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Interactive comment on "Determining lake surface water temperatures (LSWTs) worldwide using a tuned 1-dimensional lake model (*FLake*, v1)" *by* A. Layden et al.

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The authors gratefully acknowledge the time and attention given by the referees to their reviews, and the constructive comments made, to which we have paid close attention.

Referee Comments

I have one comment. On p. 8553-8554 (2.2.2 Fixed model parameters), authors listed parameters that remain fixed through the study and stated that water-to-ice heat flux (Q_wi) of 5 W/m-2 is applied to all lakes. To my knowledge, it's a strong overestimation. Malm et al. (Temperature and salt content regimes in three shallow ice-covered lakes:

2. Heat and mass fuxes. 1997. Nordic Hydrol., 28, 129-152) have shown temporal-spatial dynamics of Q_wi in shallow lakes. As it comes from their results, which can be considered as typical for shallow boreal lakes, Q_wi values for the main winter course - the ice thickness grows until early-spring radiative warming starts - are on average less than 1 W/m-2. During the 'warming' period, when ice starts melting, Q_wi may grow up to 10-15 W/m-2 due to rise of water temperature in the gradient layer beneath the ice. Concerning deeper lakes (D > 15-20 m), they usually get ice-covered much later that shallow ones. As a result, a greater loss of heat leads to water temperature in the upper part of a water column close to zero. Thus, Q_wi in deep lakes is close to zero as well. In FLake, ice 'grows' mainly from below unless a snow cover is present, and Q_wi is one of the main parameters in the process. I dare assume that ice thickness in calculations performed was erroneous. This, in its turn, demanded a kind of extra-tuning to adjust ice-off dates to realistic values.

All the tuning described inevitably produces unrealistic results on the water temperature vertical profile and depth of the mixed layer.

Then, my questions are: 1) what is a main objective of the study? 2) who are expected to be end-users of a tuned model?

Author's response

We acknowledge that the referee is concerned that a value of 5 W/m-2 applied to describe water-to-ice heat flux (icewater_flux) for the tuning of all lakes in FLake, may lead to erroneous ice thickness measurements. Furthermore, we acknowledge that icewater_flux can vary considerably between the ice growth and ice melt period. We have addressed these concerns through explanations and comments made.

Background on selection of icewater_flux values of 5 W/m-2:

The icewater_flux value was selected during the preliminary modelling work in this study. The focus of the preliminary work was to find the lake properties which had the strongest effect on the modelled LSWTs. Seven (7) seasonally ice-covered lakes (deep and shallow), with available lake characteristic data in the ILEC world lake database (http://wldb.ilec.or.jp/) or LAKENET (www.worldlakes.org), were used in this preliminary work. For these lakes, icewater_flux values of 3 W/m-2 and 5 W/m-2 showed a negligible difference between the modelled daily mean absolute difference (MAD) LSWT values. On this basis a value 5 W/m-2 was used in the tuning study. Arguably, a value of 3 W/m-2 or 4 W/m-2 could have been applied.

Comment on extra-tuning to adjust ice-off dates to realistic values:

Agreed, it is very reasonable to suggest that extra-tuning is taking place in this approach, not only for the icewater_flux values but also for other factors, such as not using the ‘heat flux from sediments module’ or the ‘snow cover module’. The heat flux from the sediments module is not switched on in the tuning study, as outlined in P.8554, line 3. Not using this module is the suggested reason why shallow lakes are tuned to a greater depth i.e., extra tuning to greater depth to compensate for not considered heat flux from sediments (P.8570, line 14). Similarly, it is suggested that the 1 °C warming day occurs earlier (compared to observed LSWTs) because the snow cover module is not in use. The last paragraph in section 5.2 ‘Findings and Discussion’, is now reworded to discuss the possibility of extra-tuning of albedo in this study.

Comment on unrealistic results on the water temperature vertical profile and depth of the mixed layer:

Yes, agreed. The tuning approach taken is specific to LSWTs. The metrics used in the tuning were chosen to capture the critical aspects of the LSWT cycle. For seasonally ice-covered lakes these are the maximum LSWTs (JAS), metrics indicative of ice-on/ice-off and the MAD throughout the cycle. For non-seasonally ice-covered lakes, the difference between the observations and model for the months where the minimum (and maximum) LSWTs occur are applied as metrics. These exert some control over temporally reconciling the modelled monthly extremes with the observed monthly extremes. The effect of the tuning on the temperature vertical profile and the depth of the mixed layer has not been considered in this study. Furthermore, the tuning of depth, particularly for lakes where depth is tuned to several times its depth, will most possibly affect the temperature vertical profile and the mixed layer depth. I have now stated this in section 1 (Introduction) and explained that over-tuning is likely due to the few lake properties that are been considered in this study.

Changes made to paper:

P8549, line 19 (Section 1: Introduction) "The tuned model is expected to improve the representation of the LSWT of these lakes in FLake. FLake is a 1-dimensional thermodynamic lake model, capable of predicting the vertical temperature structure and mixing conditions of a lake (Mironov et al, 2010)."

replaces

"The tuned model is expected to improve the representation of these lakes in FLake."

P8550, line 3 (Section 1: Introduction)

"It is the intention of this tuning study to achieve an average daily mean absolute difference (MAD) of < 1 °C between the tuned and observed LSWTs, across all lakes. An average MAD of < 1 °C is possibly accurate enough for a global scale study mean. A lower MAD target may not be achievable as this study comprises of lakes with a wide range of geographical and physical characteristics. The effect of the tuning on the sub-surface temperature vertical profile and the depth of the mixed layer is not considered in this study. Many lake specific properties can be considered in FLake. Preliminary model trial work was carried out on 7 seasonally ice covered lakes (deep and shallow) which had available lake characteristic data in the ILEC world lake database (http://wldb.ilec.or.jp/) or LakeNet (www.worldlakes.org). Through this preliminary work, the lake specific properties which exerted the strongest effect on the modelled LSWTs were selected. These properties are lake depth (d), snow and ice albedo (α) and light extinction coefficient (κ). In the next part of the preliminary work, it was determined that the modelled LSWTs could be tuned to compare well with the observed LSWTs, by adjusting the lake specific literature values for these 3 lake specific properties. On this basis, the trial work as described in this paper, was performed on 35 lakes, prior to tuning all 246 lakes.

Replaces

"It is the intention of this tuning study to achieve an average daily mean absolute difference (MAD) of < 1 °C, across all lakes. An average MAD of < 1 °C is possibly accurate enough for a global scale study mean. A lower MAD target may not be achievable as this study comprises of lakes with a wide range of geographical and physical characteristics. Many lake specific properties can be considered in FLake. Through preliminary model trials, three properties; lake depth (d), albedo; snow and ice (α) and light extinction coefficient (κ) are shown to greatly influence the modelled LSWT cycle. Furthermore, optimal values for these three properties (herein referred to LSWT regulating properties) are shown to greatly improve the LSWT modelling in FLake."

New paragraph included at end of Introduction (section 1)

"Having a reliable source of observed LSWTs (ARC-Lake), the objective of this study is to assess if FLake can be tuned to produce realistic LSWTs for large lakes globally, using relatively few lake properties. It is expected that for each lake, the tuning of lake properties will compensate to a greater or lesser degree for much of the lake to lake variability in altitude, salinity, lake shape and LSWT features affected by depth.

The motivation of this study was to develop a greater understanding of lake dynamics, globally, offering a potential to develop parameterization schemes for lakes in numerical weather prediction models. It is expected that the findings in this study will be of interest to climate modellers, limnologists and current and perspective users of FLake.

P.8568, last paragraph (section 5.1):

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“There is a snow cover module with FLake which is not operational in this version of the model. Therefore the insulating effect that snow has on the underlying ice is not modelled. As a result the snow and ice albedo are set to the same default value (0.60), possibly underestimating the extent of the albedo effect of snow. This may be the reason for the earlier 1 °C warming day and the higher JAS LSWTs, when modelled with the default albedo. As shown in the tuning process, a higher albedo results in a later (less biased in time) 1 °C warming day and as a result, reduces the period of time of the surface absorption of short-wave radiation, improving the mean JAS LSWTs. It is possible that the icewater_flux value of 5 W/m-2 may be an overestimation of the water-to-ice heat flux in the ice growth phase of deep and shallow lakes. This greater heat flux, leading to underestimated ice thickness, could have contributed to the large 1 °C warming day bias shown in table 5 (column 1). In a study by Malm et al. (1997), the water-to-ice heat flux during the ice growth phase was shown to be < 1 W/m-2 in both deep (15-20 m) and shallow lakes. Underestimated ice thickness, causing an early ice melt, possibly led to over-tuning of albedo in the tuned model.”

replaces

“There is a snow cover module with FLake which is not operational in this version of the model, therefore the insulating effect that snow has on the underlying ice is not modelled. As a result the snow and ice albedo are set to the same default value (0.60), possibly underestimating the extent of the albedo effect of snow. This may be the reason for the earlier 1 °C warming day and the higher JAS LSWTs, when modelled with the default albedo. As shown in the tuning process, a higher albedo results in a later (and more timely) 1 °C warming day and as a result, reduces period of time of the surface absorption of short-wave radiation, improving the mean JAS LSWTs. “

Included at end of Summary and conclusion (section 6)

“The findings in this study are expected to be of interest to limnologists concerned with the relationship between certain features of the LSWT cycle and lake characteristics.

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Interactive Comment

The findings also offer practical guidance in developing parameterization schemes for lakes in numerical weather prediction models. Limnologists may also benefit from other aspects of this study, for example, the effect of wind speed scaling on LSWTs and how the observed minimum monthly LSWTs may be used to estimate lake bottom temperatures. The optimal LSWT-regulating properties of the 244 lakes may provide a guide to current and prospective users of FLake for improving the LSWT modelling in FLake for other lakes, without having to tune the model for each lake separately. This is of particular use for lakes where lake characteristic information is not available."

'Mironow' corrected to 'Mironov' throughout

Additional References Malm, J., Terzhevik, A., Bengtsson, L., Boyarinov, P., Glinsky, A., Palshin, N. and Petrov M.: Temperature and salt content regimes in three shallow ice-covered lakes: 2. Heat and mass fluxes, Nordic Hydrol., 28, 129-152, 1997

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Interactive comment on Geosci. Model Dev. Discuss., 8, 8547, 2015.

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