Interactive discussion on "Seasonality of density currents induced by differential cooling"

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Response to Referee #2

R (Referee):

HESS three Prinicipal Review Criteria

1. Scientific significance is excellent with new concepts, methods, and data.

2. Scientific quality is good. The approach and applied methods are valid and the results are appropriately discussed.

3. Presentations quality is good. There is an appropriate number and quality of figures/tables, appropriate use of English language. I found that there were few typos and that the English is good. The use of some symbols and abbreviations is confusing.

General Comments

The preprint addresses an important aspect of differential cooling with new concepts and data. With an extensive data set the thermal siphon process is shown to flush the near shore region. A simple model based on practically measured or available data is used to predict this process and it's seasonal variability. I enjoyed reading all five sections and the appendices and found all of the figures engaging. In summary I beleive the work represents a significant contribution to the field and is well suited to HESS.

A (Authors): We are grateful to Referee #2 for his/her positive feedback and for his/her comments about the clarity of the manuscript. We address them below.

My only general comment is that the clarity of the paper's main findings are obscured somewhat by the complex collection of abbreviations and symbols. In the first three specific comments below I address this and other clarity issues that I think should be addressed.

Specific comments

Three specific comments related to the overall clarity:

RC1 (Referee's Comment #1):

The along-x locations and their labels are confusing even after the reader is comfortable with the XZ description of the lake:

L_lit is the distance from one end of the lake along the thalweg to MT. So MT was located at the location where the photic zone reaches the bottom? I don't think this is ever stated, rather it seems MT is located at an arbitrarily shallow location along the thalweg.

L_ML the distance from the same origin along the thalweg to the isobath that matches the depth of the mixed at MB.

x_q the distance from the same origin to MT (where q is measured/predicted but not clearly linked between Figures 1 and 2).

l_p the length of the plateau (not indicated in Figure 2).

I think the formatting of these labels should be more consistent (e.g. a capital letter L followed by a subscript) and that x_q or L_lit be omitted. A similar simplification would help with the depths (d_p,d_MT,h_TS,h_lit, etc). I never could figure out what MT and MB stood for.

AR1 (Authors Response #1): Regarding the notations, we will follow the reviewer's suggestion and use a capital letter L for distances along x (L_{lit}, L_{ML}, L_p) and a lower case h for distances along z (h_p, h_{MT}, h_{TS}, h_{lit}, h_{ML}). The letter B in MB stands for "Background". The letter T in MT stands for "Thermal siphon". We will add these definitions to lines 119-120: "*We monitored the background stratification at the deepest location ("background mooring" MB, approx. 16 m deep) as well as the dynamics of TS offshore from the plateau region ("TS mooring" MT, approx. 4 m deep), from March 2019 to March 2020 (Fig. 2a).*"

Regarding the specific length scales:

- Indeed, L_{lit} is the length of the littoral region flushed by TS at MT. As discussed in Sect. 4.3 (lines 521-526), this length scale depends on the location of measurements along x because it is used to parametrize the x-dependent flushing time scale.
  The location of MT is constant over the entire year and we never stated in the manuscript that it was selected on a photic-depth criterion (which is seasonally dependent). The photic zone, estimated from repeated Secchi Depth measurements, was deeper than the water depth at MT except during the productive period in late summer 2019, where the photic depth was reduced to ~ 4 m.
  MT was positioned along the thalweg, with the two following criteria: (1) to be in the sloping region and (2) to be shallower than the mixed layer depth during cold summer nights ($h_{ML} \approx 5$ m). These two conditions allowed us to capture downslope TS already in summer.
  We propose to add the following sentence on line 120: "*The mooring MT was located along the thalweg, at the beginning of the sloping region. This shallow water column is already vertically mixed in summer by the action of surface cooling.*"
- L_{ML} is defined from the mixed layer depth because it corresponds to the distance over which differential cooling takes place (Sect. 4.3, lines 518-521).
- We used x_q to refer to the location of discharge measurements in other studies (Table 2). In our case, the length of the littoral region L_{lit} is equal to x_q. We agree that these different notations might be confusing for the reader and we will replace x_q by L_{lit} in Table 2. We will specify in the caption that L_{lit} is the length of the flushed littoral region, defined based on the location of discharge measurements.
- We will add the x-axis, L_p and L_{lit} in Figure 2.

RC2: *Although the transect data in the schematic represents an efficient use of space and looks great I think it unnecessarily complicates the schematic. The schematic should address the seasonal cycle, identify the plateau, perhaps include the equation q=c_q h (BL)^1/3 or similar equation for U, and serve as a road map or foreshadowing for the rest of the paper. Something like Table 2 added to the introduction could compliment the schematic. Where is the origin x=0 on the map in Figure 1? Why not identify the plateau in the schematic? Could the authors incorporate a graphic illustrating the essential time scales? If aspects at the end of the paper are too complicated to include in the initial schematic provide a revised schematic at the end of the results or in the discussion. I recognize the authors have spent some time linking the text and figures including Figure 1 and Table 1 together but it still needs improvement.*

AR2: Thank you for helping us improve Fig.1, we propose a revised version of the figure below (Fig. R2.1).

We would like to keep the transect data in Fig. 1, as it provides important information on (1) differential cooling and (2) TS-induced stratification. However, we understand the concern of the reviewer about the clarity of the figure. To simplify the schematic, we suggest keeping the colormap but removing the isotherms and replacing the vertical dashed lines with points on the x-axis.

As suggested by the reviewer, we will add the plateau to the schematic and indicate L_p and h_p. We propose to use four boxes on top of the schematic to list the scales related to the littoral region, the plateau region and the thermal siphon, and to address the seasonal cycle with a conceptual graphic showing the seasonality of the forcing conditions (B_0, h_{ML}, L_{ML}). We will also include the scaling formulae for U, q and τ_F (Eqs. (9), (10), (11)) in the box about TS.

The origin $x = 0$ is already indicated in Fig.1. We believe that the reviewer is referring to the bathymetric map of Fig. 2. We will add the x-axis and its origin in Fig. 2 (see AR1).

The time scales are currently introduced in different sections: Sect. 3.2 (τ_c), Sect. 3.5 (τ_t) and Sect. 4.2 (τ_{ini}, τ_{mix}). We realized that this can be confusing for the reader and it might be the reason why the reviewer is asking for an overview of the time scales in Fig. 1. We propose to introduce τ_c, τ_{ini} and τ_t in Sect. 2.6, as they are based on previous studies. We will keep τ_{mix} in Sect. 4.2 as it is a modification of τ_{ini} that we propose in this study. It is difficult to include these time scales in Fig. 1 since the current schematic shows the spatial and not the temporal variability of TS. We will mention the initiation time scale in the box about TS but we prefer to illustrate the other time scales in Fig. 8, once they all have been introduced in the text. We will move Fig. 8b to the Appendix and replace it with a schematic illustrating the time scales τ_{ini}, τ_{mix}, τ_t and τ_c over the cooling phase. The revised version of Fig. 8 is shown below as Fig. R2.2.

We hope that the different changes mentioned above will help to better link the text to the figures.

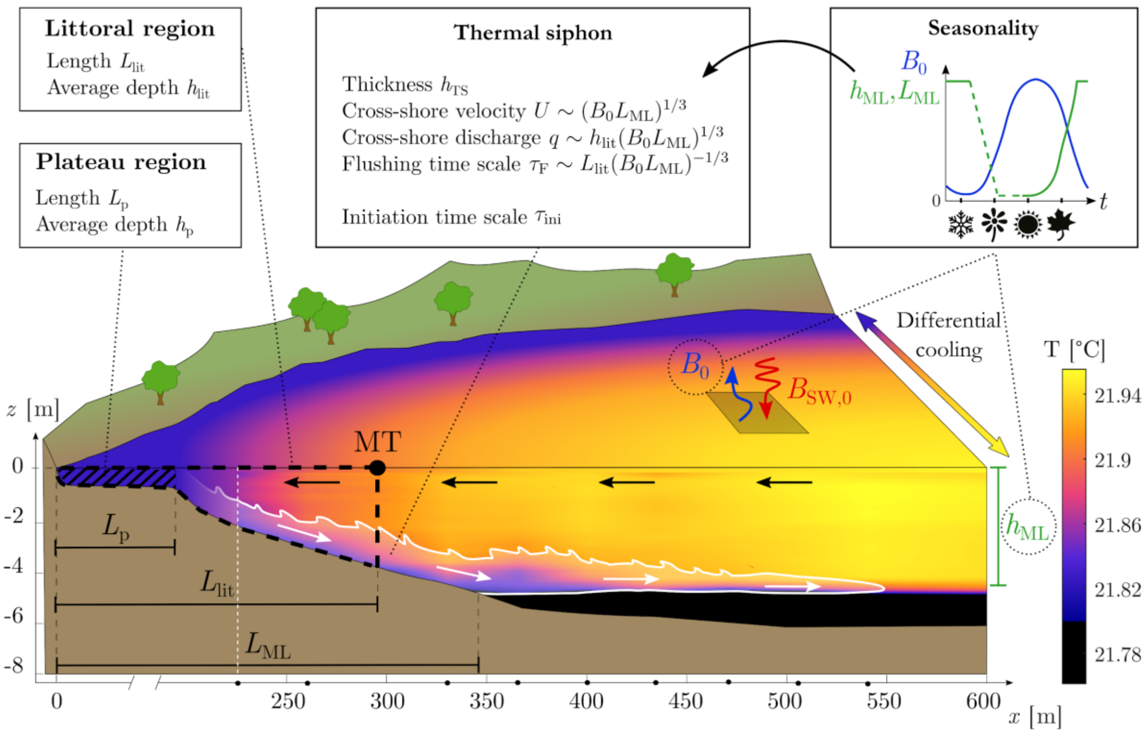

Figure R2.1 (revised Fig. 1): Data-based schematic of the cooling-driven thermal siphon representing the plateau, littoral and mixed regions, the seasonality of the forcing and the variables used for the transport scaling. The littoral region is the region upslope of MT, where the current velocity is measured and transport variables are calculated. The cross-shore temperature field is linearly interpolated from a transect of CTD (Conductivity-Temperature-Depth) profiles collected in the morning on 22 August 2019 (08:20–08:50 UTC), from x = 225 m to x = 714 m. Black dots on the x-axis show the location of the profiles. The green dashed line in the seasonality diagram corresponds to the transition period between the mixing period (winter) and the stratified period (summer), when there is not a well-defined mixed layer.

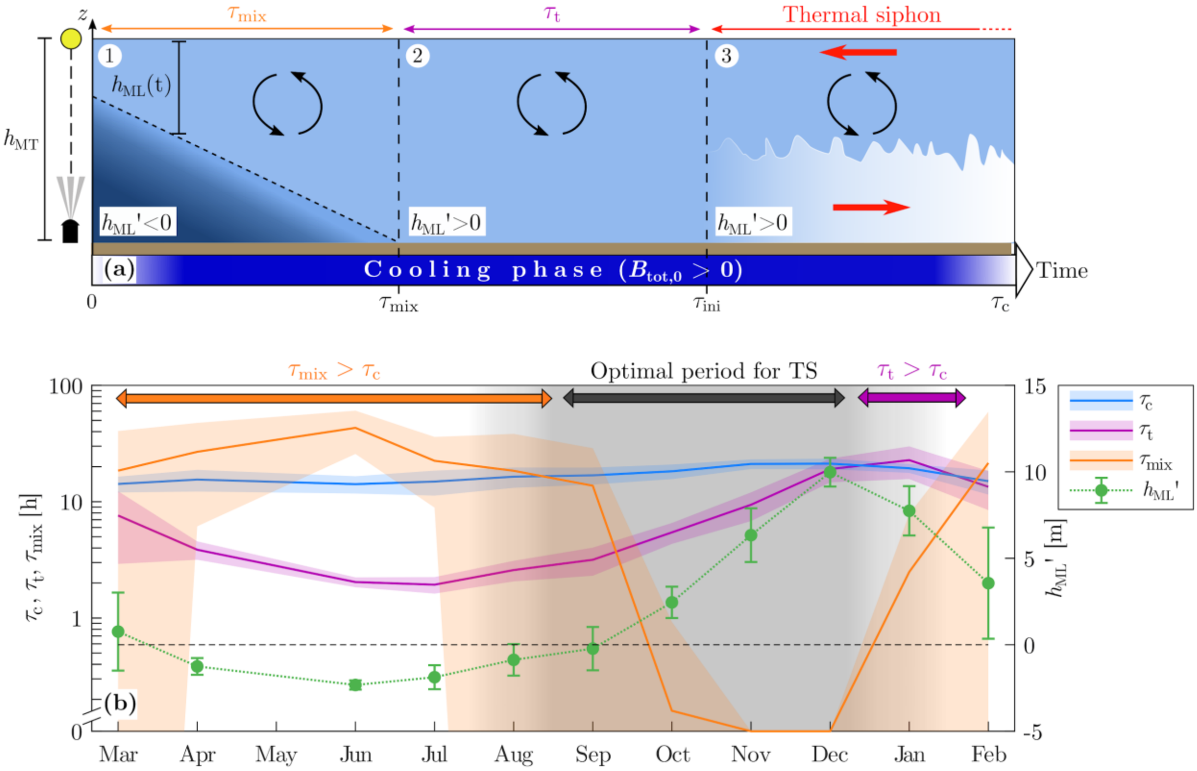

Figure R2.2 (revised Fig. 8): Time scales determining the occurrence of TS. (a) Schematic of the three periods of the cooling phase at MT parametrized by the mixing time scale τ_{mix}, transition time scale τ_t and cooling duration τ_C. The mixed layer depth is expressed as the relative depth $h_{ML}' = h_{ML} - h_{MT}$, with respect to $h_{MT} = 4$ m. The mixed layer deepens during the first period ($0 < t < \tau_{mix}$), until the complete mixing of the water column. Convection dominates over the second period ($\tau_{mix} < t < \tau_{ini}$). TS occurs during the third period ($\tau_{ini} < t < \tau_c$). (b) Effects of the seasonality of τ_{mix}, τ_t, τ_C and h_{ML}' on the occurrence of TS. Monthly averages are represented, with shaded areas (τ_C, τ_t, τ_{mix}) and error bars (h_{ML}') indicating the monthly standard deviation. Note the log-scale for the axis of timescales. The gray shaded period corresponds to optimal conditions for the occurrence of TS.

RC3:

The language related to flow direction is sometimes confusing. I think this is partially due to the fact that the shorelines to the northwest and southeast are closer to both stations than the shore line to the northeast. The authors should explicitly state early in the paper and repeat in several captions that offshore flow is southwestward flow or something similar, line 191 is inadequate. I don't think the authors ever comment on along shore flow, tell the reader why it's ignored or if there's none.

AR3: Thank you for this comment, we indeed need to better introduce the framework that we are using regarding the flow direction. Our motivation in this study is to quantify the flushing of the littoral plateau region at the north-eastern end of the lake. We use a 2D framework to study the convective circulation (Fig. 1) and focus on the TS-induced transport along the thalweg (x-axis). The x-axis defines what we call the "offshore direction". Due to its elongated shape, Rotsee is suitable for this 2D framework, with the strongest TS flowing preferentially along the thalweg. The along-shore flow (y-axis) is generally small but not necessarily zero as TS can be slightly deviated from the x-axis by Coriolis or topographic effects. The 3D aspects of TS are out of the scope of this study but could be investigated with 3D numerical experiments.

We suggest explaining our 2D framework and clarifying the language about the flow direction in Sect. 2.1, by adding the following paragraph after line 113: *"In this study, we focus on quantifying TS originating from the north-eastern plateau region (Fig. 2a). Because of the elongated shape of Rotsee, we use the 2D (x, z) framework shown in Fig. 1 by orienting the x-axis along the thalweg. We assume that TS originating from the plateau region preferentially flows along the x-axis and we do not consider flows in the perpendicular direction. We will now refer to the north-eastern end of the lake as the "shore" and call the direction of the x-axis the "offshore direction"."*

In addition, we will also modify lines 190-192 to define the cross-shore velocity: *"The horizontal velocity was projected onto the x-axis (angle of 56° from north), which crosses the isobath at MT perpendicularly (Fig. 2). Following the 2D framework of Fig. 1, we will now call the velocity U_x the "cross-shore velocity"."* We will specify "southwestward flows" where we refer to cross-shore flows in the captions of Figs. 3 and 5.

Other specific comments

RC4: *I was expecting to see more transects demonstrating the TS during other times of the year e.g. TS in July, October and December, were there no others collected?*

AR4: Transects of temperature profiles were collected during twelve campaigns from August to December 2019. We used one transect in Fig. 1 to show the cross-shore temperature distribution. We did not include the other transects in the manuscript because they do not clearly show the seasonality of TS. The bottom stratification and the TS thickness are similar between transects. The main seasonal differences are the depth and length of the mixed littoral region (L_{ML}, h_{ML}) and the duration of the TS events. Temperature transects are more relevant to study the short-term variability of TS over one diurnal cycle (periods shown in Fig. 3d), which is not the objective of this study.

We believe that the reviewer expected to see more transects because we mentioned the different campaigns on lines 133-135. We will remove this unnecessary information and modify the sentence as: "*To capture the spatial variability of TS, cross-shore transects of Conductivity-Temperature-Depth (CTD) profiles (Sea&Sun CTD 60M, sampling interval of 0.4 s) were performed along the x-axis.*"

RC5: *Figure 2. Provide the depth at MT in Figure 2 (b). I think the map of Switzerland should be idienfied as a map of Switzerland.*

AR5: The schematic of the mooring in Fig. 2b refers to both MB and MT. We propose to indicate the depth of both moorings on the map of Fig. 2a. We will mention the map of Switzerland in the caption as follows: "*The location of Rotsee is shown on the map of Switzerland with a black dot.*"

RC6: *Lines 145 to 152 - has anyone ever done this before for winds or humidity? explain why you think the simpler approach failed. Can you provide a separate R^2 for the northerly and westerly wind components, or the along and across axis wind components?*

AR6: Artificial Neural Networks are commonly used for the spatial interpolation of meteorological parameters, including wind speed (Öztopal, 2006; Kusiak and Li, 2010; Philippopoulos and Deligiorgi, 2012) and relative humidity (Yasar et al., 2012; Philippopoulos et al., 2015). Unlike pressure, air temperature and solar radiation, a simple linear interpolation cannot be used for wind speed and relative humidity because these two parameters are highly variable over time and are dependent on the surrounding environment. Philippopoulos and Deligiorgi (2012) showed for instance that Neural Networks are more performant than traditional interpolation methods of wind speed.

The values of R^2 and E_{RMS} for cross-shore (x-axis) and along-shore (y-axis) wind components are ${R_x}^2 \approx 0.85$, $E_{RMS,x} \approx 0.61$ m s^{-1} and ${R_y}^2 \approx 0.64$, $E_{RMS,y} \approx 0.26$ m s^{-1}, respectively. We will not include this information in the manuscript, as we did not use the wind direction in the analysis.

References:

Kusiak, A. and Li, W.: Estimation of wind speed: A data-driven approach, J. Wind Eng. Ind. Aerodyn., 98, 559–567, https://doi.org/10.1016/j.jweia.2010.04.010, 2010.

Öztopal, A.: Artificial neural network approach to spatial estimation of wind velocity data, Energy Convers. Manage., 47, 395–406, https://doi.org/10.1016/j.enconman.2005.05.009, 2006.

Philippopoulos, K. and Deligiorgi, D.: Application of artificial neural networks for the spatial estimation of wind speed in a coastal region with complex topography, Renewable Energy, 38, 75–82, https://doi.org/10.1016/j.renene.2011.07.007, 2012.

Philippopoulos, K., Deligiorgi, D., and Kouroupetroglou, G.: Artificial Neural Network modeling of relative humidity and air temperature spatial and temporal distributions over complex terrains, in: Pattern Recognition Applications and Methods, vol. 318, edited by: Fred, A. and De Marsico, M., Springer International Publishing, Cham, 171–187, https://doi.org/10.1007/978-3-319-12610-4_11, 2015.

Yasar, A., Simsek, E., Bilgili, M., Yucel, A., and Ilhan, I.: Estimation of relative humidity based on artificial neural network approach in the Aegean Region of Turkey, Meteorol. Atmos. Phys., 115, 81–87, https://doi.org/10.1007/s00703-011-0168-2, 2012.

RC7: *Line 239 I think this is ok for B_0 and is discussed later but I'm not so sure about L_ML, wouldn't this often increase over the cooling period?*

AR7: Yes, the mixed layer can deepen by ~3 meters during intense daily cooling periods in late summer, which leads to an increase of L_{ML} of ~70 meters over the same periods. This increase is more limited in late autumn, due to the weaker convection. We are averaging L_{ML} over the cooling phase since we are interested in the estimation of daily averaged transport variables only. We are not investigating here the short-term temporal changes of U and q over the cooling phase. Moreover, the daily increase of L_{ML} changes the velocity scale $(B_0 L_{ML})^{1/3}$ by O(10^{-3}) m s^{-1}, which is one order of magnitude lower than $(B_0 L_{ML})^{1/3}$. For typical summer conditions with B_0~10^{-7} W kg^{-1} and L_{ML}~200 m for example, an increase of L_{ML} by 70 meters changes the velocity scale $(B_0 L_{ML})^{1/3}$ by ~0.003 m s^{-1}.

RC8: *Table 1 would benefit from some recomposition to aid in connecting the four columns, particularly the fourth column, e.g. swap the third and fourth column and justify the 'definition and equation' column left.*

AR8: We will follow the reviewer's suggestion. The ranges of values will be provided in the third column and the equations will be in the fourth column and justified to the left.

Technical corrections

RC9: *Whether limnology is patriarchal or not the reference to 'fathers of limnology' reads a little too patriarchal.*

AR9: We will replace "fathers of limnology" by "pioneer limnologists".

RC10: *The whole sentence beginning 'Such shift' on line 594 needs improvement, to start, change 'Such shift' to 'Such a shift'.*

AR10: We propose to modify this sentence as follows: "*Such a timing has implications for the transport of dissolved compounds, with, for instance, stronger exchange between littoral and pelagic waters at a time of high primary production (summer and daytime).*"

RC11: *line 373 and 374 change shadow to shading.*

AR11: We will change the two occurrences of "shadow" to "shading".

RC12: *line 376 refer to figure 7 for the histograms.*

AR12: We will add the reference to Fig. 7.

RC13: *line 475 remind the reader what the depth is at MT.*

AR13: We will specify the depth of MT in the caption of Fig. 8 (see the caption of Fig. R2.2).