

Review of:

**Significant methane undersaturation during austral summer in the Ross Sea (Southern Ocean)**

Ye et al.

**General comments:**

In this manuscript, the authors present an interesting data set of CH<sub>4</sub> concentration profiles showing the distribution of CH<sub>4</sub> in the water column at 10 locations in the Ross Sea. The measurements were carried out during the austral summer in January 2020 on board of the R/V Xuelong 2. Methane concentration data in the Southern Ocean is scarce, and in this sense, the data set represents a relevant contribution to the community. Nevertheless, the manuscript requires modifications before is suitable for publication.

In terms of the structure of the manuscript, I missed a robust and organized section describing the data collection and methods to support subsequent results and discussion. It is my impression, that the text does not follow a coherent line of thought, jumping back and forth between topics and figures, which makes it hard to trace exactly how the authors arrived to the given results and conclusions. Please see specific comments below.

As I mentioned before, the data presented in the manuscript is interesting. However, a deep analysis of the different processes involved in the CH<sub>4</sub> dynamics is missing. The authors focused much of the attention to the dilution effects due to sea-ice melting, leaving aside other relevant processes. I would suggest following a process-based analysis where the relative importance of each mechanisms is assessed, instead of having the melting sea-ice as a central line.

Following are my comments, which I hope can contribute to the improvement of this manuscript.

**Specific comments:**

Abstract:

Is “fresh water injection” considered to be the same process as “advection”? In L.124 is stated that advection is negligible. Please clarify.

L.19-L.21 Please remove the sentence starting with “We estimated that the Southern Ocean...”. This result can be used as part of the discussion to give some perspective to the potential relevance of the region in the global context. However, using three days of data from one specific region to make a final statement about the role of the whole Southern Ocean as a sink or source of CH<sub>4</sub> is not appropriate.

Introduction:

L.30 I guess “emissions” refer to the “net global oceanic emissions”.

L.53 remove “on the basis of our results”

L.54 CH<sub>4</sub> consumption is not mentioned here, while in the abstract is stated to be as equally important as the sea-ice melting. Please clarify and follow a consistent rhetoric throughout the manuscript.

A paragraph describing the main processes associated with the CH<sub>4</sub> cycle would be very useful to contextualize the discussion and to aid non-expert readers. This could be included after L.31 and could be expressed, for example, using the terms of eq.3 (air-sea flux, diffusion, advection,

production/oxidation, etc.), including the relevant aspects of surface CH<sub>4</sub> and water-column distribution.

### Materials and Methods:

L.55 I suggest renaming this section to “Data and Methods”.

After L.55 start by describing the study site and measurements.

L.56 re-name this section as “Hydrographic data and water mass classification”

L.57-L.58 looks more like results (including Fig.2).

L.58 the definition of the different water masses as described in the literature (including Table S1) should be moved further down in the methods section.

L.59-L.71 is not methods. Should be moved to introduction.

L.72-L.77 this paragraph should be moved further down. Please first describe the site and measurements, before addressing how the data was analyzed.

L.74 what do you mean by sectional area? Aren't the measurements taken at individual locations each time? Please clarify.

L.78 please rename. There are two sub-sections named “sampling and analysis”. Make sure an adequate name is given to each section and sub-section.

L.80-L.81 refer to Fig.1 after the sentence “The CH<sub>4</sub> distribution was measured...”. Also please specify at which nine stations where the samples taken.

L.82 even if a detailed description of the sampling method is given in Zhan et al. please include relevant information here, such as sampling depths, measurement times, etc.

L.85 move the sentence “Hydrographic data were collected...” to the section “Hydrographic data and water mass classification”, which should follow this section.

L.101 please re-name (see previous comment for L.78)

L.108 why use an average wind speed for the gas transfer velocity? This might introduce significant biases in the flux calculations. If wind data are not available during the research cruise (which I would find strange), there are other resources with sufficient resolution that could be used for the analysis. Please reconsider using other alternatives for the  $k_w$  calculations or provide the necessary information to support your decision, including discussion of the uncertainty associated to the calculation using the mean wind value.

L.124-L.125 why is it advection considered negligible? This statement contradicts the text in the abstract (L.16) where advection is considered as one of the two mechanisms leading to the depletion of CH<sub>4</sub> in surface waters. Please explain.

L.126-L.127 The sentence “Positive values represent...” is confusing. I suggest “Positive values of  $F_x$  represent transport of CH<sub>4</sub> from the mixed layer to the surroundings, while negative values represent transport into the mixed layer” or similar, if that is what you meant. As I said, it is a bit confusing.

## Results:

L.131 here you recognize the relevance of wind as a mixing processes affecting the upper oceanic layer. Why not taking this effect into account when calculating the gas transfer velocity ( $k_w$ ) and the fluxes? Also, the stratification effects caused by the density changes might be more relevant at low wind speeds. While at higher wind speeds, large part of the flux is most probably driven by wind-induced mixing. This is of course not evident if the mean wind speed is used for the gas transfer velocity calculations.

L.136 Here “Lateral transport of water masses...” is discussed. Is this lateral transport not associated to CH<sub>4</sub> advection? How is CH<sub>4</sub> advection negligible but advection of water masses relevant? Please explain.

L.139 “Consequently, for the eastern-most stations (R7-R10), the water column...”

L.145-L.147 why is the high concentration in R7 only observed at the bottom and not in the whole water column, even when the “warm” temperature is observed from the surface to the bottom? Can this be CH<sub>4</sub> from the sediments in the sea floor? It would be interesting (maybe in the discussion) to briefly explain why this is input from sediments is observed in R7 and not in the other “shallow” stations.

L.148 this section should go together with paragraph in L.130 to L.140, as water masses are also discussed there. Maybe start with a sub-section on water masses, followed with another separate sub-section about CH<sub>4</sub> in the water column (i.e. moving L.141-L.147 further down).

L.151 “would it be expected”, does that mean that SW (contrary to what was expected) is not trapped in deep troughs? Or it is, actually, trapped?

L.156 “...was found only near the ice sheet (stations R1-R3), where supercooled...”

L.160 the sea-ice data source is only included in the legend of Fig. 3. It should also be included in the methods.

L.163 “...at the Mawson Bank (stations R1 to R5).”

L.163-L.165 refer to Fig.3d

L.170-L.172 it seems here that all other processes involved in the dynamics of CH<sub>4</sub> in the mixed layer have already been discarded. I think the sentence “We found that mixing ... is responsible for the CH<sub>4</sub> undersaturation in the shelf sea” is farfetched at this point of the manuscript. Please present a thorough assessment of the relevant mechanisms involved in the distribution of CH<sub>4</sub> or as you call it “budget in the mixed layer” before presenting such strong statement.

L.173 I assume “box model calculation” refers to what is described in Sect. 2.4 as the CH<sub>4</sub> budget in the mixed layer. At some point it is also refer to as “mass balance”. Please make use of the terminology in a consistent manner throughout the text.

L.175 “...calculated two box models...”, please refer to Sect. 2.4, Eq. 3.

L.177 “If we assume that lateral transport of CH<sub>4</sub> is zero”, why? Please clarify, as in some parts of the manuscript (i.e. the abstract) advection is stated as one of the “important drivers ...” while in other parts of the text is described as “negligible”.

L.178 what about measurements in station R7?

Discussion:

L.183 “The fate of CH<sub>4</sub>...” use “distribution”, instead.

L.186 “Hence, the CH<sub>4</sub>-poor CDW may play an important role...” why is it then that this mechanisms is not given the same importance as sea-ice melting? To me it seems like the main focus is to highlight sea-ice melting as the cause of CH<sub>4</sub> undersaturation, while different mechanisms were also found to be significant for CH<sub>4</sub> dynamics. I suggest to not over-focus on one single process as these results are all relevant! Please explore all possibilities.

L.194 the phrase “...may originate from surface water that is sufficiently exposed to the air...” is confusing as, at least during 2020, this western region (stations R1-R5) is the one that was cover with ice for the longest time (Fig. 3). Please explain. Also, could it be the other way around? That this region is most of the time cover by ice and, therefore, with very little interaction with the atmosphere. Thus, CH<sub>4</sub> is being stored there due to sediment CH<sub>4</sub> production for example (in comparison to the more “open waters” which experience more air-sea exchange). Then again, as I said before, air-sea gas fluxes (and other mechanisms) might also be relevant!

L.195- L.208 I do not think these statements are really supported by your observations. This paragraph is confusing but most of all, it is misleading as the main focus seems to be to justify the relevance of sea-ice melting. I suggest making a detail assessment of the relative importance of each process involved in the distribution of CH<sub>4</sub> in the region, and then discuss the role of all the relevant mechanisms.

L.200 “when sea ice melts in the summer, seawater with undersaturated CH<sub>4</sub> concentrations then continues to be diluted...which in turns leads to a continuous decrease ...within the surface layers” this is, to my understanding, contradicting the previous sentence in L.192 “the oversaturation of CH<sub>4</sub>...may originate from surface water...”.

L.203 “we found that the CH<sub>4</sub> saturation was decreased by 22% at the Pennel Bank...compared to that at the Mawson Bank” can you really conclude this from your observations? Why?

L.205-L.208 “As the ice-free areas increase, ... due to mixing and ...and/or exchange with the atmosphere. Thus, the magnitude of sea-ice melting may determine the degree...” this sounds much more reasonable. The conditions of the ice may actually affect several biogeochemical and physical processes! But not only changes in CH<sub>4</sub> due to dilution effects.

L.211 is it really a box model?

L.212 “...were influenced by air-sea exchange (40-70%) in the west...(90%) in the east.” These contributions seem relevant, don't they? Again, I do not understand why the speech along the manuscript is around the dilution due to sea ice melting, when other interesting results are also found.

L.213 maybe add some numbers of the relative importance of the vertical diffusion, similar to what is done for air-sea exchange (in percentage, for example).

L.216 is it east or west?

L.216 this “rapid decline in CH<sub>4</sub>” is not really seen in the west side (if that is what is meant), is it? How? From the data shown here, it seems like the highest saturation values are found in the western side where no decline in CH<sub>4</sub> saturation is observed. I also think that in order to reach such a conclusion, measurements capturing the temporal variability of CH<sub>4</sub> in each station are necessary, which are not provided here.

L.229 what is it meant with “regulations”?

**Technical corrections:**

L.15 remove “Simple”

L.31 “...the Southern Ocean in **the** global CH<sub>4</sub> **cycle**”

L.80 “The CH<sub>4</sub> **vertical** distribution...”

L.87 “Triplicate or duplicate **CH<sub>4</sub>** subsamples...”

L.114 remove “roughly”

L.122 in the equation of the Fick’s first law, it looks strange to me to express the gradient using subscripts. I would suggest using  $dC/dh$  instead of  $d_c/d_h$ .

L.123  $K_z$  (in italics)

L.135 “stations **s** R9”

L.155 “...**heterogeneous** region”

L.214 “The sea ice distribution may **be** responsible...”

L.215 “...melting or **incompletely partially** melting...”

L.218 “...after **completely a complete** melting of ...”

L.233 “..., which will result in a net **take-up uptake** of CH<sub>4</sub>...”

L.263 “Our measurements **s** of CH<sub>4</sub>...”

Throughout the text, refer to figures and tables when introducing and discussing the results.