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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Multimodel simulation of vertical gas transfer in a temperate lake" *by* Sofya Guseva et al.

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General comments

1. (1) It is stated that the study is a continuity of LakeMIP exercises accounting for biogeochemical processes comparisons. Although the first part of the paper is dedicated to thermal stratification and ice cover study, and involves the five models, the fact that only two of them have the possibility to simulate O2 and CO2 dynamics, indicate that this is not a real LakeMIP type exercise, and therefore constitutes a limitation in my view to be considered as a true intercomparison model experiment for vertical gaz transfer.

(2) Dissolved gas transport throughout the water column is mainly carried out by turbulence. Despite the fact that only two of the models have an ability directly to reproduce the concentration the gases (oxygen and carbon dioxide) our numerical experiments with a passive tracer (which can be seen as a "prototype" of gas or other constituent) involving four models out of five showed the potential simulation of gases governed by seasonal stratification and ice cover. We can consider this experiment as the intercomparison model experiment in respect to primary physical controls of gas dynamics. We consider the intercomparison experiment involving full biogeochemical models as a next step of this study.

(3) No comments/corrections are added to the manuscript.

2. (1) In the first LakeMIP exercise (Stepanenko et al., 2010) the sensitivity of lake depth has been studied and the experiment setup accounted for simulations with maximum depth, local depth and average depth. And this is crucial especially (maybe only) for FLake model as it was demonstrated that an average lake depth was necessary for FLake simulation in order to be conservative in terms of energy. In the current setup, the maximum lake depth is used for all models and this is contradictory with a correct use of FLake which should be run using the LDSim configuration. It could be interesting to compare in the same graph RefSim and LDSim at least for FLake.

(2) The main focus of our study is the vertical diffusion which is the main driver for the gas distribution. Of major interest are such gases as carbon dioxide and methane which are primarily produced in lake sediments. Setting the maximum lake depth becomes crucial in terms of the total vertical distance required for transport of bottom-originated gases to the atmosphere. For this reason, we conduct the baseline experiment with the maximum depth. We added new figures to the manuscript with results from the LDSim experiment – FLake showed the largest sensitivity to the variation of the lake depth among the other models: e.g. RMSE$_c$ for surface temperature as well as for the whole temperature profile reduced almost twofold (see Table S4, Fig. S3, S4). This suggests potential limitation of FLake for correctly simulating gas dynamics in deep lakes (given the biogeochemical block is added to the model).

(3) Page 10 line 24: Remarkably, FLake demonstrates the largest sensitivity among all models to the lake depth – RMSE_c is reduced approximately twofold (from 2.5 ° C to 1.28 ° C) (see SI, Table S4, Fig. S3, S4) when using a mean depth of 13.32 m instead of the maximal depth 37.5 m. The thickness of mixed layer depth reduces up to 4.5 m and have a better agreement with the observations in comparison with RefSim experiment. We added the mean depth of the mixed layer for all models in the LDSim experiment to the Table S2 in SI. We also put two additional figures for LDSim simulation to SI: Fig. S3, S4.

3. (1) As a consequence, the sensitivity test on light extinction for FLake is not relevant since the thermal profile cannot be well simulated, and therefore should be conducted with a depth of 13.32 m.

(2) We redid all FLake simulations using calibrated shape factor, and temperature profile is now much better reproduced compared to results presented in the first version of the manuscript. Correspondingly, the sensitivity test on light extinction coefficient with FLake demonstrates now result similar to other models (see new Fig. 4).

(3) Page 11 line 32: This leads to temperature change at respective depths up to 4 $^{\circ}C$ in FLake model and 8 $^{\circ}C$ in ALBM and LAKEoneD. Fig. 4 contains only 3 models with different types of turbulent closure because the effect of varying the light attenuation coefficient is very similar in models on the same type (e.g. k-ϵ models LAKEoneD and LAKE).

We also added the result of ExtMaxSim simulation for FLake in Fig. 4 in the manuscript.

Specific comments

4. (1) Looking at the bathymetry indicates strong gradients from the shoreline to the point of maximum depth. There are probably 3d-circulations that take place when dense waters flow along the bottom slopes. And these circulations are not accounted for in the 1d simulations. What is in your view the potential impact on these circulations

on the thermal stratification and ice cover? And on modeled vertical transport? It would be interesting to add a discussion on that particular point.

(2) 1D models have certain limitations when it comes to such a 3-dimensional system as lake. They do not capture all the lake mixing mechanisms such as density driven currents, which can be important under certain conditions. In general, these currents are very slow (only a few cm s^{-1}) (Bengtsson, 2012) and are not important in terms of the turbulence production. The strong contribution of these flows in the vertical exchange of deep and near-surface water was found for deep lakes (> 100 m) with an extended literal zone, e.g. Lake Geneva and Lake Van (Fer et al., 2001, Fer et al. 2002, Kaden et al., 2010). For Harp Lake, in particular, this process may not be important during summer due to a smaller depth and a limited area of shallow part. In winter, a large-scale convective circulation (up to 3-5 cm s^{-1}) due to heat exchange at the sediment-water interface may develop under ice (Kirillin et al., 2015). However, the importance of this circulation in terms of gas transfer have not been studied yet. At the moment, this type of the lake circulation is a topic of the ongoing research and it is not included into 1D models. Modeling such 3-d phenomena requires an application of 2D or 3D models.

(3) Added to Page 24 line 22 : - 1D models have certain limitations when applying to such a 3-dimensional system as lake. They do not capture all the lake mixing mechanisms such as density driven currents, which can be important under certain conditions (Samolyubov,1999). It was found that for deep lakes with extended literal zone, such as Lake Geneva (Fer et al., 2001, 2002) and Lake Van (Kaden et al., 2010), these flows can be significant in terms of the vertical heat and gas transfer. In particular, for Harp Lake it may not be important due to a smaller depth and a not large shallow area. In winter, a large-scale convective circulation (up to 3-5 cm s^{-1}) due to heat exchange at the sediment-water interface may develop under ice (Kirillin et al., 2015). However, the importance of this circulation in terms of gas transfer have not been studied yet. So far, to the best of our knowledge, these currents are not parameterized in 1D models.

5. (1) The abstract mentions the need to improve biogeochemical processes in lake models to enhance weather prediction and climate projection capabilities. I'm not convinced improving biogeochemical processes will improve weather prediction. What is crucial in weather prediction or climate modeling is to simulate a correct surface temperature and fluxes because these are the variables that will be used in the coupling to the atmosphere. That's true that in climate simulations the knowledge of carbon dioxide or methane emissions are of high interest, however to my knowledge only the LAKE model offers the capability to simulate CO2, O2 and CH4 dynamics and be coupled to a climate model. Please add a discussion on that point to also highlight the difficulty to increase the complexity of lake models and ensure a correct coupling to an atmospheric climate model.

(2)-(3) As in this study we do not focus on methane, due to absence of respective measurement data, and discuss models performance for CO_2 content, we added a comment on issues which will arise when implementing lacustrine CO_2 emissions in climate models (Page 21 line 29): The important role of catchment processes in building up the DIC levels in lakes introduces an extra difficulty for implementing lacustrine CO_2 emissions in the Earth system models. This is caused by the necessity to provide regional or global data on lake's catchments geometric, physical and biogeochemical properties, which are not currently available. In relation to this, we can also note a faster progress on a roadmap to introduce lake CH_4 dynamics in climate models, where simulations passed from site-levels studies to regional estimates (Tan et al., 2015), whereas CO_2 modeling is currently confined to individual lakes (Stepanenko et al., 2016; Tan et al., 2017; Kiuru et al., 2018).

6. (1) Ice cover is a key variable for vertical transfer of gases. It has been shown that freezeup or brake-up presented delays of several weeks potentially. Don't you think more effort should be put on the representation of ice and snow over ice in lake models, especially when working in NWP and/or climate contexts?

(2)-(3) We agree and added the following comment at Page 23 line 18: This implies

more efforts of a community should be spent on elaborating ice-snow schemes in lake models, where currently vertical homogeneity and temporal invariance of optical and thermodynamic properties are typically assumed which does not correspond to a bulk of existing knowledge (Lepparanta et al., 2015). In a recent study, (Tan et al., 2018) one possible direction to improve the simulation of ice-cover is shown. They demonstrated that including the conversion of snow to white or slush ice when the weight of ice and snow exceeds the buoyancy of the ice cover, can significantly improve the ice simulation results. In special case of saline lakes, effects of salts trapping in ice cover become important and should be adequately parameterized as well (Stepanenko et al., 2019).

7. (1) It would also be of interest to have a comparison of surface temperatures observed at 10cm to the model simulations to be sure that the daily cycle of temperature is well reproduced. This is a key feature for any further coupling to an atmospheric model. Could you add such a graph in the revised manuscript?

(2) The diurnal cycle of the surface temperature has a limited relevance to the problem of the vertical diffusion of gases originated from bottom. Below there is a graph showing the diurnal course of temperature for 1 month, July, averaged over all 5 years. There is a systematic difference between the results of models and observation data (e.g. up to 4 ^oC for ALBM model), however, in this study we do not discuss the reason of these errors given the main focus of the study. (see attached figure: Fig.1)

8. (1) A comparison of methane profiles for ALBM and LAKE would also be interesting (climate change context, ...) even if no observation is available.

(2) The difference between these two models in methane simulation is significant: the maximum bottom concentration is 2.8 ppm and 1.1 ppm for ALBM and LAKE, respectively. The mean bottom methane concentration in the LAKE model (0.03 ppm) is an order of magnitude smaller than in the ALBM model (0.24 ppm). In general, the modeled concentration of methane in the lake is small, because of a high oxygen con-

centration. However, there are no observations available and we cannot consider one or another model as more realistic in this respect. Hence, we do not include this result into the main manuscript. (see attached figures: Fig.2, Fig.3)

Technical comments

1. (1) Page 4 line 12: change – by of

(2) We coud not find these corrections.

2. (1) Page 6 line 5: summarized (2)-(3) Page 6 line 5: changed to "summarized"

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Additional comment: Attached file contains all changes in the manuscript and SI mentioned above.

Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2019-146/hess-2019-146-AC2-supplement.zip

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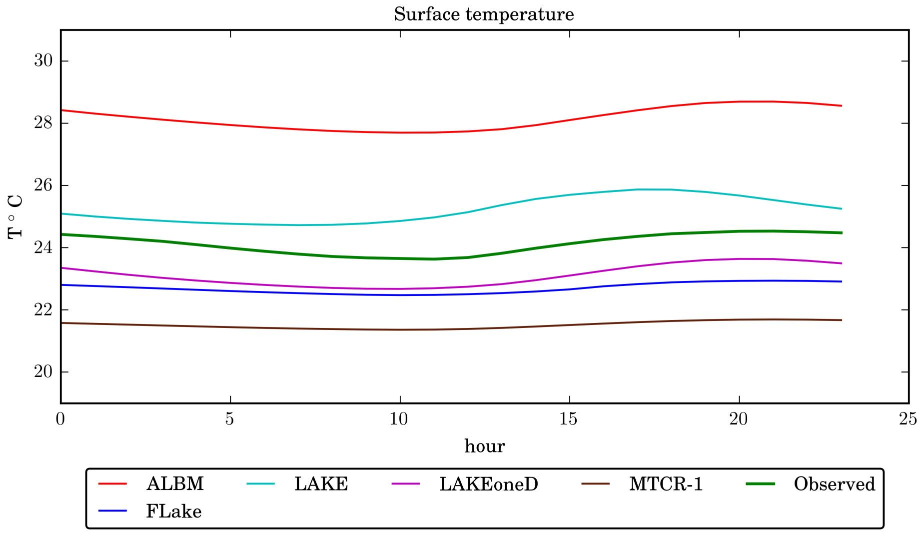

Fig. 1. The diurnal cycle of the surface water temperature (in July), averaged over 5 years.

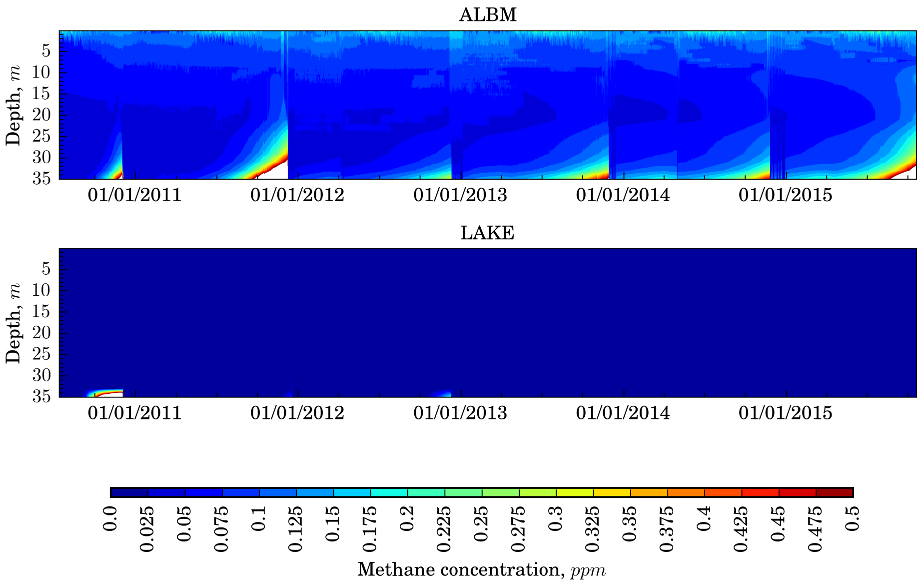

Fig. 2. Vertical distribution of methane concentration in two models: ALBM, LAKE

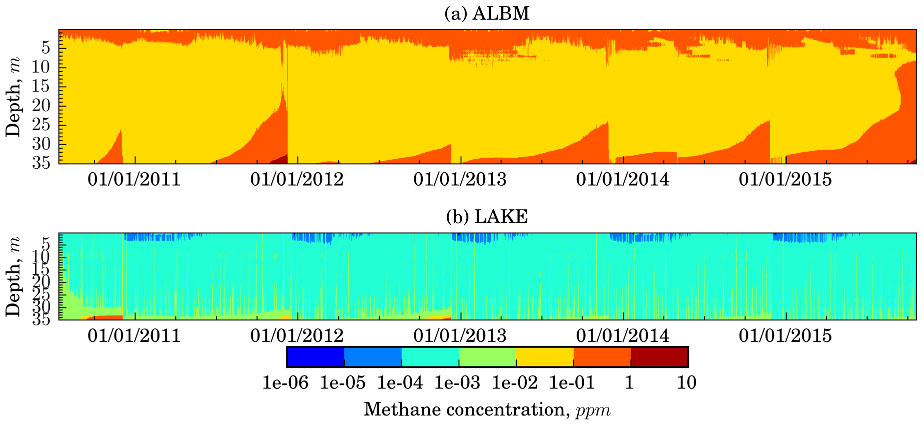

Fig. 3. Vertical distribution of methane concentration (logarithmic scale) in two models: ALBM, LAKE