) analyzed biomarkers in surface sediments from the Bering Sea and Chukchi Sea, which is indeed in our research area. However, Koch et al. (2020) deals with H-print data but not $\delta^{13}C_{org}$, data, which has limited its use for this study.

Discussion

L246-252 Yes, the concentrations are lower in the southern cores from Bai et al. and Kim et al. What is missing here is a discussion about potential differences in core storage, method as mentioned by Belt et al. (2014, Clim. Past). Are there other factors that may limit productivity, nutrients, depositional system?

We agree and re-emphasized the effect of storage and methods which is well-known within the proxy community.

L258 Cabedo-Sanz et al., 2013 worked in Barents Sea. I would recommend to mention that, as you adapt their interpretation to a new area.

This section has been removed as not only it is not in the same area but it related to a different time period (Younger Dyas).

L270 ff

I see a problem here with the interpretation of the PIP_{25} index.

- It does not make sense to use c-balance factors from other studies and other areas. As mentioned by previous surface studies Xiao et al., Kolling et al., a balance factor should be calculated based on data as there are differences in the concentrations of individual biomarkers varying between regions, (not to mention geological time intervals) depending on extraction method, storage etc... All of these make it not valid to use balance factors from surface sediments from Barents Sea (Smik et al., 2016) and a dataset from the Nordic Seas & Arctic Ocean (Xiao et al., 2015a). Further, Xiao et al.(2015a) used a different extraction method. I advise to calculate a balance factor based on your surface and downcore data, which is also recommended by Xiao et al.

c / Age	Surface sediment (this study)			R1 core (this study)			Xiao et al. (2015) & Smik et al. (2016)		
	1.29	*0.03*	*0.13*	*1.23*	*0.02*	*0.11*	*0.63*	*0.02*	*0.11*
	$P_{III}IP_{25}$	**$P_{B}IP_{25}$**	**$P_{D}IP_{25}$**	**$P_{III}IP_{25}$**	**$P_{B}IP_{25}$**	**$P_{D}IP_{25}$**	**$P_{III}IP_{25}$**	**$P_{B}IP_{25}$**	**$P_{D}IP_{25}$**
2013	0.41	0.27	0.28	0.42	0.36	0.32	0.58	0.36	0.32
2000	0.45	0.39	0.48	0.46	0.49	0.52	0.63	0.49	0.52
1986	0.58	0.45	0.55	0.59	0.55	0.60	0.74	0.55	0.60
1972	0.56	0.37	0.48	0.57	0.47	0.52	0.73	0.47	0.52
1959	0.51	0.31	0.33	0.52	0.40	0.37	0.68	0.40	0.37
1945	0.55	0.36	0.38	0.56	0.46	0.42	0.71	0.46	0.42
1932	0.74	0.66	0.69	0.75	0.74	0.72	0.85	0.74	0.72
1918	0.49	0.46	0.52	0.50	0.56	0.56	0.66	0.56	0.56
1904	0.31	0.33	0.39	0.32	0.42	0.44	0.48	0.42	0.44
1891	0.41	0.35	0.36	0.42	0.45	0.39	0.59	0.45	0.39
1877	0.38	0.34	0.33	0.39	0.44	0.37	0.55	0.44	0.37
1864	0.27	0.32	0.34	0.28	0.41	0.38	0.43	0.41	0.38
1850	0.26	0.34	0.34	0.27	0.43	0.38	0.41	0.43	0.38
1837	0.43	0.42	0.38	0.44	0.52	0.42	0.61	0.52	0.42
1823	0.67	0.80	0.71	0.68	0.85	0.74	0.80	0.85	0.74

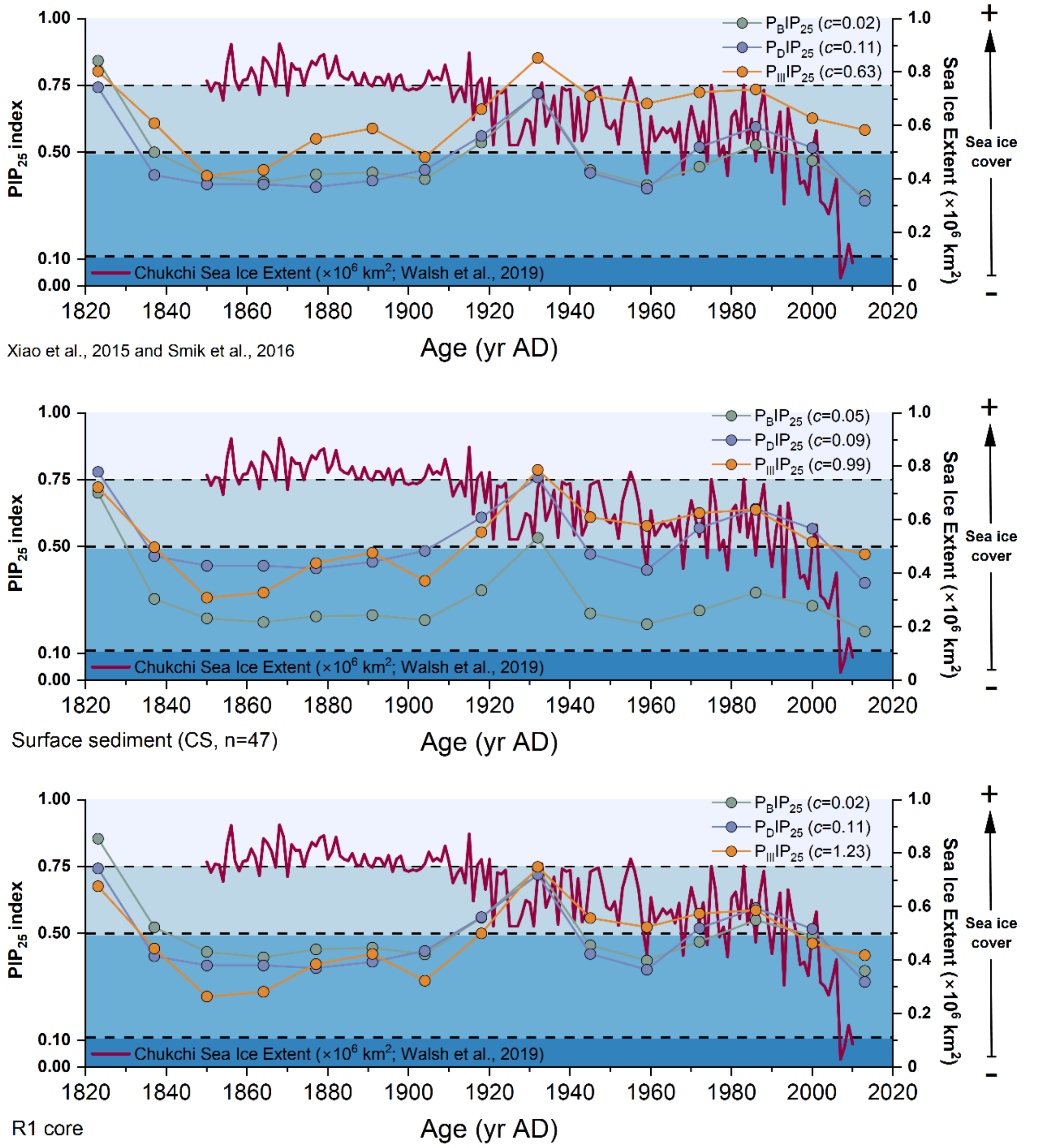
In order to address these issues we did sensitivity tests on *c*-factors to evaluate their effect on sea ice reconstructions using Xiao et al. (2015) and Smik et al. (2016) versus dataset of this study (our surface sediment set, and R1 core). The table above and figures below shows *c*-factors calculated for different cases and their corresponding PIP_{25} values. Differences between $P_{B}IP_{25}$ and $P_{D}IP_{25}$ values based on various *c*-factors are minor, as compared to the limitation of these indexes under high to permanent sea ice conditions (19th and early 20th centuries; Walsh et al., 2019). $P_{III}IP_{25}$ values based on *c*-factors from our surface sediments and R1 core are slightly lower than those derived from Smik et al. (2016) but with similar fluctuations through the record (see the figure below). Aslo, Kim et al. (2019) studied the same region and suggested that the PIP_{25} derived sea ice reconstructions were more reliable by using *c*-factors from the pan-

Arctic database (Xiao et al. (2015) and Smik et al. (2016)). Therefore we keep using the *c*-factors from Xiao et al. (2015) and Smik et al. (2016) in this study.

Kim, J.H., Gal, J.K., Jun, S.Y., Smik, L., Kim, D., Belt, S.T., Park, K., Shin, K.H. and Nam, S.I.:. Reconstructing spring sea ice concentration in the Chukchi Sea over recent centuries: insights into the application of the PIP25 index. Environ. Res. Lett., 14, 125004, 2019.

Smik, L., Cabedo-Sanz, P., and Belt, S. T.: Semi-quantitative estimates of paleo Arctic sea ice concentration based on source-specific highly branched isoprenoid alkenes: a further development of the PIP_{25} index, Org. Geochem., 92, 63–69, https://doi.org/10.1016/j.orggeochem.2015.12.007, 2016.

Xiao, X., Fahl, K., Müller, J., and Stein, R.: Sea-ice distribution in the modern Arctic Ocean: Biomarker records from trans-Arctic Ocean surface sediments, Geochim. Cosmochim. Acta, 155, 16–29, https://doi.org/10.1016/j.gca.2015.01.029, 2015.



- You are using the calibration from Müller et al (2012) from Fram Strait to interpret your PIP_{25} results as percentages of sea ice cover. This is not correct. The calibration by Müller et al (2012) was done for Fram Strait which has not been validated for any other area, which is why Müller et al. and other surface studies (Xiao et al., 2015a, Kolling et al., 2020) recommend that this calibration is only roughly applicable for other regions. Hence, I would recommend that you do not use percentages in your interpretation but the general sea ice regime as introduced by Müller et al., 2012, e.g., ice-free, variable, permanent, which you also show in Fig 5

We now use numerical values and a more qualitative narrative.

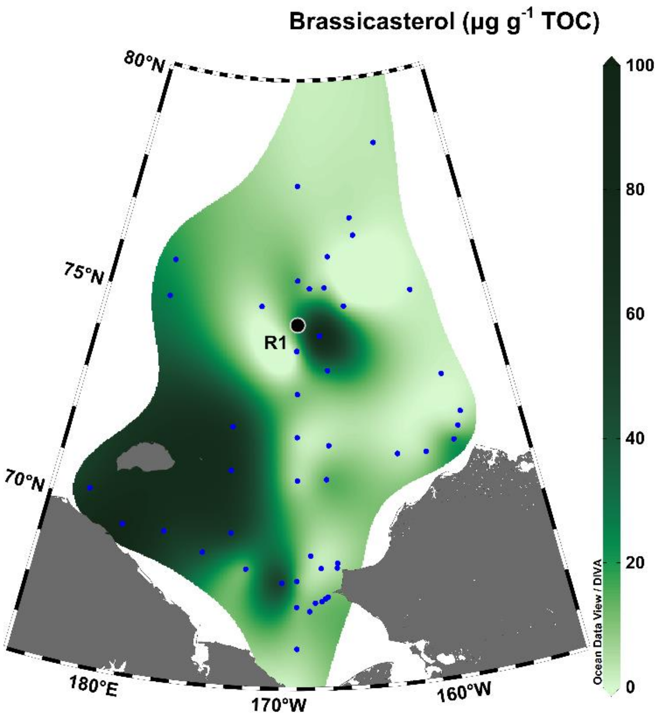
Fig 6 How do you define those margins for the different sea ice conditions? Are they based on your surface dataset, or any other published surface dataset? Or are they just estimates?

From my understanding below permanent sea ice, there should be no production of any biomarker, but you allow production of e.g., 20 mg/g TOC of Brassicasterol below permanent sea ice when maximum Brassicasterol concentrations are at 40 mg/g TOC. This does not seem realistic. In Fig 7 is becomes obvious that you barely have any PIP_{25} values that indicate permanent sea ice cover, however in Fig 6 is seems as if at least half of your datapoints lie within the range that indicates permanent sea ice cover.

We used the Chukchi Sea surface sediment dataset to determine thresholds for sea ice conditions. The maximum concentrations of brassicasterol of the southern surface sediments are up to 100 μg g^{-1} TOC, while these values decrease to less than 20 μg g^{-1} TOC in the north where minimum sea ice extent is located (see the figure below). In contrast, the highest concentration of brassicasterol in the R1 core is about 40 μg g^{-1} TOC with a mean of ~18 μg g^{-1} TOC (Table 2). Therefore, it is reasonable to set a threshold of brassicasterol of 20 μg g^{-1} TOC.

The phytoplankton biomarkers under ice cover may have been introduced by sea ice and currents, which is supported by contemporaneous terrestrial input signals ($\delta^{13}C_{org}$

and terrestrial sterols; Fig. 3 and 4).



L285 Even though I am not a native speaker I feel that the wording 'icier' is not the correct scientific term. You use it several times in your manuscript. I would suggest using 'increase in sea ice' or something similar.

We have used a different wording than icier, "…sea ice increase or extended ice cover..".

Fig 7a It is really hard to distinguish the different shades of green, especially between ARC-11-R01 and ARC4-C07. Please use different colors.

We have modified the colors in Figure 7 to make them more visible.

Fig7b What is the effect of light availability in your record? In my understanding, there should be no production below winter sea ice due to the lack of sunlight in Chukchi Sea. Further, what is the main bloom season on Chukchi Sea? Please elaborate more on this topic.

Due to the lack of sunlight there is almost no primary production under the sea ice in winter, this has been corrected on the cartoons. The primary production process in the

Chukchi Sea begins in the south during spring, coinciding with the melting of the sea ice. As the sea ice gradually recedes towards the north, the hotspots of productivity also shift northwards. This process of primary production continues throughout the summer and does not complete until late autumn, when the sea ice freezes completely.

L334 Is there a difference in light availability between ~70°N and ~80°N that could also influence the amount of biomarkers produced. How long are the general production periods in your working area, are there specific differences from North to South?

Obviously, there are differences in light availability from south to north of the study region. Due to the timing of sea ice melting and freezing in the western Arctic Ocean, the duration of primary production is significantly different between the north and south. For instance, the southern Chukchi region (~67.78°N) experienced an average open water duration of 152.3 ± 13.1 days from 1988 to 2018, compared to 109.7 ± 38.4 days in the north (72.16°N), thereby extending the production season by 3 weeks in the southern region. As a result, the net primary productivity in the south was 25.8% higher than that in the north (Payne et al., 2022). However, besides light availability, biomarker production is also influenced by nutrient supply, which is in turn driven by other factors such as stratification, water mass transport, terrestrial input, etc. These factors are also different between the south and the north of the study region.

Payne, C. M., Dijken, G. L. van, and Arrigo, K. R.: North-South Differences in Under-Ice Primary Production in the Chukchi Sea From 1988 to 2018, J. Geophys. Res: Oceans, 127, e2022JC018431, https://doi.org/10.1029/2022JC018431, 2022.

L351 & L355 'sea-ice edge' and 'sea ice carbon', if you hyphenate be consistent throughout the manuscript.

We have carefully revised the manuscript to harmonize.

Fig 8 I would suggest that you write an endmember on the scales for H-print and ^{13}C, e.g., sympagic/pelagic.

We highlighted the end-member in the figure caption.

L392-395 If land-derived organic matter is transported to the core location by sea ice, why aren't IP_{25} and terrigenous sterols not parallel? Could you include the biomarker records to this discussion?

Sedimentary sympagic/pelagic organic carbon were mixed signals from local production and long/near transport, whereas terrigenous material was only transported from long distances, so they do not necessarily parallel each other especially if this mechanism is marginal.

Conclusions

L438 nutrient limited

The typo has been corrected.

L440 CO_2 drawdown

Corrected.