Review of "A General Lake Model (GLM 3.0) for linking with high-frequency sensor data from the Global Lake Ecological Observatory Network (GLEON)" by Hipsey et al.

Overview

This paper describes a one-dimensional hydrodynamic lake model GLM, which has already been used for a number of applications in the scientific literature. The paper is generally well written and structured. It gives a comprehensive overview of the model structure and equations, and shortly describes available tools for pre- and post-processing and for linking the model to other models.

I have rejected the previous version of this manuscript because there were far too many errors already in the first few equations. This has certainly been improved in the current version. However, I feel there are still too many errors and inconsistencies. These are problematic for two reasons. First, given the large number of errors reported in the first and this second review, I have to assume that there are still quite a few remaining errors that were not spotted by any of the reviewers. This reduces the trust both in the model description and in the model itself, as the reader never knows whether the equations are only wrongly written or also wrongly implemented. Second, the inconsistencies in the notation make it sometimes hard for the model user to understand the details. I am aware that writing a flawless model description is a very tedious work, but this can't be avoided.

General comments to model description

The total lake water balance is missing in the model description. It is shortly mentioned in the caption of Figure 2, but it should be described in detail in a separate section.

Section 2.3.3: I don't understand why three different parameterizations for saturation vapor pressure are included, which should give the same results within 1-2% at most, but only one parameterization for the latent heat flux (eq. 22), where different parameterizations can yield very different evaporation rates (see, e.g., Rosenberry et al., 2007, doi:10.1016/j.jhydrol.2007.03.018).

Section 2.6.1: It is somewhat confusing that first a total energy balance is introduced as being relevant for mixing, but subsequently only parts of that energy balance are used in each step. I think it would be clearer for the reader to first describe the individual energy components, and then the different steps in the mixing calculation, and remove the total energy balance, which is not explicitly used in the model.

Section 2.6.2: It is not clear to which part of the water column this mixing regime applies (the wording includes "below the epilimnion", "below the thermocline" and "in the hypolimnion". I assume it applies to all layers that are not within the surface mixed layer, according to Eq. (53), but this should also be made clear in the text.

Section 2.8. The wave properties are calculated based on the average lake depth, but the wave velocity in the i^{th} layer is then calculated from the local depth of this layer. I don't really know, but wouldn't it be more consistent to estimate also the wave properties from the local depth of the layer? It seems to me you could potentially underestimate local wave heights and thus resuspension in shallow waters with the given approach.

Code availability: I was not able to clearly identify the source code for GLM version 2.4. or 3.0 (probably not yet available?) or previously published versions on the GitHub repository. Also, the information on the GLM website (http://aed.see.uwa.edu.au/research/models/GLM/Pages/documentation.html) is not updated and does not link to the GitHub repository. All release versions, also past versions to allow reproducing previous calculations, should be published on GitHub and linked from the GLM website.

Comments to Figures

Figure 2: Fonts are rather small. The water balance should be described in the text rather than in the figure caption. I also think the notation used here is not entirely consistent with the model description.

Figure 3: increase fonts, albedo_mode is not introduced in the text.

Figure 4: what is the grey area in Fig 4a? The area where $f_{BEN} < 0.2$? if so, the color scale should be adapted accordingly. Also, the grey area is at least 80% of A_S, but in Fig 4c, the fraction is always >30%. Is this for the same lake?

Figure 5: How is it possible that the net heat balance is always positive for Ellen Brook Nature Reserve? This should lead to a massive heating of the lake throughout the year. Also net LW radiation is not shown in this figure. Is it missing from the budget? Please check. In the legend, ϕ_{LW} should be replaced by $\phi_{LW\ Net}$

Figure 6: use larger font for conditions, these are hardly readably even zoomed to > 100%. Shouldn't S_F be multiplied with Δt in the top boxes (and R_F in box 4 from the top)? Are the equations in boxes 6 and 7 from the top correct? R_F has a unit, so it should not be in the exponent. And typical values of R_F (unit m/s) are on the order of 10^{-6}, so $\exp(-R_F)$ is virtually nothing. In the third box from the bottom, the first equation must be wrong (check units). It is not clear what happens in the lowermost case (transition from snow to white ice?).

Figure 9: What drives vertical transport in case a) where vertical diffusivity in the hypolimnion should be zero? And what causes the local minima in the vertical profiles in cases a) and c)? If a tracer is released in the bottom cell and moves upward by diffusion, it's concentration should always be monotonically decreasing upward. If other processes (such as river intrusions) are responsible for these minima, why don't they exist in case b)?

Figure 10: α_{inf} is not very clearly drawn, also what exactly is δz_{infj}? In general, it would be useful if the discretisation in Eqs. (60) ff could be more clearly linked to the Figure, using exactly the same notation (Δz_j and δx_{inf} in the figure, but Δz_{jinf} and Δx_{inf} in the equations).

Figure 12c: why is there bottom water withdrawal around day 20?

Figure 14: increase fonts, the subscripts are impossible to read at 100% size. H_S, L and T are not used in the figure or text, remove from caption. Is the lower limit of the height axes at 1 m rather than 0 m on purpose?

Figure 15: This is a useful overview of the code structure. However, I think two things are nowhere explained in the text: what is the difference between do_model and do_model_nonavg? And what is do_bubbler?

Figure 16: Fonts are very small at 100% size.

Figure 17: "exposed sediment" is impossible to read at 100% size. Figure 17b can be removed.

Figure 18: As I understand, the grey shaded areas show the 80% uncertainty range of model projections based on the posterior uncertainty of the model parameters. However, it seems strange to me that this projection can deviate so much from the observed hypolimnion temperatures. These observations have a very small uncertainty (maybe 0.1 °C?), and such large deviations should lead to very low values for the likelihood in the Bayesian analysis.

Detailed comments to equations

Eq. (1): replace $A_{b-1} + 0.5(A_b-A_{b-1})$ with $0.5(A_b + A_{b-1})$.

Eqs. (2) and (3) are now correct, but might be easier to read if V_b was defined as the level below H_{mi} rather than V_{b-1}.

Eq. (4): According to Eq. (8), ϕ_E is positive if water is evaporated, thus E is negative (line 26) and should be added rather than subtracted in Eq (4), or maybe better, the minus sign should be removed in line 26?

Explain in a few words the intention of Eqs. (5) and (6), where, depending on meteorological conditions, precipitation will either be added to the water volume, or to the snow cover, referring to section 2.4. Also, I think the notation is inconsistent between here and section 2.4. Here, S_F, and R_F are the fractions of rain and snow that are added to the fluid water volume. In section 2.4, they are used also for rain and snow that are added to the snow cover.

Eq. (8). In order to optimize the calculation speed, consider replacing the calculated density of the surface layer by an average water density. This is an option for all equations where a calculated density is used as a multiplying (or dividing) factor. Density variations in lakes are in almost all cases < 1%, which is negligible compared to other uncertainties in model parameters. These are generally only relevant if density differences are calculated.

Eq. (9): Why is f_{sw} not included in the third option? I think it would make sense to have the option available to scale SW radiation also in this case.

Eq. (10) replace C with C_x

Eq. (11) I did not see the base for this equation in Luo et al (2010).

Eq. (12a) sin $(x-\pi/2)$ and sin $(x + \pi/2)$ could be simplified to –cos(x) and cos(x), respectively.

Eq. (12c) I think RH_x should be multiplied rather than divided by 100.

I have the impression that Eqs (20c) and (20d) should be valid for different units of e_a as they are written here. Please check.

Eq. (23) Something must be wrong with all three equations. They all yield results that are far away from the correct saturation vapor pressure. Saturation vapor pressure is 6.1 hPa for 0 °C. But for T_S = 0 °C, Eq. (23a) results in exp(0.7858) = 2.2, Eq. (23b) in exp (0) = 1 and Eq. (23c) in 10^0 = 1. Also the exponent in c is far too high for any temperature other than 0°C.

Eq. (25c) The nominator should be 2, rather than L_D in front of the square root according to Markfort et al. (also because otherwise the units are not correct). Furthermore, $\cos^{-1}$ (x) is ambiguous. It is sometimes used for arccos (x), and sometimes for 1/cos(x).

Eq. (32) Shouldn't it be ϕ_{SW0} also in the second line of the equation?

Eq. (39): Should it be ρ_{SML} instead of ρ_i in the last term? If not, the term in parentheses could be simplified to sum of Δz_i ρ_i $(h_l\text{-}h_{sml})$

Eq. (41) g needs to be added to the two equations for reduced gravity.

Eq. (42) I think it should be Δt rather than t in the upper equation?

Eq. (49): I think this equation should have a minus sign. N^2 is usually defined to be positive if the stratification is stable, i.e. if the density of the upper layer is smaller than the density of the lower layer. Here it is the opposite.

Eq. (52): I don't understand the last term of this equation. $h_s – h_{iinsl}$ seems to me to be almost the same as $z_{infinsl}$ (depending on how exactly the latter is defined) so the term in parentheses should be almost zero?

Eq. (53): the meaning of σ is unclear. The unit of N^2 is s^{-2}, that of its variance would be s^{-4}, but this obviously can't be what is meant here.

Eq. (54): should be f_{dif} in the exponents.

Eqs (56) ff. Maybe I looked at the wrong place, but I was not able to find all the corresponding equations in Fischer et al. (1979) and Antenucci et al. (2005). Since Fischer et al. is rather voluminous, it might be useful to mention the respective equation number from the original publication. I did not see Eqs. (56) and (57) anywhere in Fischer, and the corresponding Eq. (2) looks rather different in Antenucci. Eq. (58) corresponds to eq (4) in Antenucci, but tan α is replaced by tan ϕ_{inf}, and the tan is in the denominator here and in the numerator in Antenucci (not sure whether that is on purpose there, though).

Eq. (61) and following line: I don't completely this. The second equation in line 9 can be simplified, using eq. 61, to $z_{infj} = z_{infj-1} + \delta z_{infj-1}$. But according to the first equation in line 9 after reducing the index j by 1, also $z_{infj-1} + \delta z_{infj-1} = h_s\text{-}h_{ij-2}$. So that means $z_{infj} = h_s\text{-}h_{ij-2}$?

Eq. (62) For a given Δz_{infj}, and a given discharge, the flow velocity should be smaller if the channel is wider, i.e. if the angle α_{inf} is larger. But this equation implies the opposite. Please check.

Eq. (71): the equation calculating the seepage as a function of lake head is somewhat inconsistent as it applies the entire lake head to the entire area, and all water is removed from the bottom layer, i.e. it in fact treats the lake as a rectangular box.

Details in the text (pxx/lyy means page xx line yy)

p5/l15: ΔH_{mi} is 0.1 m here and 0.01 m in Table 1

p6/l4: Section 2.6 only describes layer merging by mixing from above, i.e. in the surface mixed layer. Can layer merging also occur in deeper waters, and if yes, under what conditions?

p8/l16: remove "either"?

p 9/10: ς is not atmospheric diffusive radiation, but "a constant related to atmospheric diffuse radiation" according to Table 1. It remains unclear, what this means.

p11/l8: ϕ_{SWS} is defined here as the fraction heating up the surface layer but in Table 1 as the radiation flux crossing the water surface (should be ϕ_{SW0} in the table?).

p11/l23: A_{Ben}/A_s is a fraction, not a percentage.

p11/l15: unit for vapor pressure needs to be given here or in Table 1.

p15/l20ff: I am not sure I understand the procedure for calculating ice melting here. I understand that first ϕ_{SW0} is calculated from eq. 31, then T_0 is calculated such that $\phi_0 = \phi_{net}$ (how is this done?), , and if T_0 is then equal or larger than the melting temperature T_m, melting is determined from eq 30. Is that correct? Consider revising the text in this section to clarify.

p18/l5: replace possible with available?

p19/l9: the notation z_{msl} is inconsistent, as all other layer thicknesses are named Δz.

p20/l2: difference to what?

p21/l16-18: this is not clear.

p23/l6: if α_{TKE} is interpreted as diffusivity, why then $Kz = C_{HYP}$ and not $Kz = \alpha_{TKE}$?

p23/l10: "contains 85% of N2" sounds strange, as N^2 is not a property that can be reasonably summed up across layers. Table 1 defines the same variable as the "fraction that contains 85% of the N^2 *variance*". This is even less clear. Is it calculated by summing up all N^2 values and then taking the volume for which the sum is 85% of the sum for the entire lake? If so, this is virtually the same as the volume that contains 85% of the density difference between the top and the bottom of the lake.

p23/l15: which density difference?

p25/l9: delete "the tangent of"

p26/l9: really daily time step? The time scale for river intrusions is usually rather minutes to hours than days. So does this ever take more than one step?

p26/l14: should be Δz_{infj} instead of z_{infj} in the equation.

p27/l12: should refer to Eq. (52)?

p31/l5: verb is missing.

p31/l8: If no weir is present I assume Q_{Ovfl} is the same as Eq. (73), but with $Q_{weir} = 0$?

p31/l9: Is Δh_s the result of eq. (4)?

p35/l5: iti -> it

p37/l2: I can't remember having read anything about solar shading in the model description.

p37/l16: In Figure 16, glmtools is called GLMr.

References: I did not check the list, but noticed that Spigel and Imberger (1980) is missing.

Comments to Table 1

This table is very useful, but it needs to be thoroughly checked and corrected. I checked only a small part of the variables, the following list of inconsistencies and missing variables is therefore certainly incomplete:

- I think the following variables used in the paper are missing in Table 1 (incomplete list): H_0, N_{SW}, e_a, ϑ_S, ϑ_a, δ_{zsoil}, K_{soil}, c_{wn}

- The variables α_b and β_b should go to Lake domain.
- Use per mil rather than ppt for parts per thousand, as the latter is generally used for parts per trillion.
- Check definition of θ_S
- Use Kelvin without degree sign.
- A_C is A_{WS} in Eq. 25b?
- most of the h's should be height above datum rather than height above bottom.
- f_w is calculated in Eq. (83), not Eq. (78).

Furthermore, the variables are mostly ordered alphabetically, but not completely, and the assignment of variables to the different classes of variables can be ambiguous. It is therefore often rather difficult to find a variable in the Table.

Finally, is unclear which parameter values are hard-coded and which can be modified by the user. Some parameters are defined as configurable, but for some others, which can also be defined by the user according to the text, just one value is given.