

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 care given by the referees to their reviews, and the constructive comments made, to which we have paid close attention.

Details of response to comments:

Referee comment This manuscript addresses the tuning of the FLake model for world-wide lakes, with various adjustments specific to the characteristics of the lakes. This is relevant work, both for evaluation of FLake, and for generalized application of it. However, the presentation is quite poor, with many confusing statements throughout, and

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poor and often missing use of units of measure. My comments that follow cover both major scientific points and minor editorial points, although the latter class should not be viewed as an exhaustive list of editorial points. The overall sum of problems with this paper leads me to recommend rejection; better presentation would greatly improve this situation.

Author response

We note that the referee acknowledges that relevance of the work presented, and is concerned primarily about presentation, which we take to mean the clarity of what is presented. We have addressed thoroughly the comments made, and have given the entire text another careful review and edit. The additional improvements made during this careful review are listed at the end of the responses.

Referee comment

P. 8548, lines 15-19: “The sensitivity of the summer LSWTs of deeper lakes to changes in the timing of ice-off is demonstrated.” This seems to imply a direct causal relationship between the two, whereas reality has both summer LSWT and ice-off dependent on the preceding heat budget. So “correlation” might be a better word than “sensitivity.”

Author Response This statement is noting that there is a definite relationship between the two; a relationship although related to the heat budget is only evident for deep lakes. Within the paper, P.8567, line 21-29, it is suggested that deep lakes where the heat capacity is not reached during the warming period, is key in the relationship between the ice-off date and the JAS LSWT.

Referee comment Then this goes on to more confusing territory by saying that the summer LSWT response to ice-off is dependent on latitude and depth. The way that I would symbolically represent this statement is “the correlation of [correlation of summer LSWT vs. ice-off day] vs. latitude and depth is 0.5 (R²)”. Are you really taking a correlation of a correlation, or is the second part of the sentence a better represen-

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tation?: “Lake depth and latitude, explaining 0.5 of the inter-lake variance in summer LSWTs.”

Author Response The full sentence now reads “The modelled summer-LSWT response to changes in ice-off timing is found to be statistically related to lake depth and latitude, which together explain 0.50 ($R^2_{adj,p}=0.001$) of the inter-lake variance in summer LSWTs.”

Hopefully this is now unambiguous.

This is saying that latitude and depth together can explain half of the changes in JAS LSWT that occurred as a result of delaying the ice-off day.

Referee comment P. 8550, line 7: “albedo; snow and ice (α)” occurs here and elsewhere. This is a very strange description. Alpha is simply the symbol that stands for albedo, so it should just say “albedo (α)”. You can certainly make the true statement that albedo is strongly dependent on snow and ice, but the result that you use as an input to FLake is simply albedo.

Author Response From your interpretation, I realize how confusing this appears. I now refer to albedo as “snow and ice albedo” in every instance throughout the paper. This hopefully assures the reader that I am referring to snow and ice albedo and not the albedo of the liquid water. On P 8557, where I am specifically discussing the tuning of snow and ice albedo, I state that the albedo of water is not tuned remains constant, 0.07.

In P 8557, Line 7, “Albedo when discussed throughout this study refers to snow and ice albedo. Tuning of the albedo of water (liquid phase) is not considered and remains at the FLake default value of 0.07 throughout this study.”

Replaces

“Albedo when discussed throughout this study refers to snow and ice albedo.”

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Referee comment P. 8550, line 26: Change “seasonally” to “seasonal”.

Author Response Corrected typographical error

Referee comment My preference is to use a hyphen in “ice-covered” when they are used together to form a compound adjective, such as when they modify “lakes” in “ice-covered lakes”. Contrast “Ice covered the lake.”

Author Response Throughout the paper, I have now used hyphens where two words are put together to make a compound adjective. “Ice covered” now reads “Ice-covered”, “post tuning” now reads “post-tuning” and “LSWT regulating properties” now reads “LSWT-regulating properties”

Referee comment P. 8552, line 13, and elsewhere: GMD might have an editorial policy on this. Although some German-language sources might have this name spelled “Mironow”, every instance I found on Google mentioning this paper, admittedly all English-language sources, has it spelled “Mironov”, and you have it that way on p. 8574, lines 8 and 11.

Author Response Corrected, this should be “Mironov” throughout

Referee comment P. 8553: The variables “c_relax_C”, “fetch”, and “latitude” are formatted here as a list of definitions. This would make more sense visually if each of these key words were italicized, and a colon works better than a semi-colon to separate a term from its definition.

Author Response “c_relax_C”, “fetch” and “latitude” now italicized with colon

Referee comment P. 8553, line 1: I am a stickler for proper use of units, and this is the first of several comments on this topic. This line says that c_relax_C is a relaxation time scale. This implies that its units are time, such as seconds or days. Then you proceed to mention values without units, and imply that larger values of c_relax_C indicate more vigorous vertical mixing of water, meaning that a larger value of c_relax_C means a shorter relaxation time. I think its units are inverse time.

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Author Response $c_{\text{relax_C}}$ is a dimensionless constant used in the relaxation equation for the shape factor with respect to the temperature profile in the thermocline. I've updated the description

P. 8553, line 1: " $c_{\text{relax_C}}$: a dimensionless constant used in the relaxation equation for the shape factor with respect to the temperature profile in the thermocline."

Replaces " $c_{\text{relax_C}}$; is a relaxation time scale for the temperature profile in the thermocline."

Referee comment P. 8553, eq. 1: Even though not directly stated, we've established above that fetch has units of length (maybe km), so this equation should show this explicitly. Is 39.9 in units of km? What are the units of area, and how does its coefficient convert it back into the same units of length? Including units is crucial for the reader to be able to address the question, "Does this equation make sense?"

Author Response In this equation, fetch is calculated in km (the length and breadth of the lakes are in km, as is the area and the constant). The coefficient is determined from the relationship between the calculated fetch (square root of the product of lake length and breadth measurements) and the surface area of the 205 lakes with length and breadth measurements. I've now included UOM.

P. 8553, eq. 1: " $\text{fetch} = 39.9 \text{ km} + 0.00781 \text{ area km}$ "

replaces

" $\text{fetch} = 39.9 + 0.00781 \text{ area}$ "

Referee comment P. 8553, line 15: The name "Doll" should have an umlaut over the "o".

Author Response umlaut now included

Referee comment P. 8554, line 2: Units should be W m^{-2} (with superscript) rather than W m^2 .

Author Response Corrected typographical error

Referee comment P. 8554, line 15: This shows units of m for fetch. Are you really dealing with water bodies with fetch < 16 m? That's a very small water body.

Author Response Corrected typographical error, this should read “km” not “m”. Also corrected is the intended use of Hsu's equation – it is applicable to wind speeds over sea surfaces.

P. 8554, line 15: “For adjusting wind speeds over land (measured in m/s), to wind speeds over sea surfaces, Hsu (1988) recommends the scaling shown in Eq. (2). For bodies of water with fetch < 16 km a scaling of 1.2 is considered reasonable (Resio et al., 2008).”

replacing

“For water bodies with fetches >16 m, Hsu (1988) recommends the scaling shown in Equation 4. For bodies of water with fetch < 16 m a scaling of 1.2 is considered reasonable (Resio et al., 2008).”

Referee comment P. 8554, eq. 2 needs units.

Author Response units in m/s

P. 8554, eq. 2

" $U_{\text{water}} = 1.62 \text{ m/s} + 1.17 U_{\text{land}}$ "

Where U_{water} = wind speed over water (m/s), and U_{land} = wind speed over land (m/s)”

Replaces " $U_{\text{water}} = 1.62 \text{ m} + 1.17 U_{\text{land}}$ "

Referee comment P. 8555, eq. 3: This strongly implies that kappa has units of m^{-1} (as does eq. 4), so the intercept 0.07 in this equation should have those same units. On the next line, it is ambiguous whether units of m refer to Secchi disk depth or inverse Secchi disk depth; it is much more straightforward to say “where S = Secchi disk depth

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(m)".

Author Response Yes correct, κ_{sd} is in units of m^{-1} for both eq 3 and eq 4, as is the intercept in eq 3. This is now clarified.

P. 8555, line 5 "The light extinction coefficients values for the untuned model trial are derived from Secchi disk depth, κ_{sd} (m^{-1})"

replaces

"The light extinction coefficients values for the untuned model trial are derived from Secchi disk depth (κ_{sd})"

Agreed, to avoid unnecessary forms of the same term, I now refer to all Secchi disk depth measurements (S) in meters and have updated the equations to reflect this.

P. 8555, line 19 (eq 3)

$\kappa_{sd} = (0.757/S) + 0.07m^{-1}$ replaces $\kappa_{sd} = 0.757*S^{-1} + 0.07$

P. 8555, line 20

where S = Secchi disk depth (m) replaces where S^{-1} = inverse Secchi disk depth (m)

P. 8556, line 2 (eq 4) $\kappa_{sd} = 1.7 / S$ replaces $K_{sd} = 1.7 / \text{Secchi disk depth}$

Referee comment P. 8559, eq. 5: It is necessary to make it really straightforward what is meant by this operation. You're calculating varjas for whole groups of lakes, right? So N isn't just the number of years, but the sum of the number of years over all of the lakes. And \bar{x} is the mean across both years and lakes. Whether I'm right or wrong about this, it needs clarification.

Author Response varjas is calculated for each lake, so for a given lake, N is the number of years with LSWT observations and \bar{x} is the mean across all years.

N and \bar{x} are now explained in equation

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P. 8559, line 7 “where obs_jas = observed JAS LSWT

N = number of years with JAS LSWTs

x bar = mean across all years”

Replaces “where obs_jas = observed JAS LSWT ”

Referee comment P. 8559, line 7: You have interjas in the same definition format as on p. 8553, so it should be set off by a paragraph break, italics, and followed by a colon.

Author Response Corrected

Referee comment P. 8559, line 14: Then you need to clarify what “max” and “min” mean. Are these the monthly mean values that happen to be warmer (cooler) than any other month of the year. If most years have August with the warmest LSWT, but one has the warmest water in September, do I insert the September value for that year, or is do I always use the same month, with the highest mean value?

Author Response Yes these are monthly mean values that happen to be warmer (cooler) than any other month of the year. These LSWTs are not tied to a particular calendar month. The minimum LSWT refers to the month in which the minimum LSWT occurs, be it August or September or any other month. The same applies to the maximum LSWT. I have now included a description of the terms used in the equations (obs_min, mod_min, obs_max and mod_max) on P. 8559, line 14. varmax, Intermin and varmin, are already described in the text P8558 line 22 to P.8559, line 3 (section 2.4.3)

P. 8559, line 14, now states “Where obs_min (and mod_min) = mean LSWT observed (and modelled) in the month where the minimum LSWT occurs, and where obs_max (and mod_max) = mean LSWT observed (and modelled) in the month where the maximum LSWT occurs”

Referee comment P. 8559 and elsewhere: When you use the form varjas(K2), it seems

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to mean “varjas in units of K squared”. On the other hand, $\text{interjas}(R2_{\text{adj}})$ seems to mean “interjas, which can be thought of as being like a correlation coefficient, but with adjustments for the number of predictor variables”. Both of these are at odds with what I think of at the standard form $f(x)$, “f as a function of x”, so this becomes quite confusion and needs to be explained.

Author Response Correct, varjas, varmin and varmax are in units of kelvin squared. varjas measures the observed JAS LSWT variance for each seasonally ice-covered lake. varmin (and varmax) measure the observed variance in the mean LSWT value for the month of minimum (and maximum) LSWT, for each non-seasonally ice-covered lake. interjas, intermin and intermax measure the respective fraction ($R2_{\text{adj}}$) of the observed variance that is accounted for in the tuned model for each lake.

Referee comment P. 8563, lines 14-15: Are you saying that water density is lower because of atmospheric pressure? Lakes and oceans add about 1 atmosphere of pressure for each 10 m of depth, but this has a rather minimal effect on water density. Then I don't see how lower water density inhibits heat transfer, especially if you balance the effects of density on effective thermal conductivity (eddy diffusivity) and on thermal capacity.

Author Response I'm not referring to depth here. I'm saying that at higher altitudes the atmosphere is rarified, so the natural convective and thermal heat transfer processes are less effective.

Referee comment P. 8564, line 27: When it says $p=0.000$ here and on the next page, is that a typo, or does it mean that it's less than 0.0005?

Author Response Yes, it also means that the p value is less 0.0005. The p-values are reported to 3 decimal places throughout – I've changed “ $p = 0.000$ ” to “ $p < 0.0005$ ” for correctness.

Referee comment P. 8566, lines 18-20: This is a similar problem to some of the wording

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in the abstract. I think you did one correlation of depth and latitude to the delay in 1 deg warming day due to increased albedo, and another of depth and latitude to the decrease in JAS LSWT. If this is correct, then change “between” to “in” and add another “in” before “the JAS LSWT. . .” If this is incorrect, then what you actually did needs more careful explanation.

Author Response You’re right, this is very confusing, it was worded incorrectly. The correlation is drawn between the JAS LSWT decrease (caused by the change in the 1°C warming day) and latitude & depth. I’ve re-worded this section

P. 8566, lines 16 “A higher albedo (α_2 , Table 2) delays the 1 °C warming day by 27 ± 12.6 days and decreases the mean JAS LSWT bias by half, to 0.98 ± 2.51 °C, across the 21 lakes. There is no correlation between the modelled JAS LSWT decrease and the length of the delay in the 1 °C warming day (due to the increased albedo) over the 21 lakes. This indicates that the JAS LSWT of the lakes do not respond in the same manner to changes in the 1 °C warming day. Lake depth and latitude were found to cause much of the modelled variability in the JAS LSWT decrease (caused by the changes in the 1 °C warming day). Across the 21 lakes, together (using stepwise regression), lake depth and latitude account for 0.50 (R^2_{adj} , $p = 0.001$) of the variance in the JAS LSWT decrease. Separately, depth accounts for 0.35 ($p = 0.003$) and latitude for 0.26 ($p = 0.01$) of the variance.”

Referee comment P. 8566, line 26: “. . .as a result of” implies a direct cause-effect relationship. I suspect that the delay in 1 deg warming day didn’t actually cause the LSWT decrease, but that they were associated because albedo caused both. The same statement of causality also occurs in the following sentence, as well as p. 8567, lines 8-11.

Author Response

Recalling that the albedo in question is that of snow & ice (not the liquid phase), there appears to be a causal chain: higher albedo delays the ice-off day, allowing less time

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for the water to warm, such that for those cases where the summer peak temperature is not close to equilibrium with the summer environment, e.g. deeper lakes, a lower JAS LSWT results.

Referee comment P. 8567, line 23: Remove “of”.

Author Response Corrected

Referee comment P. 8567, line 27: Pull “lakes” outside of the parentheses.

Author Response Corrected

Referee comment P. 8568, line 12: Start a new sentence at “Therefore”.

Author Response Updated as suggested

Referee comment P. 8568, line 17: When you say “more timely” here, I think it means “less biased in time”, which would be a better description.

Author Response Updated as suggested

Referee comment P. 8568, line 26: Change “being” to “been”.

Author Response Corrected

Referee comment P. 8569, lines 15-16: The units should be kg per cubic meter, so I think the exponent of -3 belongs to the number 10, not the unit of kg, and the exponent for m should be -3, not 3.

Author Response Corrected

Referee comment P. 8569, line 19: “. . .buffering effect against wind” is vague. Against wind causing what? Heat flux through the thermocline or surface?

Author Response reworded P.8569, line 19 “It is possible that the large density difference between these two layers (LSWT and hypolimnion) in high latitude lakes during the stratification period, may produce a buffer against wind induced mixing and there-

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fore lessen the heat flux through the thermocline.” Replaces

Referee comment P 8569, line 20: “Purports to” doesn’t make sense here. Possibly substitute “is set to”.

Author Response P 8569, line 25: Reworded “Although the density differences between the two layers are considered in FLake, the model is forced with over land wind speed measurements.”

Referee comment P. 8570, line 5: I think the idea is that you have done a generalized tuning that can apply across all lakes, with dependence on the lakes’ properties. Therefore, “without needing to tune the model” should have appended “for each lake”.

Author Response P.8570, line 4-5 “The optimal LSWT-regulating properties of the 244 lakes provide a guide to improving the LSWT modelling in FLake for other lakes, without having to tune the model for each lake separately.”

Referee comment P. 8570, line 20: This is where I’ve bothered to note that you missed capitalizing the “L” in “FLake”, but it occurs elsewhere, too. My autocorrection just tried to overrule me on doing it this way.

Author Response P. 8570, line 21 “As FLake” replaces “As Flake”

P. 8578, Table 1 header “FLake input” replaces “Flake input”

P. 8578, Table 1, 1st row “FLake input” replaces “Flake input”

P8605, Figure 17 caption (3rd line) “FLake lake model” replaces “Flake lake model”

Referee comment P. 8571, line 5: To make it clear that 21 m is part of the first clause of the sentence, and 13 m is part of the second part, follow the number 21 with the unit of m, then a comma.

Author Response

P8571, line 5 Corrected sentence

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“The average depth of lakes tuned to κ_d4 and κ_d5 is 21 m and 13m respectively.”
Replaces “The average depth of lakes tuned to κ_d4 is 21 and 13m for lakes tuned to κ_d5 .”

ADDITIONAL IMPROVEMENTS MADE TO PAPER AT SUGGESTION OF FIRST REFEREE

P8548, line 4-7

“The model, which was tuned using only 3 lake properties (lake depth, snow and ice albedo and light extinction co-efficient), substantially improves the measured biases in various features of the LSWT annual cycle, including the LSWTs of saline and high altitude lakes.”

Replaces

“The model, tuned using only 3 lake properties; lake depth, albedo (snow and ice) and light extinction co-efficient, substantially improves the measured biases in various features of the LSWT annual cycle, including the LSWTs of saline and high altitude lakes”

P8548, line 7-14

“Lakes whose lake-mean LSWT persists below 1 °C for part of the annual cycle are considered to be ‘seasonally ice-covered’. For seasonally ice-covered lakes, the daily mean and standard deviation of absolute differences (MAD) are reduced by model tuning from 3.01 ± 1.12 °C to 0.84 ± 0.26 °C. For all other lakes (non-seasonally ice-covered), the improvement is from 3.55 ± 3.20 °C to 0.96 ± 0.63 °C.”

Replaces

“The daily mean absolute differences (MAD) and the spread of differences (± 2 standard deviations) across the trial seasonally ice covered lakes (lakes with a lake-mean LSWT remaining below 1 °C for part of the annual cycle) is reduced from 3.01 ± 2.25

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°C (pre-tuning) to 0.84 ± 0.51 °C (post-tuning). For non- seasonally ice-covered trial lakes (lakes with a lake-mean LSWT remaining above 1 °C throughout its annual cycle), the ... "

P8548, line 15-18

"The relationship between the changes in the summer LSWTs of deeper lakes and the changes in the timing of ice-off is demonstrated. The modelled summer-LSWT response to changes in ice-off timing is found to be statistically related to lake depth and latitude, which together explain 0.50 (R^2_{adj} , $p = 0.001$) of the inter-lake variance in summer LSWTs"

Replaces "The sensitivity of the summer LSWTs of deeper lakes to changes in the timing of ice-off is demonstrated. The modelled summer LSWT response to changes in ice-off timing is found to be strongly affected by lake depth and latitude, explaining 0.50 (R^2_{adj} , $p = 0.001$) of the inter-lake variance in summer LSWTs."

P8548, line 19-21

Lake characteristic information (snow and ice albedo and light extinction co-efficient) is not available for many lakes. The approach taken to tune the model, bypasses the need to acquire detailed lake characteristic values. replaces The tuning approach undertaken in this study, overcomes the obstacle of the lack of available lake characteristic information (snow and ice albedo and light extinction co-efficient) for individual lakes.

P8548, line 22-23

"Furthermore, the tuned values for lake depth, snow and ice albedo and light extinction co-efficient for the 244 lakes provide some guidance on improving FLake LSWT modelling."

Replaces

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“Furthermore, the tuned values for lake depth, snow and ice albedo and light extinction co-efficient for the 244 lakes provide guidance for improving LSWTs modelling in FLake.”

P8550 line 6

“Through preliminary model trials, three properties: lake depth (d), snow and ice albedo (α) and light extinction coefficient (κ) are shown to greatly influence the modelled LSWT cycle.” Replaces “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.”

P8551 line 6 2.1 Data: ARC-Lake observed LSWTs replaces 2.1 Data; ARC-Lake observed LSWTs

P8551 – lines 7-12 “LSWT observations from ARC-Lake are used to tune the model. These cover 246 globally distributed large lakes, principally those with surface area >500km² (Herdendorf, 1982; Lehner and Doll, 2004) but also including 28 globally distributed smaller lakes, the smallest of which is 100km² (Lake Vesijarvi). The LSWTs are generated from three Along-Track Scanning Radiometers (ATSRs), from 1991–2011 (MacCallum and Merchant, 2012).”

Replaces

“The ARC-Lake LSWT observations for 246 globally distributed large lakes, principally those with surface area >500km² (Herdendorf, 1982; Lehner and Doll, 2004) but includes 28 globally distributed smaller lakes, the smallest of which is 100km² (Lake Vesijarvi) are used to tune the model. These LSWTs are generated from three Along-Track Scanning Radiometers (ATSRs), from 1991–2011 (MacCallum and Merchant, 2012).”

P8551 – lines 14-26 “The ARC-Lake observations have been shown to compare well with in situ LSWT data. Validation of the observations was performed through a match-

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up data set of in situ temperature data consisting of 52 observation locations covering 18 of the lakes (MacCallum and Merchant, 2012). Furthermore, the timing of ice-on and ice-off events is observed to be consistent with in situ measurements. This is demonstrated through analysis of the average (over the period of ATSR observations) days of the year on which the lake-mean LSWT drops below 1 °C and rises above 1 °C. Layden et al. (2015) define these as the 1 °C cooling and 1 °C warming days respectively, and observe good consistency with in situ measurements of ice-on and ice-off days for 21 Eurasian and North American lakes. Layden et al. (2015) also demonstrates the integrity of the ARC-Lake LSWTs on a global scale, through the strong relationship the observed LSWTs have with meteorological data (air temperature and solar radiation) and geographical features (latitude and altitude). On this basis, the ARC-Lake LSWTs are considered reliable and suitable for use in this tuning study.”

Replaces

“The ARC-Lake observations have been shown to compare well with in situ LSWT data. Validation of the observations was performed through a match-up data set of in situ temperature data consisting of 52 observation locations covering 18 of the lakes (MacCallum and Merchant, 2012). Furthermore, the 1 °C cooling and warming day, which is defined as the day of the year on which the average (over the period of observations) lake-mean LSWT drops to below 1 °C (1 °C cooling day) and rises to above 1 °C (1 °C warming day), show a good consistency with in situ measurements of ice-on and ice-off days for 21 Eurasian and North American lakes (Layden et al., 2015). Layden et al. (2015) also demonstrates the integrity of the ARC-Lake LSWTs on a global scale, through the strong relationship between the observed LSWTs and meteorological data (features of air temperature and solar radiation) and geographical features (latitude and altitude). On this basis, the ARC-Lake LSWTs are considered reliable and suitable for use in this tuning study.”

P8552 – line 16 ...and ice models: meteorological forcing data. . .

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Replaces

...and ice models; meteorological forcing data. . .

P8552 – lines 23-25

“As outlined in the introduction, optimisation of LSWT-regulating properties, lake depth (d), snow and ice albedo (α) and light extinction coefficient (κ), can greatly improve the LSWTs produced in FLake.”

Replaces

“As outlined in the introduction, optimisation of LSWT regulating properties; lake depth (d), albedo; snow and ice (α) and light extinction coefficient (κ), can greatly improve the LSWTs produced in FLake.”

P8554 – lines 4-6

“Inflow from the catchment and heat flux from sediments are not considered in this study. The light extinction coefficient is only considered when its effect on LSWT is most prominent (summer time), as discussed in Sect. 2.4 (i.e. variations throughout the annual cycle are not considered).”

Replaces

“The inflow from the catchment and heat flux from sediments are not considered in this study. Variation (throughout the annual cycle) of light extinction coefficient is not considered. However, the effect of light extinction coefficient on LSWT, when its effect is most prominent (summer time) is considered, as discussed in Sect. 2.4.”

P8554 – lines 10-12 “Mean daily values of the following parameters are used to force the mode (as shown in Table 1): shortwave solar downward radiation (SSRD), air temperature and vapour pressure at 2m, wind speed, and total cloud cover.”

Replaces

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“Shortwave solar downward radiation (SSRD), air temperature and vapour pressure at 2m, wind speed and total cloud cover, in their mean daily values, as shown in Table 1 are used to force the model.”

P8554 – lines 13-15 “Scaling of wind speeds is considered during the trials, as most long-term records of wind speed are measured over land (Uland) and are considered to underestimate the wind speed over water (Uwater).”

Replaces

“As most long-term wind speed records are measured over land (Uland) and are considered to underestimate the wind speed over water (Uwater), scaling of the wind speeds is considered during the trials.”

P8555 – lines 20-22 “Of the 5 studies, this formula produces the lowest (most transparent) κ values, potentially more representative of open water conditions of large lakes, and is therefore used in this study.”

Replaces

“Of the 5 studies, this formula produces the lowest (most transparent) κ values, and possibly more likely to represent open water conditions of large lakes and is therefore used in this study.”

P8556 – lines 7 “attenuation process of ocean water and its changes with turbidity (Jerlov, 1976) is applied.”

Replaces

“attenuation process of oceans and its changes with turbidity (Jerlov, 1976) is applied.”

P8556 – lines 10 “The spectre for these 10 ocean types are divided (in fractions of 0.18, 0.54, 0.28) into three wavelengths: 375, 475 and 700nm, respectively.”

Replaces

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“The spectre for these 10 ocean types are divided (0.18, 0.54, 0.28) into three wavelengths; 375, 475 and 700nm, respectively.”

P8558 – lines 23-25 and P8559 – line 1

“For the observed LSWTs, the variance (K2) over the length of the tuning period is determined for the following LSWT parameters: LSWT for the month of minimum and maximum LSWT for non-seasonally ice-covered lakes (varmin and varmax), and JAS LSWT for seasonally ice-covered lakes (varjas).”

Replaces

“For the observed LSWTs, over the length of the tuning period, the variance (K2) in the month of minimum and maximum LSWT for non-seasonally ice covered lakes (varmin and varmax) and in the JAS LSWT for seasonally ice-covered lakes (varjas) is determined.”

P8560 – lines 23-25 and P8559 – line 1 “For the remainder of the trials (tuned), for non-seasonally ice-covered lakes, wind speed scaling, u1, was applied to lakes at latitudes < 35 °N/S and u3 to lakes at latitudes > 35 °N/S.”

Replaces

“For the remainder of the trials (tuned), wind speed scaling u1, was applied to lakes at latitudes < 35 °N/S and u3 to lakes at latitudes > 35 °N/S for non-seasonally ice covered lakes.”

P8561 – lines 5-9 “These results demonstrate that the tuning process with the applied wind speed scalings can provide significant improvements on the untuned model: run using the lake mean depth, light extinction coefficients derived from Secchi disk depth (as shown in Sect. 2.3.1) and default the model default albedo (seasonally ice-covered lakes only).”

Replaces

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“These results demonstrate that the untuned model, run using the lake mean depth, light extinction coefficients derived from Secchi disk depth (as shown in Sect. 2.3.1) and default the model default albedo (seasonally ice covered lakes only) can be greatly improved by the tuning process with the applied wind speed scalings.”

P8561 – lines 14 MAD of 1.11 ± 0.56 °C Replaces MAD of $1.11 + 0.56$ °C

P8561 – lines 14-15 “Across the 160 lakes, an average MAD of below 1 °C was achieved (0.80 ± 0.56 °C, Table 5).” Replaces

“Across the 160 lakes, an average MAD (0.80 ± 0.56 °C, Table 5), of below 1 °C was achieved.”

P8561 – lines 16-18 “For non-seasonally ice-covered lakes, an average MAD of below 1 °C is again achieved (0.96 ± 0.66 °C) when 84 of the 86 lakes are considered (Table 5). However, the remaining two lakes yield highly unsatisfactory results.”

Replaces

“For non-seasonally ice covered lakes, the average daily MAD result for 84 of the 86 lakes is 0.96 °C, with a spread of differences of ± 0.66 °C (2), Table 5, achieving an average MAD of below 1 °C. Two of the 86 lakes yield highly unsatisfactory results.”

P8561 – lines 23-24 “For the remaining 25 lakes, the tuned metrics (not shown in Table 6) are comparatively poor: the 1 °C cooling day was 14 days too early and/or the bias in JAS LSWT value was ≥ 2 °C. Consequently, the modified tuning method, discussed below, was applied to these lakes.”

Replaces

“For the remaining 25 lakes, the tuned metrics are comparatively poor; the 1 °C cooling day was 14 days too early and/or the JAS LSWT value was ≥ 2 °C.”

P8562 – lines 5-8 “This indicates that the these lakes require a greater modelled depth to increase the heat capacity - postponing the 1 °C cooling day - and lower trans-

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parency values (higher κ_d), causing less heat to be retained in the surface and decreasing the JAS LSWT.”

Replaces

“This indicates that the these lakes require a greater modelled depth to increase the heat capacity, postponing the 1 °C cooling day and lower transparency values (higher κ_d) causing less heat to be retained in the surface, decreasing the JAS LSWT.”

P8562 – lines 17-19 “Poor tuning results are observed for two of the 86 lakes (Lake Viedma and the Dead Sea). This is most likely due to differences between the altitude of the ERA T2 air temperature (geopotential height) and the lake altitude.”

Replaces

“For 2 of the 86 lakes, Lake Viedma and the Dead Sea, the difference between the altitude of the ERA T2 air temperature (geopotential height) and the lake altitude is the most possible cause for poor tuning results.”

P8562 – lines 19-23 “Lake Viedma, an Argentinian freshwater lake of unknown depth, yielded a daily MAD of 3.1 °C. The Dead Sea, a deep and highly saline lake (340 g L⁻¹) located in Asia at 404 m below sea level, yielded a daily MAD of 4.1 °C.”

Replaces

“Lake Viedma, an Argentinian freshwater lake of unknown depth yielded a daily MAD of 3.1 °C and The Dead Sea, a deep and highly saline lake (340 g L⁻¹) located in Asia at 404 m below sea level yielded a daily MAD of 4.1 °C.”

P8562 – lines 23-24 “For the Dead Sea, a temperature difference (in the month of maximum temperature) between the observed LSWT (33 °C) and ERA T2 air temperature (25 °C), results in a negative modelled bias of 6.3 °C in LSWT for this month.”

Replaces

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“For the Dead Sea, a difference in the month of maximum temperature between the observed LSWT (33 °C) and ERA T2 air temperature (25 °C), results in a negative modelled bias of 6.3 °C in the month of maximum LSWT.”

P8563 – lines 6-8 “This bias can be, at least, partially explained by the difference in altitude (> 500 m a.s.l.) between the altitude of Lake Viedma (297 m a.s.l.) and the altitude of meteorological data (825 m a.s.l.) at the lake centre co-ordinates.”

Replaces

“This bias can be at least, partially explained by the difference in altitude of > 500 m a.s.l., between the altitude of Lake Viedma (297 m a.s.l.) and the altitude of meteorological data at the lake centre co-ordinates of 825 m a.s.l.”

P8564 – lines 3-6 “The fraction of observed LSWT variance (varmin and varmax for non-seasonally ice-covered lakes and varjas (K2) for seasonally ice-covered lakes), that is detected in the tuned model (intermin, intermax, interjas (R2adj)), is determined as shown in Sect. 2.4.3.”

Replaces

“The fraction of observed LSWT variance, varmin and varmax for non-seasonally ice covered lakes and varjas (K2) for seasonally ice covered lakes, that is detected in the tuned model, intermin, intermax, interjas (R2adj) is determined as shown in Sect. 2.4.3.”

P8565 – lines 20-22 “The mean metric results and the spread of differences across the 135 seasonally ice-covered lakes are highly comparable across all 3 years of the tuned and untuned periods, with marginally better MAD metrics observed for the untuned period.”

Replaces

“The mean metric results and the spread of differences across the 135 seasonally ice

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covered lakes for the tuned and untuned period are highly comparable across all 3 years, showing marginally better MAD metrics for the untuned period.”

P8565 – lines 25-27 “For the other 3 metrics for the 25 shallow lakes, the untuned year has a lower spread of differences across lakes than for 2010. Marginal improvements are also seen in the JAS LSWT and 1 °C cooling day.”

Replaces

“For the other 3 metrics for the 25 shallow lakes, the untuned year has a lower spread of differences across lakes than for 2010 and a marginally better JAS LSWT and 1 °C cooling day.”

P8566 – lines 12-14 “Through the trial work, the effect of the timing of the 1 °C warming day (indicative of ice-off) on the JAS LSWT and on the timing 1 °C cooling day (indicative of ice-on) is demonstrated, for deep high latitude or very deep seasonally ice-covered lakes.”

Replaces

“Through the trial work, the effect of the timing of the 1 °C warming day (indicative of ice-off) on the JAS LSWT and on the timing 1 °C cooling day (indicative of ice-on) of deep high latitude or very deep seasonally ice covered trial lakes is demonstrated.”

P8567 – line 16 “resulted in the 1 °C cooling day occurring 3.4 days earlier.” Replaces “resulted in an earlier 1 °C cooling day of 3.4 days.”

P8567 – lines 17-18 “For Great Bear (72 m), the JAS LSWT decrease of 3.40 °C causes an earlier 1 °C cooling day, by 7.6 days.”

Replaces

“For Great Bear (72 m), the JAS LSWT decrease of 3.40 °C causes an earlier 1 °C cooling day of 7.6 days.”

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P8568 – lines 7-10 “For example, Lake Nipigon and Lake Manitoba, both located in Canada (50 °N and 51 °N) and at similar altitudes (283 m a.s.l. and 247 m a.s.l.) have considerably different depths, 55 m and 12 m respectively. Significant differences are observed in JAS LSWT for these lakes, the deeper lake having an average JAS LSWT 4.4 °C lower than that of the shallower lake (15.4 °C compared to 19.8 °C).”

Replaces

“For example, Lake Nipigon, located in Canada at 50 °N and at 283 m a.s.l., has a mean depth of 55 m and an average JAS LSWT of 4.4 °C lower (15.4 °C) than that of Lake Manitoba (19.8 °C), also located in Canada (at 51 °N and 247 m a.s.l.), but with a mean depth of only 12 m.”

P8569 – lines 3-6 “Although changes in other factors affect hypolimnion temperature, such as influx of cooler water and geothermal heating, the monthly minimum LSWTs from satellite can offer a good indication of hypolimnion temperature; useful in cases where this otherwise can not be or isn’t observed directly.”

Replaces

“Although, changes in other factors affect hypolimnion temperature, such as influx of cooler water and geothermal heating, the monthly minimum LSWTs from satellite can offer a good indication of hypolimnion temperature in cases where this otherwise can not be or isn’t observed directly.”

P8569 – lines 8-11 “The trials showed that while non-seasonally ice-covered lakes at latitudes < 35 °N/S required no wind speed scaling (u1), the largest wind speed scaling (u3) improved LSWTs for non-seasonally ice-covered lakes at latitudes > 35 °N/S and all seasonally ice-covered lakes, as outlined in Sect. 2.2.3.”

Replaces

“The trials showed that while non-seasonally ice covered lakes at latitudes < 35 °N/S required no wind speed scaling (u1), non-seasonally ice covered lakes at latitudes > 35

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°N/S and all seasonally ice covered lakes produced more representative LSWTs using the largest wind speed scaling (u_3) as outlined in Sect. 2.2.3.”

P8571 – line 10 “Scarce” Replaces “scare”

P8571 – lines 13-16 “In the first model run, the average Ksd value (derived from Secchi disk depth data) of the trial lakes of each lake type is applied to all lakes of corresponding type. For the 21 seasonally ice-covered trial lakes, $K_{sd} = 0.82$; for the 14 non-seasonally ice-covered trial lakes, $K_{sd} = 1.46$.”

Replaces

“In the first model run, the average Ksd (derived from Secchi disk depth data) of the 21 seasonally ice covered trial lakes, 0.82, is applied to all seasonally ice covered lakes and the average Ksd of the 14 trial non-seasonally ice covered lakes, 1.46, is applied to all non-seasonally ice covered lakes.”

P8571 – lines 18-19 “For both model runs the default albedo and the mean depth are applied, while all other model parameters are kept the same.”

Replaces

“For both model runs the default albedo and the mean depth are applied and all other model parameters are kept the same.”

P8572 – lines 13-18 “The 1-dimensional freshwater lake model, FLake, was successfully tuned for 244 globally distributed large lakes (including saline and high altitude lakes) using observed LSWTs (ARC-Lake), for the period 1991 to 2010. This process substantially improves the measured biases in various features of the lake annual cycle, using only 3 lake properties (depth, snow and ice albedo and light extinction co-efficient), as summarised in Table 5.”

Replaces

“The 1-dimensional freshwater lake model, FLake, was successfully tuned for 244 glob-

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ally distributed large lakes using observed LSWTs (ARC-Lake), for the period 1991 to 2010. This process substantially improves the measured biases in various features of the lake annual cycle (including saline and high altitude lakes), as summarised in Table 5 using only 3 lake properties (depth, snow and ice albedo and light extinction co-efficient).”

P8572 - line 24 “temperature, with a 1:1 relationship shown (Fig. 17).” Replaces “temperature (1:1), Fig. 17.”

P8572 - line 24-25 “This is highly useful where the lake bottom temperature can not be or isn’t observed directly.”

Replaces

“This is highly useful where lake bottom temperatures can not be or isn’t observed directly.”

P8573 – line 19 “place of the default value” Replaces “place default value”

P8573 – lines 23-26 “The tuned model is forced with ERA data over the available time span of LSWT observations (16–20 years) but has the potential to be forced with ERA data covering a longer time span (ERA data are available for a period of > 33 years; 1979–2012).”

Replaces

“The tuned model forced with ERA data over the available time span of LSWT observations (16–20 years), has the potential to be forced with the complete time span of available ERA data, available for a period of > 33 years; 1979–2012.”

P8581 – Table 4 caption “The effect of wind speed scalings on untuned modelled LSWTs, presented as mean values across lakes with the \pm spread of differences defined as 2σ . Results are presented for seasonally and non-seasonally ice-covered trial lakes.”

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Replaces

“The effect of wind speed scalings on untuned modelled LSWTs of the seasonally and non-seasonally ice covered trial lakes, with the spread of differences across lakes, 2σ .”

P8562 – Table 5 caption “Summary of the untuned and tuned metrics for the trial lakes and the tuned metrics for all lakes. Results are presented for seasonally and non-seasonally ice-covered lakes in each instance. The spread of differences across lakes is defined as 2σ .”

Replaces

“Summary of the untuned and tuned metrics for the trial seasonally and non-seasonally ice covered lakes and the tuned metrics for all seasonally and non-seasonally ice covered lakes showing the spread of differences across lakes, 2σ .”

P8583 – Table 6 caption “Comparison of metric results for seasonally ice-covered lakes: 135 lakes using the original tuned setup (Table 2), 25 lakes tuned with the modified set-up, all lakes, and trial lakes. The spread of differences across lakes is defined as 2σ .”

Replaces

“Metric results for seasonally ice-covered lakes (135 lakes using the original tuned setup, Table 2 and 25 lakes tuned with the modified set-up), compared with the results for the trial lakes, showing the spread of differences across lakes, 2σ .”

P8586 – Table 9 caption “The fraction ($R2_{adj}$) of observed inter-annual variability detected in the model. Maximum and minimum LSWT is used for non-seasonally ice-covered lakes (intermax and intermin), while JAS LSWT is used for seasonally ice-covered lakes, (interjas). This table highlights that where the observed inter-annual variability is low, the proportion of variability detected in the model is also low (high altitude seasonally ice-covered lakes and tropical lakes).”

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Replaces

“The fraction ($R2_{adj}$) of observed inter-annual variability detected in the model, for the maximum and minimum LSWT for non-seasonally ice covered lakes (intermax and intermin) and for the JAS LSWT for seasonally ice covered lakes, (interjas), highlighting that where the observed inter-annual variability is low, the proportion of variability detected in the model is also low (high altitude seasonally ice covered lakes and tropical lakes).”

P8587 – Table 10 caption “Results of independent evaluation of the tuning process for seasonally ice-covered lakes. The spread of differences across lakes is defined as 2σ . These results illustrate that the metrics from the untuned year (2011) compare well with metrics from 1996 (the first full year of data from ATSR2) and 2010 (the last year of tuned data from AATSR).”

Replaces

“Results of independent evaluation of the tuning process for seasonally ice covered lakes with the spread of differences across lakes, 2σ , showing that the metrics from the untuned year (2011) compare well with metrics from 1996 (the first full year of data from ATSR2) and 2010 (the last year of tuned data from AATSR).”

P8588 – Table 11 caption “Results of the independent evaluation of the tuning process for non-seasonally ice-covered lakes. The spread of differences across lakes is defined as 2σ . Metrics for the untuned year (2011) are compared with those from the first full year of data from ATSR2 (1996) and the last year of tuned data from AATSR (2010).”

Replaces

“Results of the independent evaluation of the tuning process for non-seasonally ice covered lakes 3 with the spread of differences across lakes, 2σ , showing the untuned year (2011) with the first full year of data from ATSR2 (1996) and the last year of tuned data from AATSR (2010).”

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P8605- Figure 16 The blue box with on top left hand side of figure reads “high snow and ice albedo” replaces “high albedo”

P8605- Figure 17 caption “Comparison of lake-bottom temperatures from Flake with monthly minimum climatology LSWTs from ARC-Lake, for 14 deep (> 25 m) non-seasonally ice-covered lakes (55 °S to 40 °N). FLake lake-bottom temperature during stratification obtained from model run using perpetual hydrological year, 2005/06.”

Replaces

“Lake bottom temperature during stratification and climatological monthly minimum LSWT of 14 deep (> 25 m) non-seasonally ice covered lakes from 55 °S to 40 °N, showing the modelled equilibrium result (lake bottom temperatures obtained from Flake lake model, using perpetual hydrological year, 2005/06) compared with observed monthly minimum climatology LSWTs from ARC-Lake.”

P8606 – Figure 18 caption “The lake mean depth vs. the modelled effective depth for 244 tuned lakes. Colour coding illustrates the effective depth factors. The average lake depth for each effective depth factor used in the tuning process is also given (insert). This figure demonstrates that deeper lakes are tuned to a lower effective depth and shallower lakes to a greater effective depth.”

Replaces

“The lake mean depth vs. the modelled effective depth for 244 tuned lakes, colour coded by the effective depth factors and the average lake depth for each effective depth factor used in the tuning process (insert), demonstrating that deeper lakes are tuned to a lower effective depth and shallower lakes to a greater effective depth.”

P8577, Line 3 "Layden, A., Merchant, C.J. and MacCallum, S.N." replaces "Layden, A., Merchant, C. and MacCallum, S."

P8577, A. Layden¹, S.N. MacCallum² and C.J. Merchant³ replaces A. Layden¹, S. MacCallum² and C. Merchant³

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