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Interactive comment on "Seasonal methane accumulation and release from a gas emission site in the central North Sea" *by* S. Mau et al.

Anonymous Referee #2

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the paper aims to constrain the seasonal variation of sea-air methane fluxes originating from shallow gas seepage, which is an important research question. The area of interest is located in a summerly thermally stratified part of the North Sea showing complete mixing in winter. A two layer model is introduced to investigate the seasonal changes of physical methane fluxes and relate those to microbial uptake.

The paper tackles complex tracer oceanographic problems requiring well planned sampling strategies, current measurements, solution of advection-diffusion equations and estimates about seasonal variation of vertical eddy diffusive transport. But the paper only presents an extremely simplified model. The oceanographic understanding appears limited and the model suffers from incompleteness and severe misunderstanding.

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Interactive Discussion
Discussion Paper

(1) The vertical eddy diffusivity kz was estimated constant to 10e-4 from literature (and tested for model uncertainty with 10-3, and 10-5 respectively. A seasonal built-up and destruction of a thermocline gives rise to a non-static kz with variation by orders of magnitude throughout the year. The authors should have derived monthly kz, e.g. by Thorpe Scale analyses, from CTD data.

(2) A 1D model is suggested to describe the flux of methane from the "deep" layer to the upper/mixed layer using Ficks 1st law. The authors derive model parameter dC_CH4/dz from their field data by assuming a 1D case. This would require a distinct dC_CH4/dz gradient with more or less homogeneous horizontal distribution of methane. However, the nearfield water column methane distribution pattern surrounding individual gas seepage clusters appears highly variable, i.e. with significant variation in three dimensions as shown by the authors themselves (Fig. 4). Surface methane values measured up to 2127nM with UWMS were reported. Obvious reasons are gas bubbles as visualized with acoustics. But the model assumes the only CH4 source is the lowermost layer in their model. In summer the thermocline may reach down by 30m leaving a lowermost layer with 10m thickness. Methane gas bubbles easily bypass a 10-20m bottom layer without losing major fractions of their initial moles as shown in the cited paper McGinnis et al. (2006). No field data is provided about the crucial model parameters initial gas bubble size and methane mole fraction. Overall, bubbles most likely provide a strong source for methane input to the upper layer, but this is totally neglected in the model.

(3) monthly mean wind speed was taken for sea-air flux modeling. But the sea-air gas transfer is highly non-linear with wind speed and a monthly mean approach needs discussion. The sea-air flux potential is also governed by an interplay between strength and continuation of wind in relation to the remaining dissolved methane pool in the "wind-exhausted" layer. I.e. strong wind will not necessarily drive enhanced sea-air flux once the upper CH4 layer was exhausted already.

(4) The box model approach is only feasible in a closed system, but most likely the

sampled area is an open system with significant advection and methane loss in various directions, and gas bubble methane dissolution up to the sea surface. The paper refers to using the disputable approach from Mau et al. (2012).

(5) No current data are presented for the study site. But the North Sea is highly affected by the tides and the dominating M2 tide will likely cause significant current changes in amplitude and phase on an hourly timescale. Therefore the tempo-spatial methane distribution and the respective sampling are highly controlled by the actual current around the seep sites. The methane distribution pattern in winter shown in Fig. 4b is interpreted as a result from enhanced mixing. However, it could also be caused from current amplitude and direction "flushing" the seepage area with background water during the time of measurement (e.g. frontal jets have been discussed for the Dogger Bank with currents exceeding 15 cm s -1, but are not mentioned in the paper). No background CTD is available, and the amount of lateral input of methane into the layers remains unknown.

The observation of enhanced MOx activity at depth is a valid observation. Also the high resolution in situ mass spectrometer CH4 data in the near-field of gas seepage is valuable, because such data are very rare (but the respective 3D methane distribution it is not presented in the paper). The authors could think about a complete new story using such data. With the severe shortcomings of the model and missing current information the content of the paper can not support the conclusions. Therefore this paper can not be suggested for publication.

Technical Comments - equations are missing to allow for reconstructing the individual model steps - Fig. 1: the wind recording station can hardly be detected. The flow pattern of the North Sea currents are provided, but the ones prevailing in the study area remain unclear, also in the text!

- Fig. 2: poor quality and unclear. The three figures/inserts have three different color codes for the depth, confusing....The UWMS sampling path could be better presented

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in 3D together with the methane concentration distribution in the results chapter.

- Fig. 3: The CH4 concentration profiles should be included here.

- Sea-air flux calculations: rather provide classical and comprehensive work introducing the generic sea-air flux equation equ. 4 than self-citation.

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