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Geoscientific
Model Development
Discussions

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

A. Layden et al.

aislinglayden99@gmail.com

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Comment from Referee 3 Anonymous Referee #3 Received and published: 9 December 2015

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.

This paper is a useful investigation into the adjustment of tuning parameters avail- able with the FLake model. The authors demonstrate that the LSWT produced by the FLake model matches observations more closely using their improvements. This has been demonstrated for a large number of lakes, and has applications for extension to modelling of further lakes. This is therefore a very useful study to improve the accuracy of the FLake model for users. Below I have provided comments in four sections: general comments, more specific comments, figures and tables, and technical corrections.

General comments

Referee comment 1. Needs an introductory paragraph outlining the application of this work, e.g. use of FLake in NWP etc; why is this work important.

Author's response New paragraph included at end of Introduction (section 1)

Author's change

"Using the 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 some of the lake to lake variability in geographical and physical characteristics. The motivation for this study was to develop a greater understanding of lake dynamics globally, offering the potential to help 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."

Referee comment 2. Throughout, rename "non-seasonally ice covered lakes" just "non-ice covered lakes" - much less confusing!

Author's response Changed throughout

Referee comment 3. Table and figure captions should stand alone from text - the reader should not have to look up acronyms and definitions to understand them. Define all subscripts, acronyms and symbols as much as possible.

Author's response All acronyms, symbols and terms are now explained in the table and

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figure cations

Referee comment 4. p 8552, line 1: By using an average of the day and night lake temperatures to get your LSWT observation, won't you get a sort of part diurnal signal? Would it not be better to just use either nighttime (no diurnal signal) or daytime (diurnal signal)?

Author's response Possibly yes. I don't expect that the model tuning would be greatly influenced by a diurnal signal in the observed LSWTs. The fact that it is a global scale study, it was considered best to fully utilise the data, as the average temporal resolution of LSWT retrievals is < 1 week. Using either day or night data, particularly in cloudy regions, could compromise retrievals.

Referee comment 5. "Biases" should really be "mean differences" throughout, as your reference dataset is not necessarily truth.

Author's response Mean difference(s) is now used in place of bias throughout in text, tables,figures and captions.

Referee comment 6. Think about order of sections, and do not keep revisiting same topic if it can be put into one section, e.g. wind speeds.

Author's response The application of wind speed scaling has been discussed in section 2.3.5 only and removed from section 2.2.3. Section 3 'Applied wind speeds' is now renamed as 'Trial results for wind speed scaling'

Specific comments

Referee comment Abstract: clarify that the tuning is for individual lakes, not one tuning applied to 244 lakes. When mentioning differences (e.g. MAD), need to state differences to what reference.

Author's change A "A tuning method for FLake, a 1-dimensional freshwater lake model, is applied for the individual tuning of 244 globally distributed large lakes using lake

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surface water temperatures (LSWTs) derived from Along-Track Scanning Radiometers (ATSRs)."

Replaces

"FLake, a 1-dimensional freshwater lake model, is tuned for 244 globally distributed large lakes using lake surface water temperatures (LSWTs) derived from Along-Track Scanning Radiometers (ATSRs)."

Author's change B "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 mean differences in various features of the LSWT annual cycle, including the LSWTs of saline and high altitude lakes, when compared to the observed LSWTs."

Replaces

"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 mean differences in various features of the LSWT annual cycle, including the LSWTs of saline and high altitude lakes."

Author's change C "For trial seasonally ice-covered lakes (21 lakes), the daily mean and standard deviation (2σ) of absolute differences (MAD) between the modelled and observed LSWTs, are reduced from 3.07 ± 2.25 °C to 0.84 ± 0.51 °C by tuning the model."

Replaces "For seasonally ice-covered lakes, the daily mean and standard deviation (2σ) of absolute differences (MAD) are reduced by model tuning from 3.07 ± 2.25 °C to 0.84 ± 0.51 °C."

Referee comment Introduction: p. 8549, line 10: mention Great Lakes too, as these also have a significant effect on the local climate inducing lake-effect snow storms etc.

Author's changes "The Great Lakes and the large Canadian lakes of Great Bear and

Great Slave can alter the local climate through lake-effect storms, impacting on the fluxes of heat, moisture, and momentum, and on the mesoscale weather processes (Sousounis and Fritsch, 1994; Long et al., 2007)."

Replaces

"The large Canadian lakes of Great Bear and Great Slave can alter the local climate through lake-effect storms, impacting on the fluxes of heat, moisture, and momentum, and on the mesoscale weather processes (Long et al., 2007)."

References included: "Sousounis, P.J., and Fritsch, J.M.: Lake-aggregate mesoscale disturbances. Part II: A case study on the effects on regional and synoptic-scale weather systems, Bull. Amer. Meteor. Soc., 75,1793-1811, 1994."

Referee comment p. 8550, line 2: difference to ...what? reference data - ARC-Lake observations

Author's change "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."

Replaces

"It is the intention of this tuning study to achieve an average daily mean absolute difference (MAD) of < 1 °C, across all lakes."

Referee comment p. 8550, line 10: Give location of lake (country, or lat/lon)

Author's change "An example of the preliminary trial work is shown for Lake Athabasca (Canada), in Fig. 1a." Replaces "An example of the preliminary trial work is shown for Lake Athabasca, in Fig. 1a."

Figure 1 caption "Preliminary modelled runs for Lake Athabasca, Canada,. . .. . .." Replaces Figure 1 caption "Preliminary modelled runs for Lake Athabasca, ..."

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Referee comment p. 8550, line 14: It's confusing here why you would want to use a shallower depth than the mean as this is less realistic. This is explained later on in the paper, but perhaps you should refer to this discussion or add an extra sentence to justify this a bit better.

Author's change "In Fig. 1b, it is demonstrated that by using a shallower d than the mean depth of the lake, the ice-on day occurs earlier and corresponds more closely to the observed ice-on day. Lake depth is essentially being used as a means to adjust the heat capacity of the lake, exerting control over the lake cooling and therefore the ice-on date."

Replaces

"In Fig. 1b, it is demonstrated that by using a lower d than the mean depth of the lake, the ice-on day occurs earlier and corresponds more closely to the observed ice-on day."

Referee comment p. 8550: line 21: where do your observed LSWTs come from? (or put this section after you have introduced ARC-Lake)

Author's response ARC-Lake is introduced on the previous page (p. 8449: line 16) but have now included ARC-Lake to remind reader of the source.

Author's change "In this study, for each lake, the modelled mean differences for several features in the LSWT annual cycle are measured, quantifying the level of agreement with the observed LSWTs ARC-Lake LSWTs." replaces

"In this study, for each lake, the modelled mean differences for several features in the LSWT annual cycle are measured, quantifying the level of agreement with observed LSWTs."

Referee comment p. 8552: line 25: replace sentence beginning "Values for other lake" with "Other lake- specific properties adjusted for this study are:"

Author's change "Other lake-specific properties adjusted for this study are: c_relax_C, fetch, latitude and the starting conditions."

Replaces "Values for other lake-specific properties outlined in this section are retained throughout the investigative and tuning process."

Referee comment p. 8553: line 17: what is the spin-up time for the model?

Author's response Its very short, if the starting conditions are well estimated; a day or two for most lakes. The average spin up time included below (< 3 days)

Author's change "Starting conditions: these provide FLake with the lake specific initial temperature and mixing conditions: temperature of upper mixed layer, bottom temperature, mixed layer depth, ice thickness and temperature at air–ice interface. A good estimation of the starting conditions for each lake was obtained from the FLake model based on the hydrological year 2005/06 (Kirillin et al., 2011). Other than shortening the model spin-up time (to an average of <3 days), the starting conditions showed no influence over the modelled LSWTs thereafter."

Replaces

"Starting conditions: these provide FLake with the lake specific initial temperature and mixing conditions. Other than shortening the model spin-up time, the starting conditions showed no influence over the modelled LSWTs thereafter. The starting conditions are temperature of upper mixed layer, bottom temperature, mixed layer depth, ice thickness and temperature at air–ice interface. A good estimation of the starting conditions for each lake was obtained from the FLake model based on the hydrological year 2005/06 (Kirillin et al., 2011)."

Referee comment p. 8553: line 26: The light extinction coefficient is one of the tuned properties, so this is very confusing. Do you mean in seasons other than summer? See also p. 8554, lines 4-6. Needs rewording.

Author's response Yes, this is confusing. Light ext. coefficient is tuned but it remains fixed throughout the annual cycle of each lake. There is an option to include a variation but I've not used this. Instead I've tuned it at the most responsive part of the annual cycle i.e., summertime. I've removed all reference to variation in the light ext. coefficient (p. 8553: line 26 to p. 8554, lines 6 & p.8558, sect 2.4.1) . Instead I have pointed out (figure 6) the stronger effect of light ext. coefficient on the maximum LSWT than on the minimum LSWT.

Author's change A- p. 8553: line 26 to p. 8554 "The model parameters that remain fixed throughout the investigative and tuning process, across all lakes (fixed model parameters) are icewater_flux, inflow from the catchment and heatfrom flux sediments For icewater_flux (heat flow from water to ice) G. Kirillin (personal communication, 2010) suggests values of $\sim$ 3–5Wm-2. In this study a value of 5Wm-2 is applied to all lakes. Inflow from the catchment and heat flux from sediments are not considered in this study. " Replaces

"The model parameters that remain fixed throughout the investigative and tuning process, across all lakes (fixed model parameters) are icewater_flux, inflow from the catchment, heat flux from sediments and variation in the light extinction coefficient. For icewater_flux, (heat flow from water to ice) G. Kirillin (personal communication, 2010) suggests values of $\sim$ 3–5Wm-2. In this study a value of 5Wm-2 is applied to all lakes. 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 in the light extinction coefficient throughout the annual cycle are not considered)."

Author's change B - p. 8558, section 2.4.1 "The metrics and the effect of the LSWT-regulating properties on them, for seasonally ice-covered lakes is summarised in Table 3. The effect of light extinction coefficient on the JAS LSWTs is demonstrated in Fig. 7, showing that the tuned light extinction coefficient (κd) value, κd6 in place of a lower (more transparent) κd value (κd2), described in Table 2, substantially improves the JAS LSWT, when compared to the observed LSWT. In this figure, the greater effect of light extinction coefficient on the maximum LSWT than on the minimum LSWT is also demonstrated."

Replaces

"The metrics and the effect of the LSWT regulating properties on them, for seasonally ice-covered lakes is summarised in Table 3. The light extinction co-efficient effect on the summertime LSWT; July, August and September (JAS) LSWT is demonstrated in Fig. 6, showing that the tuned κd value (κd6) substantially improves the JAS LSWT."

Referee comment p. 8554, line 2: missing "-" in both units

Author's response Corrected

Referee comment p. 8554, section 2.3.3 - Suggest combining this section with others on wind speed.

Author's response The application of wind speed scaling has been discussed in section 2.3.5 only and removed from section 2.2.3. Section 3 'Applied wind speeds' is now renamed as 'Trial results for wind speed scaling'

Referee comment p. 8555, line 25: If this is a universal relation, then why change it between 2-10 m? Perhaps reword as the best thing to use if no other information is available.

Author's change "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 for lakes with Secchi disk depths of 2-10 m. In the absence of a light extinction coefficient formula outside this Secchi disk depth range (less than 2 m and greater than 10 m) that is suitable for large lakes, the Poole and Atkins (1929) formula is applied. This formula, Eq. (3), provides sufficiently accurate estimations of light extinction coefficients in waters with all degrees of turbidity (Sherwood, 1974)."

Replaces "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

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therefore used in this study. For Secchi disk depths outside the 2–10m range (less than 2m and greater than 10 m) the Poole and Atkins (1929) formula is applied. This formula, Eq. (3), is used as it is considered to serve as a universal relation between light extinction coefficient and Secchi disk depth data and provides sufficiently accurate estimations of light extinction coefficients in waters with all degrees of turbidity (Sherwood, 1974)."

Referee comment p. 8556, line 11: What are the figures in brackets? This sentence is unclear.

Author's change "The spectra for these 10 ocean water types are divided (in fractions of 0.18, 0.54, 0.28) into three wavelengths: 375, 475 and 700nm, respectively."

Replaces

"The spectra for these 10 ocean types are divided (0.18, 0.54, 0.28) into three wavelengths: 375, 475 and 700nm, respectively."

Referee comment p. 8557, section 2.3.4: Unclear here why 0.60 is too low, and not clear where this value came from.

Author's response This is now explained in more detail

Author's change "FLake uses two categories of albedo for snow (dry snow and melting snow) and two categories for ice (white ice and blue ice). As the snow cover module with FLake is not operational in this version of the model, the snow and ice albedo are set to the same default value in the FLake albedo module, 0.60 for dry snow and white ice and 0.10 for melting snow and blue ice. These default snow and ice albedo values are referred to as $\alpha1$ in this study. During the preliminary trials, a higher albedo (than $\alpha1$) was shown to delay ice-off, substantially improving the timing of early ice-off, compared to observed LSWTs (demonstrated in Fig. 1a). A higher snow and ice albedo causes more of the incoming radiation to be reflected, resulting in a later ice-off. On this basis, we apply 3 additional albedos of higher values ($\alpha2 : \alpha4$), shown in

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Table 2, for tuning seasonally ice-covered lakes. Albedo when discussed throughout this study refers to the albedo of snow and ice. The albedo of water (in liquid phase) is maintained at the default value of 0.07 throughout this study.

Replaces “The model default albedo (α) value is 0.60 for snow and white ice and 0.10 for melting snow and blue ice, referred to as α1. On the basis of the modelled biases outlined in the introduction, we apply 3 additional albedos of higher values (α2: α4), shown in Table 2, when tuning of seasonally ice-covered lakes. A higher albedo causes more of the incoming radiation to be reflected, causing a later (and more timely) ice-off. Albedo when discussed throughout this study refers to snow and ice albedo.”

Referee comment p.8558, line 5: Need to define kappa here too.

Author’s change “. . ...showing that the tuned light extinction coefficient (κd) value, κd6 (described in Table 2), substantially improves the JAS LSWT.”

replaces

“. . .. . ..showing that the tuned κd value (κd6) substantially improves the JAS LSWT.”

Referee comment p. 8559, equation 5: x mean is not defined. N is defined below the next equation, should be introduced here.

Author’s change

varjas = (xiobs_jas - Xbar)2 / (N - 1) (5) where obs_jas = observed mean JAS LSWT = mean across all years N = number of years with JAS LSWTs

Replaces varjas = (xiobs_jas - xbar)2 / (N - 1) (5)

Referee comment p. 8559, section 2.4.4: Suggest putting this at start as introduction. Then can say each part is described in more detail below.

Author’s response Now referred to in the Introduction -Last line of 2nd last paragraph. Figure captions and references from 2-8 are now renumbered

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“An overview of the tuning approach applied to these two lake categories is shown in Fig. 2, and described in detail within section 2.”

Removed from section 2.4.4 2.4.4 Overview of tuning method “An overview of tuning approach for seasonally ice-covered lakes and non-ice covered lakes is shown in Fig. 8.”

Referee comment p. 8560, line 3: This still doesn’t match particularly well, need to state this.

Author’s response This doesn’t match well as the wind speed scalings are modelled using the untuned model. I’ve stated this now in the figure caption and have also referred to it in the text

Author’s change Figure 9 Effect of wind speed scalings on the modelled lake surface water temperature (LSWT) for Lake Simcoe, Canada (depth 25 m), showing that the greatest wind speed scaling, u3 (Uwater = 1.62+1.17Uland), in place of the unscaled wind speed, u1, reduces the daily mean absolute difference and July, August September LSWT mean difference by ∼50%. Modelled with untuned LSWT- regulating properties: mean lake depth (Zd1), default snow and ice albedo (α1) and light extinction coefficient derived from Secchi disk depth data (κsd)

Replaces Figure 9 Effect of wind speed scalings on the modelled lake surface water temperature (LSWT) for Lake Simcoe, Canada, showing that the greatest wind speed scaling, u3 (Uwater = 1.62+1.17Uland), in place of the unscaled wind speed, u1, reduces the daily mean absolute difference and July, August September LSWT mean difference by ∼50%.

Author’s change (Section 3, Paragraph 1) “Wind speed was examined in the untuned model trial for both seasonally ice-covered lakes and non-ice covered lakes. Wind speeds, u1, u2 and u3 were modelled with untuned LSWT properties: mean lake depth (Zd1), default snow and ice albedo (α1) and light extinction coefficient derived from

Secchi disk depth data (κsd). The trials show that wind speed has a consistent effect on the modelled LSWT of seasonally ice-covered lakes. The higher wind speed scaling (u3) causes earlier cooling and later warming (reducing the 1 °C cooling day and 1 °C warming day mean differences), lengthening the ice cover period and reducing the JAS LSWT, as demonstrated for Lake Simcoe, Canada in Fig. 9. It is expected that the tuning of d, α and κ, with an applied wind speed of u3, will produce modelled LSWTs substantially closer to the observed LSWTs than those shown in Fig. 6, where tuning of d, α and κ is not applied."

Replaces

"Wind speed was examined in the untuned model trial for both seasonally and non-seasonally ice covered lakes. The trials show that wind speed has a consistent effect on the modelled LSWT of seasonally ice covered lakes. The higher wind speed scaling (u3) causes an earlier (and more timely) cooling and later (and more timely) warming, lengthening the ice cover period, as demonstrated for Lake Simcoe in Figure 9."

Referee comment p. 8560, line 9/10: Suggest replace half with 50%

Author's response done throughout

Referee comment p. 8561, line 3: differences between modelled and observed

Author's change "The average MAD and spread of differences (2σ) between the modelled and observed LSWTs for seasonally ice-covered lakes and non-ice covered lakes," Replaces

"The average MAD and spread of differences (2σ) for seasonally ice-covered lakes and non-ice covered lakes,"

Referee comment p. 8561, line 25: reword to make more of this. What did the 25 lakes have in common which makes them not fit? All shallow... anything else?

Author's change "Relative to the size (depth and area) of the larger seasonally ice-covered lakes, these 25 lakes are shallow (average mean depth < 5m) and small (18 of the 25 lakes are < 800 km2). Twenty (20) of the 25 lakes are located in Eastern Europe or Asia, at relatively low altitudes; 22 of the 25 lakes are < 752 m a.s.l.. These 25 lakes were tuned to the highest depth factor, Zd4 (1.5 times the mean depth) and/or the highest light extinction coefficient, κd5 (lowest transparency)."

Replaces "These 25 shallow lakes (average depth < 5m) were tuned to the highest depth factor, Zd4 and/or the highest light extinction coefficient, κd5 (lowest transparency)."

Referee comment p. 8561, line 25: is Zd4 the highest depth factor? Use Zd5:Zd7 as greater depth factors later on... do you mean shallowest?

Author's response Yes Zd4 the highest depth factor (1.5 times mean depth) in the initial tuning of the 160 lakes. I expand the re-tuning the 25 shallow lakes to include 3 greater depth factors (2, 2.5 and 4 times the mean depth), renamed as Zd6:Zd8, as Zd5 was incorrectly referenced here (apologies for the confusion). This is now corrected in the text. I've also change the presentation of the corresponding table (table 2) – there is no bold text.

Author's change A

Table 2 Effective depth factors (Zd), light extinction coefficient values (κd) and snow and ice albedo values (α) used in tuning study. Eighty (80) possible combinations used for tuning of seasonally ice-covered lakes (Zd1 : Zd4 x κd1 : κd5 x α1 : α4) . The modified tuning for the 25 shallow seasonally ice-covered lakes utilised greater depth factors; Zd6 : Zd8 and 2 higher light extinction coefficient values, κd6 and κd7. Sixty (60) possible combinations used for tuning of non-ice covered lakes (Zd1 : Zd6 x κd1 : κd10) . The spectre for the 10 κd values are divided (in fractions of 0.18, 0.54, 0.28) into three wavelengths: 375, 475 and 700nm, respectively.

Replaces

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Table 2 Lake depth factors (Zd), light extinction coefficient values (κd) and snow and ice albedo values (α) used in tuning study; 80 possible combinations for seasonally ice-covered lakes (plain text only) and 60 possible combinations for non-ice covered lakes (plain and bold text; all 6 Zd factors x all 10 κd values)

Author's change B - p.8562: line 8 "The tuning approach for these lakes is expanded to include 3 greater depth factors of 2.5, 2 and 4 times the mean depth (Zd6, Zd7 and Zd8) and 2 higher light extinction coefficient values, κd6 and κd7 (Table 2)."

Replaces

"A tuning modification, using 3 greater depth factors, Zd5: Zd7, and 2 higher light extinction coefficient values, κd6 and κd7 (Table 2) is applied."

Referee comment p. 8562, line 9: Confused about the tuning modification - implies multiple depths and light extinction coefficients for each lake produce these results?

Author's response The tuning approach for the 25 shallow lakes was expanded to include greater depth factors and higher light extinction coefficients to allow. The changes made in relation to the previous comment addresses this comment.

Referee comment p. 8563, line 10: Previous section suggests it is not successful - reconcile this.

Author's change "The results from the tuning approach applied to the 135 seasonally ice-covered lakes, the 84 non-ice covered lakes and the modified approach applied to the 25 shallow seasonally ice-covered lakes (described in Table 2) indicates that FLake is successful for tuning both saline and high altitude lakes, as well as freshwater and low altitude lakes. The tuned metrics categorized as saline, freshwater and low and high altitude lakes, are shown in Table 7 (seasonally ice-covered lakes) and in Table 8 (non-ice covered lakes)." replaces "The tuning of FLake is successful for both saline and high altitude lakes, as well as freshwater and low altitude lakes, as shown in Table 7 (seasonally ice-covered lakes) and in Table 8 (non-ice covered lakes)."

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Referee comment p. 8563, line 15: reference for this statement needed. Would have thought this effect was negligible.

Author's response Referee 1 has made similar comment. I have removed this statement and have now stated that altitude is considered through the altitude associated with meteorological data grid points.

Author's change "Although the density of freshwater in FLake is determined at sea level (normal atmospheric pressure) (Mironov, 2008) and the altitude of lakes are not directly considered in FLake, lake altitude (ranging from -12 to 5000 m a.s.l., over the 246 lakes) is considered indirectly through the geopotential height of the ERA forcing data."

replaces "The density of freshwater in FLake is determined at sea level (normal atmospheric pressure) (Mironov, 2008). At higher altitudes, the lower water density results in less effective natural convective and thermal heat transfer processes. Although lake altitude is not considered in FLake, the effect of altitude (ranging from -12 to 5000 m a.s.l.,) on LSWT is shown to be minimal or else compensated for by the tuning process.“

Referee comment p. 8563, line 24/ p. 8564 line 4: variance of what?

Author's change "The fraction (R2adj) of observed LSWT variance that is detected in the tuned model is quantified; intermin and intermax (non-ice covered lakes) quantifies the observed variance (K2) in the month in which the minimum LSWT (varmin) and maximum LSWT (varmax) occurs and interjas (ice-covered lakes) quantifies the observed variance (K2) in the mean JAS LSWT (varjas)."

replaces "The fraction of observed LSWT variance that is detected in the tuned model is quantified."

Referee comment p. 8564, section 4.3.1: Give inter_min, inter_max definitions so reader does not have to look up.

Author's response Now fully explained in preceding section (section 4.3) – see previous change This section has been removed "The fraction of observed LSWT variance (varmin and varmax for non-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."

Referee comment p. 8565, line 6: only looking at 3 months so why is annual range relevant?

Author's response Paragraph deleted

Referee comment p. 8566, section 4.3.2: Why are results better for year with no tuning? Say something about this. Interannual variability?

Author's change "Although inter-annual variance may somewhat obscure year-on-year comparisons, the results of the modelled LSWTs for the untuned year (2011) compare well to the modelled results from the tuned years (1996 and 2010) showing that the model remains stable when run with ERA forcing data outside the tuning period."

replaces

"Overall, the result of the modelled LSWTs for the untuned year (2011) compare well to the modelled results from the tuned years (1996 and 2010) showing that the model remains stable when run with ERA forcing data outside the tuning period."

Referee comment p. 8569, section 5.2: Explain the relationship between surface temperature and bottom temperature. What do the FLake profiles look like? Is there mixing, lack of diurnal heating etc?

Author's response I've now explained the relationship between surface temperature and lake-bottom temperature. The lake-bottom temperatures were extracted during the stratification period, obtained from FLake model run using perpetual hydrological year, 2005/06. Other than all lakes showing a stratification period, the FLake profiles for these lakes were not examined.

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Author's change "Empirically, it has previously been shown that from the equator to approximately 40° (N/S), the steep decline in the minimum LSWT is reflected in the hypolimnion temperature (Lewis, 1996). This relationship is applicable to deep stratified non-ice covered lakes. For these lakes, the surface water, when at its coolest in the annual cycle (minimum LSWT) and therefore its densest, sinks to the lake-bottom. During the summer stratification period, the water in the upper mixed layer is warmer and less dense and therefore remains in the upper layer (with exception to high wind or storm conditions, which can induce intense vertical mixing). The strengthened density gradient in the summer thermocline (as demonstrated for Lake Malawi in Fig. 4) also protects the hypolimnion from heat flux through the lake surface. As a result, the lake hypolimnion temperature of deep non-seasonally ice covered lakes can reflect the minimum LSWT. The comparability between the monthly minimum LSWT (using the ARC-Lake monthly minimum climatology LSWTs) and the bottom temperature, for all deep (> 25 m) non-ice covered lakes (14 lakes) supports this empirical observation (Fig. 17)."

Replaces

"Empirically, it has previously been shown that from the equator to approximately 40° (N/S), the steep decline in the minimum LSWT is reflected in the hypolimnion temperature (Lewis, 1996). The comparability between the monthly minimum LSWT (using the ARC-Lake monthly minimum climatology LSWTs) and the bottom temperature, for all deep (> 25 m) non-ice covered lakes (14 lakes) supports this empirical observation."

Referee comment p. 8659, line 13: suggest "the maximum LSWT and the hypolimnion temperature" changed to "the two layers of the maximum LSWT and the hypolimnion temperature" if I have understood this correctly. The section is a little confusing.

Author's response I have reworded this below, referring to the lake surface (in the month of maximum LSWT) in the first instance.

Author's change "For the deep (> 25 m) non-ice covered lakes (14 lakes), the den-

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sity difference between the lake surface (in the month of maximum LSWT) and the hypolimnion during the summer stratification period (when the density gradient of the thermocline is strongest, as illustrated in Fig. 4) was calculated (Haynes, 2013). The density gradient of the thermocline is dependent on the temperature difference between the lake surface and the hypolimnion. For lakes at latitudes below 35 °N/S, the average density difference between these two layers is substantially lower (0.352 x 10-3kg/m-3) than for lakes at latitudes above 35 °N/S (1.183 x 10-3kg/m-3). This is due to the smaller annual temperature range of the lower latitude lakes."

Replaces

"For the deep (> 25 m) non-seasonally ice covered lakes (14 lakes), the density difference between the maximum LSWT and the hypolimnion temperature during the stratification period were calculated (Haynes, 2013). The density difference for lakes at latitudes below 35° N/S is substantially lower (0.352 x 10-3kg/m-3) than for lakes at latitudes above 35° N/S (1.183 x 10-3kg/m-3). It is possible that the greater density difference between these two layers (LSWT and hypolimnion) in higher latitude lakes during the stratification period, may produce a stronger buffering effect against wind, than for lakes with a smaller density difference between the two layers."

Referee comment p. 8569, line 24: clarify density gradient is due to temperature difference. Author's response Include in change for previous comment

Referee comment p. 8570, line 1: "may show" - refer to later discussion

Author's change

"As a result, higher latitude lakes may show more representative LSWTs using a higher wind speed scaling, as discussed in section 6." Replaces

"As a result, higher latitude lakes may show more representative LSWTs using a higher wind speed."

Referee comment p. 8570, line 7/p. 8573, line 15,16, Figure 18: change "lower" to

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"shallower" as lower depth means deeper. Similarly, "greater" depth should be "deeper" for consistency with this.

Author's response Done

Referee comment p. 8570, line 21: If there is no hypolimnion in FLake you need to reconcile this with section 5.2

Author's change Added to first paragraph in section 5.2 "Although FLake is a two-layer model; the depth of the hypolimnion layer is not calculated, the bottom modelled temperature is representative of the hypolimnion temperature, which remains constant with depth."

Referee comment p. 8570, section 5.4.1: So lake "depth" is not really depth but a tuning parameter influenced by depth. This could be described better.

Author's response The tuned lake depth is referred to as the effective depth. This is now clarified in Section 2.3.3 –

Author's change (in Section 2.3.3) "In the tuning process, depth factors (outlined in Table 2) are applied to the lake-mean depth. The tuned depth is referred to as the effective depth."

Referee comment p. 8571, line 5: give range as well as means so matches up with the <16 m, >16 m used below.

Authors response The range of depths are wide for both kd values (1-138 m for kd5 and 1-57 m for kd4). I have reworded paragraph 1, reporting the average depth (16 m) and range of depths for all lakes (1-138). In paragraph 2, when applying kd4 /kd5 to the second model run I state that it makes sense to apply kd5 to shallower lakes, i.e., to lakes below the average depth (16 m).

Author's change Section 5.4.2 – paragraph 1 and 2 "Across all lakes, 57% were tuned to light extinction coefficient values of κd4 or κd5. These lakes are globally distributed and have a wide range of mean depths (1-138 m) with an average mean depth of 16 m. In view of this finding and considering that light extinction coefficient values are scarce for the majority of lakes, we assess if κd4 and κd5 can be used to provide a good estimation of the light extinction coefficient for modelling LSWTs in FLake. The untuned model is forced using two sets of light extinction coefficient values and the MAD results are compared. In the ïňĄrst model run, the average κsd 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, κsd = 0.82; for the 14 non-ice covered trial lakes, κsd = 1.46. In the second run, the model is forced with κd4 or κd5 values. κd4 applied to all lakes > 16 m in depth (the average depth of lakes tuned with κd4 or κd5) and κd5 to all lakes < 16m in depth. It makes practical sense to apply the less transparent of these two κd values (κd5) to shallower lakes, as shallow lakes are generally more affected by lake bottom sediments than deeper lakes. For both model runs the default albedo and the mean depth are applied, while all other model parameters are kept the same."

replaces "Across all lakes, 57% were tuned to light extinction coefficient values of either κd5 and κd5. The average depth of lakes tuned to κd4 is 21 m, and 13 m for lakes tuned to κd5. Tuning of deeper lakes to the more transparent of these two κd value (κd4) and shallower lakes to the less transparent value (κd5) makes sense as water clarity of a shallower lake is more affected by the lake bottom sediments than that of deeper lake. In view of this finding and considering that light extinction coefficient values are scarce for the majority of lakes, we assess if κd4 and κd5 can be used to provide a good estimation of the light extinction coefficient for modelling LSWTs in FLake.

The untuned model is forced using two sets of light extinction coefficient values. All the seasonally ice covered lakes were modelled using the average κsd (0.82; derived from Secchi disk depth data) of the 21 trial lakes and the non-seasonally ice covered lakes were modelled using the average ksd (1.46) of the 14 trial lakes. This is compared with the untuned model forced with κd4 applied to lakes > 16 m in depth and with κd5 for lakes < 16 m in depth. All other model parameters are kept the same. For both model runs the default albedo and the mean depth are applied."

Referee comment p. 8572, section 5.4.3: You recommend alpha3 but have said you use alpha1, alpha2 and alpha3. Need to state something along lines of recommend alpha3 if no informa- tion is available.

Authors change

"For seasonally ice-covered lakes, only 19% of the lakes were tuned to the default snow and ice albedo, α1, (snow and white ice = 0.60 and melting snow and blue ice = 0.10). Sixty four (64) % of lakes were tuned to two higher albedos α2 or α3, (snow and white ice = 0.80 and melting snow and blue ice = 0.60 for α2 or 0.40 for α3), indicating that the default snow and ice albedo may be too low for the majority of lakes. In the absence of lake-specific snow and ice albedo information, the albedo value α3 (snow and white ice = 0.80, melting snow and blue ice = 0.40) may provide a good estimate. The α3 values are highly comparable to albedo values measured on a Lake in Minnesota using radiation sensors, where the mean albedo of new snow was shown to be 0.83 and the mean ice albedo (after snow melt) was 0.38 (Henneman and Stefan, 1999)."

Replaces

"For seasonally ice-covered lakes, only 19% of the lakes were tuned to the default snow and ice albedo, α1, (snow and white ice = 0.60 and melting snow and blue ice = 0.10). 64% of lakes were tuned to two higher albedos α2 or α3, (snow and white ice = 0.80 and melting snow and blue ice = 0.60 for α2 or 0.40 for α3), indicating that the default snow and ice albedo is too low. To reduce the mean differences in the ice-off and JAS LSWTs, the albedo value α3 (snow and white ice = 0.80, melting snow and blue ice = 0.40) is recommended in place default value (α1). The α3 values are highly comparable to albedo values measured on a Lake in Minnesota using radiation sensors, where the mean albedo of new snow was shown to be 0.83 and the mean ice

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albedo (after snow melt) was 0.38 (Henneman and Stefan, 1999).”

Referee comment p. 8573, line 1: variance of what?

Authors change “The amount of observed inter-annual LSWT variance (in the month in which the minimum LSWT and maximum LSWT occurs for non-ice covered lakes and in the JAS LSWT for ice covered lakes), detected in the tuned model was quantified. It can be concluded that lakes at lower latitude and high altitude (for all lakes where the observed LSWT variance is low and for non-ice covered where the annual range is low) are less well represented in the model, than lakes with greater observed LSWT variance and the annual range.”

Replaces

“By determining the amount of observed LSWT variance detected in the tuned model, it can be concluded that lower latitude and high altitude lakes (lakes where the observed LSWT variance and annual range is low) are less well represented in the model, than lakes with greater observed LSWT variance and the annual range.”

Referee comment p. 8573, line 9/10: add "between the *surface layer of* maximum LSWT" as it’s the density difference between two layers, rather than a temperature and a layer.

“A greater wind speed scaling for high latitude lakes may be required to overcome a greater buffering effect possibly caused by a greater temperature and density difference between the surface layer of maximum LSWT and the hypolimnion during stratification than in low latitude lakes.” Replaces

“A greater wind speed scaling for high latitude lakes may be required to overcome a greater buffering effect possibly caused by a greater temperature and density difference between the maximum LSWT and the hypolimnion during stratification than in low latitude lakes.”

Referee comment p. 8573, line 13: without having to tune the model? Surely the improvement is in how to tune the model for new lakes?

Author response Tuning of FLake for new lakes would require applying a tuning process to the model that requires reliable observed LSWT information. This is now explained

Author change - p. 8573, line 11: “The optimal LSWT regulating properties (effective depth, snow and ice albedo and light extinction) for the 244 lakes are shown to be sensible and may provide a guide to improving the LSWT modelling in FLake for other lakes, without having to apply a lengthy tuning process the model, requiring reliable observed LSWT information.” replaces “The optimal LSWT regulating properties of the 244 lakes are shown to be sensible and provide a guide to improving the LSWT modelling in FLake for other lakes, without having to tune the model.”

The closing paragraph includes “The described approach to this study can provide practical guidance to scientists wishing to tune FLake to produce reliable LSWTs for new lakes.”

Referee comment p. 8573, line 28: not "true changes" but rather long-term changes. Short term variability is still a true change.

Reference to true change removed

Author’s change Now reads “This offers the potential to provide a better representation of LSWTs changes over a longer period of time, as satellite observations for the relatively short period may reflect some inter-annual variance.”

Referee comment p. 8574, line 26: southern hemisphere rather than tropical.

Author’s change Now reads To overcome this problem, the lake bottom temperature for non-ice covered lakes in August; southern hemisphere winter, was used to set to the temperature of maximum density, before compiling and running the model.

Figures and Tables

Referee comment Tables 4&5: "with the spread of differences" as you have used +-

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you are giving an un- certainty estimate so should describe it as such. Also need to specify that differences are between modelled and observed values.

Author's response Captions updated – I have left the spread of difference as it is here, for the present, as I have referred to 'spread of differences' throughout text and tables. It also describes well, the spread of results across the number of lakes being examined. Did you intend for me to change to uncertainty estimates in table 4 and 5 only?

Author's change "Table 4 The effect of wind speed scalings on untuned modelled LSWTs, presented as the mean difference, between the modelled and observed values, across lakes with the spread of differences defined as 2σ, where wind speeds u1 is unscaled, u2 is factored by 1.2 and u3 (Uwater = 1.62+1.17Uland). Results are presented for seasonally ice-covered and non-ice covered trial lakes. Results highlight that u3 is most applicable to seasonally ice-covered lakes but there is no one wind speed most suited for all lakes (While the mean difference is improved with u3, the spread of the mean differences across lakes for mthmin and mthmax show little change)."

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. Results highlight that u3 is most applicable to seasonally ice covered lakes but there is no one wind speed most suited for all lakes (While the average bias is improved with u3, the spread of biases across lakes for mthmin and mthmax show little change).

Referee comment Table 5: Need to reword the caption.

Author's change Now reads "Table 5 Summary of the untuned and tuned metrics for the trial lakes and the tuned metrics for all lakes (metrics are explained in Table 4). The results, presented for seasonally ice-covered and non-ice covered lakes in each instance, show the mean between the modelled and observed values, across lakes with the spread of differences 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"

Referee comment Table 10: Untuned has still been tuned with other parameters - need to say this

Author's change "Table 10 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 (explained in Table 4) from the untuned year (2011) compare well with metrics from 1996 (the ïňĄrst full year of data from Along-Track Scanning Radiometers 2 (ATSR2) and 2010 (the last year of tuned data from Advanced ATSR. For the untuned year (2011), for each lake, the model is forced with the effective lake depth (zd), snow and ice albedo (α) and light extinction coefficient (κd) values determined during the tuning process, shown in the supplement."

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)

Table 11 Results of the independent evaluation of the tuning process for non-ice covered lakes. The spread of differences across lakes is defined as 2σ. Metrics (explained in Table 4) for the untuned year (2011) are compared with those from the ïňĄrst full year of data from Along-Track Scanning Radiometers 2 (ATSR2) (1996) and the last year of tuned data from Advanced ATSR (2010). For the untuned year (2011), for each lake, the model is forced with the effective lake depth (zd), snow and ice albedo (α) and light extinction coefficient (κd) values determined during the tuning process, shown in the supplement.

Replaces

Table 11 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)

Referee comment Figure 1: Where do the observed values come from? Reference to ARC-lake LSWTs included in the caption

Referee comment Figure 2: State Lake Malawi is in southern hemisphere. Make clear the plots are FLake predictions. If you refer to the "upper mixed layer" and "bottom layer" in the caption these should be shown on plot.

Author reponse. The figure is constructed from ILEC database information (now included in caption) – the aspects of the temperature and mixing profile that are capable of being predicted by FLake are highlighted in the caption. The caption is updated to reflect this more clearly

Author’s change

“Figure 4 Summer and winter mixing and temperature profile of Lake Malawi, Africa (12° S 35° E), illustrated using data from the ILEC world lake database (http://wldb.ilec.or.jp/); showing the summer and winter lake water surface temperature (LSWT), mixed layer depth, thermocline temperature gradient and the hypolimnion. FLake is a two-layer model, capable of predicting the LSWT, the depth and temperature of the ‘upper mixed layer’ and the temperature of the ‘bottom layer’ “

Replaces

Figure 4 Summer and winter mixing and temperature profile of Lake Malawi; showing a mixed layer depth of 40-100 m. FLake predicts the LSWT and depth of the ‘upper mixed layer’ and the temperature of the ‘bottom layer’

Referee comment

Figure 5: At 10 m there is a range of 50% of y-axis value, so not that close. Have included the word ‘reasonably’, now reads (also included in Text) “A comparison of 5 methods relating light extinction coefficients to Secchi disk depths, showing that all method compare reasonably well at Secchi disk depths > 10 m”

Referee comment Figure 6: Would be good to see a similar plot with observed kappa too. Give country or lat/lon for Lake Geneva.

Now included - Lake Geneva, Europe (46° N 6° E), - I have done this for all lake-specific figure captions Lake Geneva was not one of the trial lakes – so I haven’t modelled it with light extinction derived from Secchi disk data. For the trial lakes (untuned model), the average results and the spread of differences across the lakes are in table 5. For seasonally ice-covered trial lakes, the mean difference between the modelled and observed JAS LSWTs (3.71 $\pm$ 3.51 oC) indicate that the light ext. coeff used are not suitable. JAS LSWT mean difference is reduced to -0.12 $\pm$ 1.09 oC after tuning - keeping in mind that this the post-tuning result of depth, light ext and albedo.

Referee comment Figure 7: Would like to see mean depth x 1.0 too

Author’s response I recall having this shown with mean depth at some stage but I removed it as it was it sat halfway between the depth x 0.5 and depth x 1.5 - it didn’t add anything as such-just slightly cluttered the figure

Figure 8: Specify what "model forcing data:wind" equations are for (what categories of size). Need to clarify that e.g. 80 outputs per lake is to do with the various combinations

Author’s response Figure 8 is now Figure 2

Author’s change “Figure 2 Study approach overview (trials, tuning, evaluation and results) for a) seasonally ice-covered lakes and b) non-ice covered lakes. For the trials, wind speed scaling, u1, u2 (recommended for lakes with fetch < 16 km and u3 recommended for open ocean water) is assessed on the untuned model, tuning is then trialed with a range of factors for d and values for α and κ using the selected wind speed scaling. The tuning approach produces modelled LSWTs for all possible combination of d, α and κ, 80 modelled runs for seasonally ice-covered lakes and 60 for non-ice covered lakes. For the evaluation, the tuning metrics (normalized and equally weighted) are the basis for selection of the optimal (tuned) LSWT model for each lake."

Referee comment Figures 9/10: need to refer back to u1, u3 etc in the text

Author's change "Figure 9 Effect of wind speed scalings on the modelled lake surface water temperature (LSWT) for Lake Simcoe, Canada, 44° N 79° W (depth 25 m), showing that the greatest wind speed scaling, u3 (Uwater = 1.62+1.17Uland), in place of the unscaled wind speed, u1, reduces the daily mean absolute difference and July, August September LSWT mean difference by ~50%. Modelled with untuned LSWT properties: mean lake depth (Zd1), default snow and ice albedo (α1) and light extinction coefficient derived from Secchi disk depth data (κsd) "

Replaces

Figure 9 Effect of wind speed scalings on modelled LSWT for Lake Simcoe, Canada, showing that the u3 scaling halves the daily MAD and JAS LSWT bias

Author's change "Figure 10 Effect of wind speed scaling on lake surface water temperatures (LSWT) for a temperate non-ice covered lake a) Lake Biwa, Japan (36° N 136 ° E) and for a tropical non-ice covered lake b) Lake Turkana, Africa (4° N 36 ° E) showing that the modelled LSWT for the temperate lake is better represented using u3 (Uwater = 1.62+1.17Uland), and the modelled LSWT for the tropical lake is better represented using u1 (unscaled wind speed). mthmin (and mthmax) is the difference between the observed and modelled LSWTs for the month where the minimum (and maximum) LSWT is observed"

Replaces

"Figure 10 Effect of wind speed scaling on LSWT for a temperate non-seasonally ice covered lake a) Lake Biwa, Japan (35.6° N) and for a tropical non-seasonally ice cov-

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ered lake b) Lake Turkana, Africa (3.5° N) showing that the modelled LSWT for the temperate lake is better represented using u3 and the modelled LSWT for the tropical lake is better represented using u1”

Referee comment Figure 11: "lakes tuned with modified are" doesn’t make sense, reword

Author’s change “Figure 11 Tuning metric mean differences between modelled and observed LSWTs for all 160 lakes with seasonal ice-cover. The results for the 25 lakes tuned with modified tuning approach are marked by diamond symbols a) July August September (JAS) LSWT mean difference, b) Daily mean absolute difference (MAD), c) 1 °C cooling day mean difference and d) 1 °C warming day mean difference” Replaces

Figure 11 Tuning metric results for all 160 lakes with seasonal ice cover. The results for the 25 lakes tuned with modified are marked by diamond symbols a) JAS bias, b) MAD bias, c) 1 °C cooling day bias and d) 1 °C warming day bias

Referee comment Figure 14: write out the default albedo for comparison

Author’s change “Figure 14 Lake surface water temperatures (LSWTs) for Great Bear (66° N 121° W) and Great Slave (62° N 114° W)modelled with low snow and ice albedo (default albedo, α1: snow and white ice = 0.60 and melting snow and blue ice = 0.10) and high albedo (α2: snow and white ice = 0.80 and melting snow and blue ice = 0.60) demonstrating that the higher snow and ice albedo delays the 1 °C warming day, causing a lower July August September LSWT”

replaces “Figure 14 LSWTs for Great Bear and Great Slave modelled with low albedo (default albedo) and high albedo (snow and white ice = 0.80 and melting snow and blue ice = 0.60) demonstrating that the higher albedo delays the 1 °C warming day, causing a lower JAS LSWT”

Referee comment Figure 15: need to reword, as "C decrease per week of later 1C warming day" doesn’t make sense. More responsive than what? Also, this is only suggested by the plot, as the sample size is very small and therefore can't be statistically significant. Need to be careful with your wording, both here and in the text.

Author's response – presenting the results in JAS LSWT change per week of delayed warming is needed to be able to do a like for like comparison across lake – I tried to explain this a bit better.

Author's change A - P 8567: line 4, reference to figure 15 is reword in text "In Fig. 15, the lake-mean depth of the 21 trial lakes are plotted against latitude. The relationship between the depth and latitude of the lakes and the change in the JAS LSWT caused by the later 1 °C warming day (due to the higher albedo), is shown in this figure, by use of coloured circles. This figure shows that for deep high latitude lakes the decrease in the JAS LSWT (presented as the decrease in the JAS LSWT, per week of later 1 °C warming day, °C week-1), is more pronounced than for shallow low latitude lakes."

Replaces

"The relationship between lake depth and latitude and the JAS LSWT decrease per week of later 1 °C warming day, shown in Figure 15, demonstrates the greater JAS LSWT change for deeper higher latitude lakes".

Author's change B - Figure 15 caption "Figure 15 The relationship between latitude and lake-mean depth of the 21 trial ice-covered lakes and the decrease in the July August September (JAS) lake surface water temperature (LSWT) caused by the later 1 °C warming day (as a result of using a high albedo, $\alpha2$: snow and white ice = 0.80 and melting snow and blue ice = 0.60 in place of the default albedo $\alpha1$: snow and white ice = 0.60 and melting snow and blue ice = 0.10). The changes in the JAS LSWT, presented as the decrease in the JAS LSWT, per week of later 1 °C warming day, °C week-1, are categorised by coloured circles. This figure indicates that high latitude and deep lakes show a larger decrease in the JAS LSWT per week of later 1 °C warming day, signifying that the LSWTs of these lakes are more responsive to changes in the 1 °C warming day, than low latitude and shallow lakes. "

Replaces

“The JAS LSWT decrease (shown as °C decrease per week of later 1 °C warming day) caused by a higher albedo for the 21 trial lakes shown with respect to lake depth and latitude. This figure shows that high latitude and deep lakes show largest JAS LSWT decrease with later 1 °C warming day, signifying that the LSWT of high latitude and deep lakes are more responsive to changes in the 1 °C warming day”

Referee comment Figure 17: Stated in the text there’s a 1:1 relationship but the equation you have sup- plied gives 1.02 (plus offset). I would suggest just not showing this equation. If lake is stratified, how do surface temperatures match bottom? What do FLake profiles look like? Is FLake forced with observed data here (non-independent)? What does this plot look like for other months?

Authors response How surface temperatures can reflect bottom temperature is now included in the text in section 5.2. This version of FLake is an online version that models the perpetual hydrological year, 2005/06, The forcing for this model is independent; adopted from the Global Data Assimilation System (GDAS). All lakes in the Flake profile showed a stratification period, other than that, the Flake profiles for these lakes were not examined. The lake bottom temperature during the stratification period was extracted from the modelled results

Authors change - Cation “Figure 17 Comparison of lake-bottom temperatures during the stratification period, obtained from FLake model run using perpetual hydrological year, 2005/06 (Kirillin et al., 2011) and the monthly minimum climatology lake surface water temperature (LSWT) observations from ARC-Lake, for 14 deep (> 25 m) non-ice covered lakes (55 °S to 40 °N). The monthly minimum observed LSWTs have a ∼1:1 relationship with the lake-bottom temperatures during the stratification period.”
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, show-

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ing the modelled equilibrium result (lake bottom temperatures obtained from Flake lake model, using perpetual hydrological year, 2005/2006) compared with observed monthly minimum climatology LSWTs from ARC-Lake “

Technical corrections p. 8550, line 4: global scale study mean does not make sense, reword “An mean daily MAD of < 1 °C is possibly accurate enough for a global scale study.”

p. 8550, line 16: remove comma removed

p. 8550, line 17: "result" should be "results" corrected

p. 8551, line 3: Last sentence of this paragraph needs rewording.

In order to capture the critical features of both ice-covered and non-ice covered lakes, the mean difference in the features between the observed and modelled LSWTs differ with lake type. replaces To capture the critical features in the LSWT cycle, the mean differences quantified, differ for the 2 lake categories

p. 8551, line 9: "includes" should be "including" corrected

p. 8551, line 22: "demonstrates" should be "demonstrate" corrected

p. 8552, line 19: remove comma after "Although" corrected

p. 8552, line 23: remove semi-colon after "properties" corrected

p. 8555, line 4: "coefficients" should be "coefficient" corrected

p. 8555, line 15: "become" should be "becomes" corrected p. 8558, line 5: "tuning of seasonally" remove "of" corrected p. 8558, line 3: "is" should be "are" corrected p. 8558, line 9: erroneous bracket corrected p. 8559, line 16: should be "overview of *the* tuning" corrected p. 8561, line 7: remove the first "default" corrected p. 8562, line 16: "are" should be "is" corrected p. 8565, line 7: replace "possible" with "probably" paragraph removed p. 8566, line 13: add "timing *of the* 1C cooling day" p. 8566, line

20: remove comma after "lakes" corrected

p. 8567, line 23: remove "of" corrected p. 8567, line 24: "become" should be "becomes" corrected p. 8568, line 2: add "timing of *the* 1C warming" corrected p. 8568, line 12: replace comma after model with a semi-colon corrected p. 8568, line 17: add "reduces *the* period" corrected p. 8568, line 26: replace "being" with "been" corrected p. 8569, line 3: remove comma after although corrected p. 8569, line 4: replace "satellite" with "satellites" corrected p. 8571, line 5: replace "and" with "or"; need "m" after "21" paragraph reworded

p. 8571, line 8: add "of *a* deeper" paragraph reworded

p. 8571, line 10: replace "scare" with "scarce" corrected

p. 8571, line 15: k used instead of kappa corrected

p. 8571, line 20: remove comma after "runs" and replace "show" with "shows" corrected

p. 8572, line 25: replace "isn't" with "aren't" corrected

p. 8573, line 4: remove "the" from "the annual range" corrected

p. 8573, line 16: remove comma after "18" corrected

p. 8573, line 19: add "place *of the* default" corrected p. 8574, line 4: replace "quantity" with "quantify" corrected

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