We thank the reviewer very much for the valuable comments on our manuscript. The comments (bolded) are fully addressed as follows.

The manuscript presents results of introducing "K profile" parameterizatioin of turbulence into lake module of Community Land Model. This is likely the first time K profile parameterization is used in a 1D lake model, though it is widely applied in ocean models. Incorporation of new turbulence closure instead of standard Henderson-Seller diffusivity lead to significant improvement of simulation of late-summer destratification event in an Alaskan lake.

General comment

My general comment on the manuscript is that since single mixing event is simulated, more physical analysis could be provided to explain why K profile closure performed better than Henderson-Sellers in this case. Analysis presented in sections 3.1 and 3.2 is superficial and does not touch this question. One mixing case is not enough to state that K profile is better in similar situations in general, so more substantial inquiry into physics behind both parameterizations is needed. The authors state that KPP includes effects of thermal forcing, whereas original scheme of CLM model does not. This is actually not correct. First, original CLM model includes convective adjustment scheme (Subin et al., 2012) which instantaneously mixes the unstably stratified water column. Then, the effects of stable stratification are included via Brunt-Vaisala frequency in Henderson-Sellers (H-S) diffusivity. Thus, thermal (density) stratification is taken into account. The mixing event the authors focus on happens during weakly stable stratification under strong wind forcing. One may conclude from simulation results presented is that given the same stable temperature profile the larger wind speed is needed for H-S to mix completely the water column than for KPP model. This may be elaborated by conducting idealized simulations with both turbulence closures with varying wind speeds and temperature profiles where this statement may be checked and respective quantitative estimates provided.

Response: Thank you for your insightful comments. We modified several places in the manuscript to address your questions. Our general reply is as follows.

The difference of the current mixing parameterization of the CLM (CLM-ORG) and the KPP (CLM-KPP) is in the equations used to estimate eddy diffusivity. In CLM-KPP, the eddy diffusivity is estimated separately for the lake boundary layer and lake interior. In the lake boundary layer, the eddy diffusivity is not determined by local gradient of mean variables, but it is determined by surface forcing and the boundary layer depth. The non-local effect is taken into account by estimating the boundary layer depth first, and the eddy diffusivity is specified with a prescribed profile in the boundary layer. In the lake interior, the mixing is generally weak and associated with internal wave activity and shear instability. From our point of view, the major shortcomings of CLM-ORG are that it does not consider a boundary layer for eddy development, and it requires an ad hoc parameter to enhance the estimated eddy diffusivity. In the KPP scheme, an explicit inclusion of an ad hoc enlarging parameter is avoided. The KPP scheme was tested for different time scales, diurnal change, seasonal cycle, and single event for different locations (Large et al. 1994). We have also conducted more simulations for other lakes with quite different environment settings, e.g. Nam Co at Tibetan Plateau with a focus on its long term change, and the results are presented below.

For Nam Co, located in the Tibetan Plateau, we conducted simulations at a 10-km spatial resolution over the period of 2003 through 2012. Our simulations showed that the lake water surface temperature simulations with CLM-KPP were significantly improved when compared with CLM-ORG simulations. We have added simulations and analysis for Nam Co to the manuscript:

"We validated both CLM-ORG and CLM-KPP with the monthly Moderate Resolution Imaging Spectroradiometer (MODIS) data for Nam Co by conducting 10-km spatial resolution simulations for this lake over the period of 2003 through 2012. We can see that CLM-KPP improved WST simulations averaged over the entire lake (34 model grid cells) when compared with the CLM-ORG simulations (Fig. R1). The RMSE of WST decreased from 4.58 ˚C with CLM-ORG to 2.23 ˚C with CLM-KPP, and the R increased from 0.90 to 0.96 at the same time.

The differences in the mixing coefficients of CLM-KPP and CLM-ORG cause the difference in WST simulations. We averaged the K_w^{ORG} and K_w^{KPP} over the water columns with the depth greater than 25 m for Nam Co (Fig. R2), and the total of such columns were 28 out of 34 for this lake. Figure R2 indicated that K_w^{KPP} was slightly smaller than K_w^{ORG} mostly in the mixed layer of the lake during summer time. In the deeper part of the lake, K_w^{KPP} was much smaller than K_w^{ORG} during summer time. In the spring and fall seasons, K_w^{KPP} was significantly larger than K_w^{ORG} where the buoyancy flux may contribute strongly to K_w^{KPP}. During the winter time when the lake froze, both CLM-KPP and CLM-ORG were set to use K_w^{ORG}. We can see that the most significant improvements in WST for Nam Co occurred during the ice-free seasons when the KPP was activated."

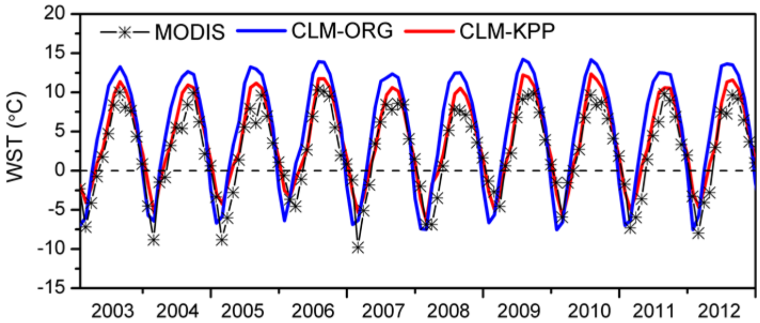

Figure R1. The time series over the period of 2003 through 2012 of monthly WST observations from MODIS (black star line) and simulations with CLM-ORG (blue line) and CLM-KPP (red line) (Unit: ˚C).

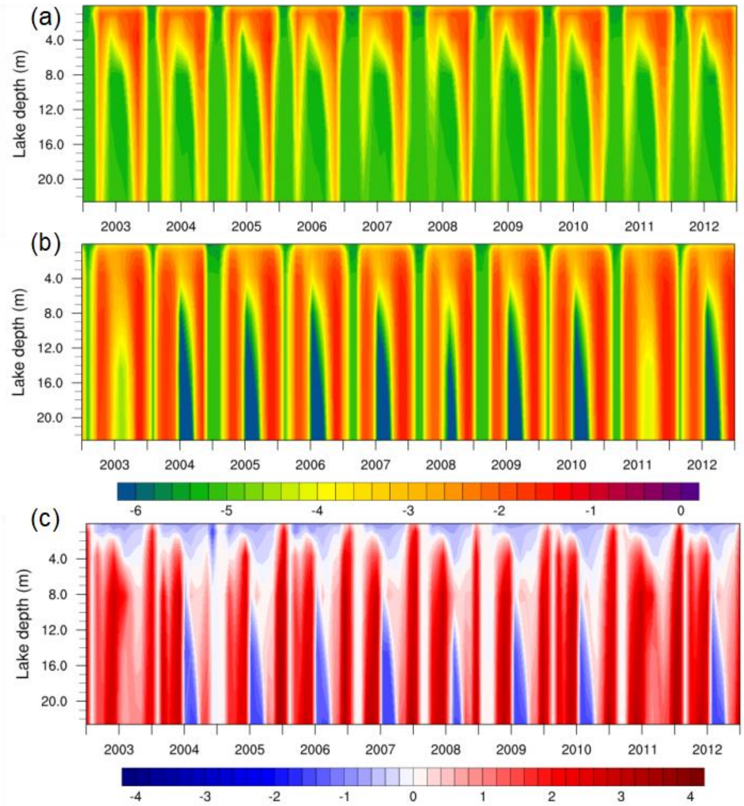

Figure R2. The simulated (a) $\log_{10} K_w^{ORG}$ with CLM-ORG, (b) $\log_{10} K_w^{KPP}$ with CLM-KPP (Unit: m^2/s) averaged over the water columns with the depth greater than 25 m (28 of 34 grid cells), and (c) the differences between $\log_{10} K_w^{KPP}$ and $\log_{10} K_w^{ORG}$ ($\log_{10} K_w^{KPP} - \log_{10} K_w^{ORG}$).

In CLM-KPP, the eddy diffusivity formulation is different for the boundary layer and lake interior. In the lake boundary layer, the eddy diffusivity is related with boundary layer depth and surface forcing. In the lake interior, the eddy diffusivity is relatively weak, associated with internal wave activity and shear instability. Overall the CLM-KPP can enhance the eddy diffusivity during spring and fall and maintain weak eddy diffusivity in the lake interior during summer when stratification is strong. The outcome of the CLM-KPP eddy diffusivity is an improved WST simulation.

For Fog3 Lake in Alaska, numerical experiments were conducted for CLM-ORG with enhanced wind. Figures R3 and R4 showed simply providing larger winds could not significantly improve CLM-ORG simulations for this lake (Table R1). When stronger wind is used, the CLM-ORG can simulate the mixing event around 16 Aug. However, the strong wind causes WST to have a negative bias, presumably caused by heat loss from the lake. Thus, as shown in the manuscript, the CLM-KPP provides a better parameterization of eddy diffusivity and improved lake temperature simulations.

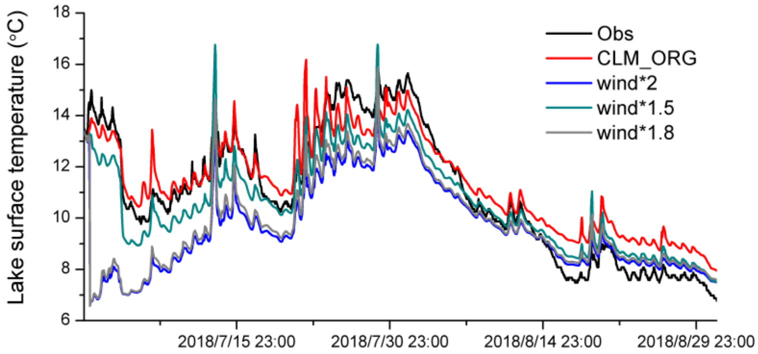

Figure R3. WST observations (black line) and CLM-ORG simulations with the default wind data (red line), with wind data 2-fold increased (blue line), with wind data 1.5-fold increased (green line), and with wind data 1.8-fold increased (grey line) (unit: ˚C).

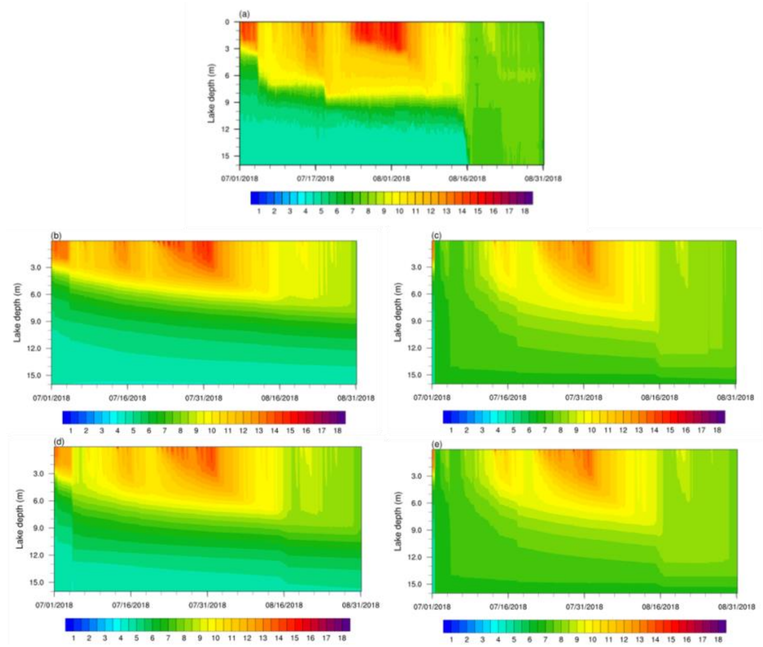

Figure R4. Lake temperature profiles of (a) observations and CLM-ORG simulations with (b) the default wind data, (c) with wind data 2-fold increased, (d) with wind data 1.5-fold increased (green line), and (e) with wind data 1.8-fold increased (grey line) (unit: ˚C**).**

Table R1. RMSEs (˚C) and Rs of the temperature profile simulations with CLM-ORG, the case with wind 2-fold increased, the case with wind 1.5-fold increased, and the case with wind 1.8-fold increased for Fog3 Lake for the three periods of 1 July through 15 August, 16–31 August, and 1 July through 31 August in 2018.

	1 July–15 August, 2018		16–31 August, 2018		1 July–31 August, 2018	
	RMSE (˚C)	R	RMSE (˚C)	R	RMSE (˚C)	R
CLM-ORG	1.1	0.93	1.4	0.57	1.2	0.90
wind×2	2.0	0.83	0.5	0.63	1.7	0.83
wind×1.5	0.83	0.97	1.1	0.59	0.91	0.94
wind×1.8	2.0	0.84	0.6	0.62	1.6	0.84

We mentioned the convective adjustment scheme in the manuscript. The convection scheme works when there exists density instability (Hostetler and Bartlein, 1990).

Specific comments

(1) Lines 88-90: "Researchers have attempted to advance this lake model to more closely reflect reality over the last two decades (Fang and Stefan, 1996; Henderson-Sellers, 1985; Hostetler and Bartlein, 1990; Subin et al., 2012)." Three of four papers cited here do not deal with CLM model.

Response: We deleted this sentence.

(2) Lines 92-93: "... is the enhanced eddy diffusivity for unresolved mixing processes". All mixing processes in 1D model are unresolved and are parameterized, because only 3D model of sufficiently high resolution simulates turbulence explicitly.

Response: We agreed with this reviewer on this comment. We changed "for unresolved mixing processes" to "to strengthen mixing processes."

(3) Line 98: "$0.0012u_2$" I guess, you can write drag coefficient C_d instead of 0.0012, to make the physical sense of this equality clear.

Response: Yes, we changed "0.0012" to "C_d" in the manuscript.

(4) Eq. (5): please separate this fraction into two.

Response: Yes, we separated the fraction into two parts.

(5) Section 2.1.1: you didn't mention convective adjustment scheme in CLM lake model. It should work during nights in your simulation.

Response: Yes, based on the general comment, we included convective adjustment scheme to the manuscript.

(6) Section 2.2: too concise description of the lake. Put more info on climate and landscape conditions, hydrological regime, previous research of the lake.

Response: Yes, we added more description of Fog3 Lake to the manuscript:

Change "Fog 3 Lake, is in Arctic Alaska at (68.67˚ N, 149.10˚ W) (Fig. 1a). In 2018 it had a surface area of 35,230 m^2 and a maximum depth of 19.74 m. The lake has a long ice duration, and ice-off is usually in late June, while ice-on typically occurs in early October (Arp et al., 2015)."

to

“Fog 3 Lake, is in Arctic Alaska at (68.67˚ N, 149.10˚ W) (Fig. 1a). In 2018 it had a surface area of 38,863 m^2 and a maximum depth of 20.96 m. The lake has a long ice duration, and ice-off is usually in late June, while ice-on typically occurs in early October (Arp et al., 2015). Around this lake, the mean annual air temperature is about ~ -6 ℃, and the mean annual precipitation is ~ 200 mm (Ping et al., 1998). This kettle lake is surrounded with lower hills mainly covered with shrubs and tundra. Due to the treeless and landscape, there are no effects from tree shielding on wind. In addition, Fog 3 Lake is formed by glaciers, and has less connection to other surrounding surface waters.”

(7) Line 154: “wind-only driven scheme”. Again (see above), it is incorrect to state that basic CLM lake model includes only wind forcing, as it accounts for both stable and unstable stratification.

Response: Yes, see the response for the general comment.

(8) Section 2.3: I would add more info on the organization of measurements. Is there a mast on a lake? Which organization runs measurements? Any relevant references?

Response: Fog3 Lake is near Toolik Field Station (68°37.796’ N, 149°35.834’ W), in the northern foothills of the Brooks Mountain Range, Alaska (https://toolik.alaska.edu/edc/abiotic_monitoring/index.php). The weather station is on the shore of Fog 3 Lake, and Utah State University runs the measurements included in this study.

(9) Line 173: “estimates a stratified lake”: sounds badly, please rephrase.

Response: Yes, we changed this sentence to **“**CLM-KPP accurately captured the mixing event (Fig. 3c), while CLM-ORG produced strong stratification in the upper part of the lake throughout the simulation period (Fig. 3b).**”**

(10) Table 1 is too small, you can easily present those numbers directly in text.

Response: We separated our entire simulation period for Fog3 Lake into the before and after mixing periods and calculated RMSEs and Rs for these two periods as well as the entire simulation period (Table R2). We can see that CLM-KPP remarkably improved the water mixing simulations in Fog3 Lake when compared with CLM-ORG.

Table R2. RMSEs (˚C) and Rs of the temperature profile simulations with CLM-ORG and CLM-KPP for Fog3 Lake for the three periods of 1 July through 15 August, 16–31 August, and 1 July through 31 August in 2018.

	1 July–15 August, 2018		16–31 August, 2018		1 July–31 August, 2018	
	RMSE (˚C)	R	RMSE (˚C)	R	RMSE (˚C)	R
CLM-ORG	1.1	0.93	1.4	0.57	1.2	0.90
CLM-KPP	1.3	0.92	0.3	0.99	1.0	0.95

(11) Lines 183-184: "Thermal forcing played a vital role in this enlarged diffusivity, which was considered only in CLM-KPP and not in CLM-ORG." See my comment 7 above and general comment.

Response: Yes, see the response for the general comment.

(12) Line 188: "10^{-7}" please put units and elsewhere in the document.

Response: Yes, we put units and elsewhere in the manuscript.

(13) Line 188: "was the product" It is not product, but a sum.

Response: Yes, we changed "product" to "sum" in the manuscript.

(14) Lines 198-201: two sentences, stating almost the same.

Response: The first sentence states the N^2, while the second sentence states the water stratification.

(15) Line 238: "absorbed solar radiation". It is radiation flux.

Response: Yes, we modified "absorbed solar radiation" to "radiation flux" in the manuscript.

(16) Lines 239-240: "total eddy diffusivity". Better: total diffusivity.

Response: Yes, we modified "total eddy diffusivity" to "total diffusivity" in the manuscript.

(17) Eq. (A3): a0, a1, ... Better to put numbers into subscript (a_0, a_1, ...).

Response: Yes, we put numbers into subscript accordingly in the manuscript.

(18) Eq. (A4) (both equations): there is a derivative sign in numerator and not in denominator.

Response: Yes, we made it more clearly in the manuscript.

(19) Line 244: Not clear, what is $\vartheta(h)$? You say, it is "water diffusivity". But, water diffusivity is K_w. There are also molecular diffusivity, background diffusivity, diffusivity caused by internal waves … all denoted differently above.

Response: $\vartheta(h)$ refers to the total diffusivity of water, a sum of molecular diffusivity, background diffusivity, diffusivity caused by internal waves. We made it more clearly in the manuscript.

(20) Line 246: replace "buoyancy difference" by "buoyancy".

Response: Yes, we replaced "buoyancy difference" by "buoyancy" in the manuscript.

References

Arp, C. D., Jones, B. M., Liljedahl, A. K., Hinkel, K. M., and Welker, J. A.: Depth, ice thickness, and ice-out timing cause divergent hydrologic responses among Arctic lakes, Water Resour. Res., 51(12), 9379-9401, https://dx.doi.org/10.1002/2015WR017362, 2015.

Hostetler, S. W., and Bartlein, P. J.: Simulation of lake evaporation with application to modeling lake level variations of Harney-Malheur Lake, Oregon, Water Resour. Res., 26(10), 2603-2612, https://dx.doi.org/10.1029/WR026i010p02603, 1990.

Large, W. G., Mcwilliams, J. C., and Doney, S. C.: Oceanic vertical mixing: A review and a model with a nonlocal boundary layer parameterization, Rev. Geophys., 32(4), 363-403, https://dx.doi.org/10.1029/94RG01872, 1994.

Ping, C. L., Bockheim, J. G., Kimble, J. M., Michaelson, G. J., and Walker, D. A: Characteristics of cryogenic soils along a latitudinal transect in arctic Alaska, J. Geophys. Res., 103, 28917-28928, https://dx.doi.org/10.1029/98JD02024, 1998.