Authors replies to the interactive comments of anonymous referee #1 (30 May 2019) on “High-resolution under-water laser spectrometer sensing provides new insights to methane distribution at an Arctic seepage site” by Pär Jansson et al.

RC: denotes referee’s comments

AR: denotes authors’ reply

MC: denotes manuscript changes

RC: General Comments: As pointed out by the authors this is a FIRST, and hopefully the instrumentation described will enable a new era of high-quality data to be gathered for ocean and climate studies. The authors can document and quantify both the temporal and spatial heterogeneity of CH4 concentrations in the water column. That such heterogeneity exists is not new, but that it can be quantitatively studied is new. So far technology has limited researchers to either discrete sampling or use of sensors with long response times both making it practically impossible to describe the heterogeneities described in the present study. Coarse data allows for coarse models and budgets. This becomes evident in the data analysis presented. Although the data is high resolution, general applicability of the method for inventory (budgets) studies requires a large amount of auxiliary data (current, CTD, TS, background/reference measurements). But this is the everyday challenge of the oceanographer (and modeller). The data will allow for substantial discussions within the modelling community. Hopefully, in the future we will see sensors with similar characteristics to that of the "MILS" fitted to groups/swarms of AUV’s that can do concurrent sampling and monitoring of larger regions. This could enable true high-resolution characterization of a region of interest and enable high resolution modelling of CH4 dispersion dynamics. Such data will need to be collected in order to be able to use "bottom up" studies to build confidence in "top down" data and models used for inventory monitoring at the ocean and climate scales.

AR: Thank you for taking the time and effort to read and comment on our manuscript. You acknowledge the need for this kind of research, and recognize the hardship of acquiring useful data, even with the new advanced technology. We appreciate your comments, which we believe has improved the manuscript. We agree that this type of high-resolution measurements is the beginning of a new era of Oceanographic surveys, and that more data, both in time and space, is needed for a broader understanding.

RC: Specific comments: Page 5 L114-117: Where was the pump inlet located? This is not described in the paper nor in Grilli et al. 2018. A schematic is provided of the membrane assembly in SI3 of Grilli et al. 2018. Page 6 L121-129:

AR: The water circulation pump (Seabird SBE 5T) was located at the bottom of the MILS instrument approx. 25 cm away from the membrane assembly block. Short sections of ½” hose and a T-piece were used to connect the pump outlet to the membrane block inlets. The pump inlet was shielded with a cover and a fine mess to avoid ingress of particles and/or bubbles.

MC: This information was added to the text in lines 121–123.

RC: Regarding the position correction. A cylinder of height and width of the MILS probe was used. The assembly in Figure 1b show that the CTD, Battery and commercial CH4 sensor is far from symmetric, and the drag of these side mounted addons should probably have been accounted for in the position correction. These addons could also lead to a wobbling and rotation of the assembly. Was this monitored by onboard IMU sensors (inertial measurement unit)?

AR: For the position correction, a cylinder shape was used with a height and diameter equivalent to the displacement/buoyancy of the total assembly of instruments (i.e. not just the height and width of the MILS). This ensured that the simulated buoyancy of the total assembly was as close to reality as possible to allow for the (unknown) drag coefficient to be determined by making the simulation match with all the other known parameters such as instrument depth, cable length, ship speed, ship direction, and currents. It is unknown how stable the instrument assembly was while being towed, but wobble and/or rotation would have no significant effect on the measurements. No IMU sensors were used to monitor the movement of the assembly during profiling.

MC: This information has now been added to the discussion in lines 364–365

RC: Section 3.1 Water properties It is not clear from the text that the current information is derived from data obtained simultaneously with the CH4 measurements. This is however stated in Jansson (2019) Figure 8b.

AR: We agree that this should be more clearly stated. We added a note on that in the manuscript

MC: lines 204–206 state the above.

RC: When interpreting the inclination of the flairs is flair inclination perpendicular to the ship motion taken into account?

AR: The split-beam echosounder (Simrad EK60) resolves the location of scattering objects in 3 dimensions, but the echosounder swath width (~7°) will set a limit to the positions of the scattering objects. Particularly, in the direction perpendicular to the ships' movement, the bubbles may easily escape the beam if the current carries them across the ship trajectory. During our survey, the heading of the ship is biased towards the N/S and S/N direction, and it is therefore possible for flares to extend more in that direction. However, careful investigation of the flare data shows that the flares detected during cross-slope sailing have very small east-west components even though they could potentially extend across-slope within the echosounder beam. We are therefore convinced that our flare-inferred currents represent real currents. Furthermore, ocean currents generally flow along isobaths, and the streamlines determined by potential vorticity conservation, follow the isobaths closely in this area Nilsen et al. (2016).

RC: There can of course be unknown sources of the CH4, but there is mention of WSC meandering, and negligible tidal effects. Have typical eddy sizes been characterized? The time between transect lines 1 and 5 are by rough estimation 12 hrs i.e. roughly one tidal period. The whole cruise was two tidal periods. What is the direction of the tidal flow in this region? Both eddy size and tidal currents could result in noticeable advection over a 12-hr period.

AR: Eddies are difficult to observe with sparse observations, but high resolution modelling suggests that mesoscale (a few km) eddies are important for transport of water properties across the slope in the study area. Mesoscale and smaller eddies form on each side of the WSC core, which also meanders off- and onshore of our study site (Hattermann et al., 2016, supplementary information). This process obviously affects also methane concentrations, which could appear high or low without other obvious explanations. We do not discard the possibility that eddies transport CH_4 enriched water in ways that we cannot predict without perfect knowledge of the velocity field. We simply put forward the possibility that unknown sources could be tracked with the new instrument. The CH_4 enriched water that we observe in the northern part of line 3, not explained by acoustically observed flares, was accompanied with a TS anomaly. This suggest intrusion of a different water mass, but not all of the intrusion was enriched with CH_4. Possibly, this is eddy induced, or it could be a result of bottom Ekman transport.

MC: We added the possibility for eddies in the discussion (line 385).

AR: The survey lasted for three days (October 21st – 23rd). The probe was deployed each morning around 10 AM, and was measuring continuously for 4, 9, and 10 hours respectively. The tidally driven currents in the area range between -1 and 1 cm s^{-1} in both the east and north directions. The probe was deployed at the approximate same tidal state and the modelled tides during the deployments were 0–1 vs -0.5–0.5 cm s^{-1} in the N and E direction respectively.

RC: Page 13 L267: with the given speed of the cruise and the response time of the instrument (15 sec), spatial resolution is of the order 10m. However, how does the instrument obtain a measurement? Is it by continuous flow at a given flow rate over the membrane, or does it work in a batch mode with discrete samples passed over the membrane unit?

AR Both the water flow over the membranes and the gas flows inside the instrument are continuous and constant during the cast/deployment.

RC: Page 13 L280: What is the reasoning behind scaling up the flair by 40%? Can the authors justify this quantitatively?

AR: The 40% upscaling is based on the "dissolution function" or "non-dimensional source-function" (sect 2.6), which shows that a large portion of the initial CH_4 is already lost from the bubbles when we observe them with the echosounder in the layer 5 – 10 masf.

MC: The upscaling due to dissolution is now better explained in line 292.

RC: Technical corrections: Page 4 – L62-75 A map/graphic could be included for illustration if authors have access to graphical assistance.

AR: An illustration with currents carrying the different water masses would be nice, but it is outside the scope of this paper to produce an infographic on water mass movements. The physical oceanography is well documented in the referenced papers and we do not wish to review them extensively in our manuscript. To partly meet your suggestion, we added the main controlling ocean currents in figure 1a (inset map). Water mass classifications are found in the TS-diagram in Figure 2b and 2c.

MC: Figure 1 was updated and now indicates the dominating currents.

RC: Page 4 – L80 and L95-97: purely cosmetic but I like it when lists come in the same order, e.g. temp, salinity and concentration.

AR: We agree.

MC: Order of parameters changed in line 102.

RC: Page 7 – L150-180: I feel that the presentation in paragraphs 2.5 and 2.6 could benefit from a graphic illustrating the computational domains. I believe that this will aid the reader in understanding and conceptualizing the differences between the two methods better.

AR We posted a supplementary containing a schematic showing the control volume and the 2D model, which indicates the included processes for easier understanding.

MC: Fig. SI 1 was added in the supplementary document.

RC: Figure 2: Second line: it should read "Gibbs seawater package". In the last line: the mean bubble rise velocity is 23 cm s-1, could you provide the mean bubble size as well?

AR: Thanks for noticing that. We corrected the caption for figure 2. We added the bubble size distribution.

MC: Manusript changed accordingly. Bubble size distribution in line 159.

RC: Figure 7: The figure would be much easier to read if it was in colour.

AR: Ok.

MC: Figure 7 and its caption has been updated accordingly.

Hattermann, T., Isachsen, P. E., Appen, W. J., Albretsen, J. & Sundfjord, A. 2016. Eddy-driven recirculation of Atlantic Water in Fram Strait. *Geophysical Research Letters*, 43(7), pp. 3406-3414.

Nilsen, F., Skogseth, R., Vaardal-Lunde, J. & Inall, M. 2016. A Simple Shelf Circulation Model: Intrusion of Atlantic Water on the West Spitsbergen Shelf. *Journal of Physical Oceanography*, 46(4), pp. 1209-1230. doi: 10.1175/jpo-d-15-0058.1.