The present study elaborated to investigate the future climate impacts on the spring hydrological and ecological processes (i.e. spring discharge, ice-off, spring phytoplankton peak, onset of stratification) in a typical temperate lake Erken. The findings have critical implications because these processes were rarely evaluated simultaneously and their different sensitivities to climate change may result in different change paces or rates, and eventually lead to profound consequences on lake ecosystem in the future. The paper is well-prepared and concisely written. I have a few major and minor concerns and would like to recommend publication if the authors can address them properly during the revision.

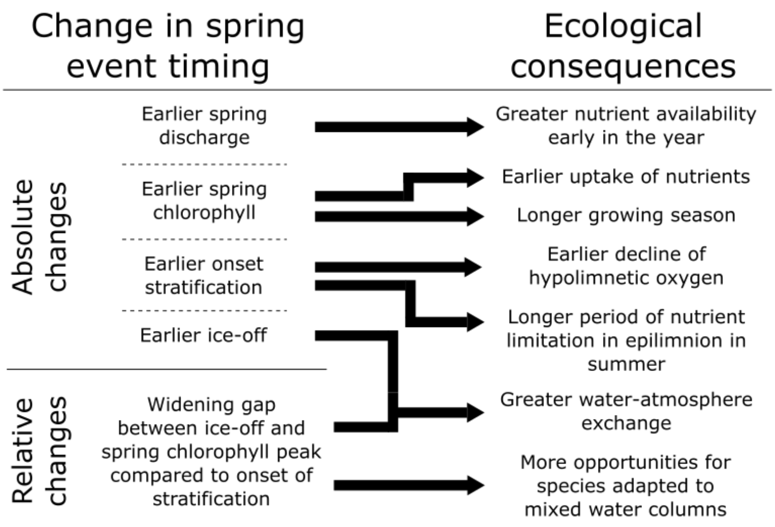
We appreciate the compliments and also the concerns and suggestions raised by the reviewer. We respond to each comment below, with our responses in text boxes and proposed additions to the text in red. Added references are given at the end of our reply.

Major comments:

- 2A The manuscript repeatedly emphasizes the ecological consequences of the different rate of advancing among the four investigated events, but these are not actually evaluated and subject to inferences and speculation, which may be attributed to the limitation in the model. This can be compensated, and manuscript can be improved, if the author can add a conceptual diagram in the discussion section, which summarizes the findings from the study (i.e. different advancing rate among the processes, increasing gap between stratification onset and other processes, and the potential ecological consequences from literature, for example, increasing magnitude of winter diatom blooms, see e.g., Hebert et al., 2021 e2114840118 PNAS , or Kong et al, 2021, 190, 116681 Water Research). Please consider this suggestion during the revision.

We agree that a conceptual diagram would more clearly link the predictions of the model to potential ecological consequences. We will add the diagram as Figure 5 and refer to it in the Discussion. In addition, we add a section to the Discussion that outlines the consequences of the absolute changes as well. We would not include the papers suggested by the reviewer in this section, because Hebert et al. attribute most of their findings to a later start of ice-on (while we focus on ice-off) and Kong et al. point to warmer water temperatures promoting winter (i.e. pre-spring) blooms, but our model did not simulate winter blooms and observations indeed suggest that these are uncommon in Lake Erken (at least in comparison to the magnitude of the spring blooms), perhaps due to the larger depth or more intense winters compared to that study.

New figure:



Caption Figure 5. Conceptual diagram of how the changes in spring event timing in Lake Erken under a warming climate, as simulated by the GOTM-WET and SWAT+ models, would link to ecological consequences in the lake.

Add after L. 224: These absolute changes in the timing of spring events may lead to several changes in lake state (Figure 5). For instance, the earlier spring chlorophyll peak leads to an earlier uptake of nutrients and a longer growing season. However, not all effects are restricted to spring itself. An earlier onset of stratification leads to lower hypolimnetic oxygen concentrations in the summer (Jane et al., 2023) and a longer period of nutrient limitation in the epilimnion (Sommer et al., 2012). These trends were indeed seen in our future projections, with chlorophyll and epilimnetic nitrate concentrations remaining constant despite increased nutrient loading (Jiménez-Navarro et al., 2023), and were likely partially driven by the earlier stratification onset.

- 2B It is confusing to learn that the model did not catch the actual dynamics in certain years (Fig. 2). Despite the reason of the methodology or definition of the events, it would be necessary to provide an acceptable explanation for these 'bad' years not only in the supplements but also in the main text. For example, are these bad years featured by hydrological or climatic extremes? or there were malfunctions of the sampling infrastructure?

We will expand the text on the potential causes of the bad years, with a particular intent to see if there were consistent patterns that were missed by the model. One important addition, therefore, was that the ice-off date was simulated significantly too late in years that had very little ice cover, and this may have implications for our future projections as well. However, we prefer to avoid discussing individual years in the main text, so we retain the discussion of individual years in the Supplement (Figure S5, Table S1). As the reviewer argues, it would indeed be interesting to know if there are consistent features that are causing the model to underperform, and we wanted the text to reflect this, rather than discussing peculiarities of certain years.

L. 155: Particularly, this occurred in years with short ice cover duration, in which the 2 °C threshold may estimate ice-off to occur too late.

Add after L. 205: The method to estimate ice-off from the model results (a 2 °C threshold) tended to simulate ice-off too late in years with low ice cover. Therefore, our study is likely underestimating the advancement rate of ice-off date, and ice may be disappearing even faster than the rates predicted here.

Change to Table S1: indicate as annotation for years 2008, 2014, 2020, and 2021, for ice-off, that these years had the lowest recorded ice duration in the study period.

As said, bad fits of ice-off tended to occur in years with little ice, in which the 2-°C threshold did not prove accurate (though surface water temperature was simulated well), as factors like wind may play a bigger role. We could not find consistent patterns in bad fits of discharge or spring chlorophyll: as can be seen in Figure 2, anomalous years (late discharge in 2010; early chl peak in 2008) were sometimes simulated very well by the models and sometimes not at all (late discharge in 2013; early chl peak in 2000). For stratification, and this will now be further clarified in the text, the issue simply seems to be the noise in the observed data interfering with the threshold-approach to determine onset. We tested multiple thresholds, but due to observations being noisier than simulations, there were some consistent mismatches regardless of the choice of threshold value (despite such methods being well-established in literature). However, these issues are unlikely to have an effect under future climate, and in fact, as Figure S5 shows, bottom-top density difference early in the year was actually very well simulated by the model.

New L. 152-153: Upon this further inspection, we concluded that for the five badly simulated years for discharge and chlorophyll, the model did indeed not capture the dynamics of the lake or catchment, though without indication that particular events led to a systematic over- or underestimation.

L. 157: As such, we concluded that it was noise in water temperature observations that caused the threshold method to occasionally fail, rather than an inability of the model to simulate the state of the lake.

- 2C The mixture terminology of ‘processes’ and ‘events’ should be reconciled. Are there any differences? If not, please avoid switching terms and be consistent throughout the text. It would facilitate reading if all the ‘events’ changed to ‘processes’, or vice versa.

This is a valid comment and in line with comment 1C of Reviewer 1. When referring to the four spring events (ice-off, onset stratification, etc.), we will now consistently use the term “events”.

Minor comments

- 2D Abstract, please specify which 'process' are referring here at the very beginning (e.g. eco-hydrological processes).

We will now specify that this relates to physical and biogeochemical events

New L. 13-14: Lakes experience shifts in the timing of physical and biogeochemical events as a result of climate warming, and especially relative changes in the timing of events may have important ecological consequences.

- 2E Line 45, if these processes are well acknowledged to be interlinked and occurs in causality and order already, what is the rationale to study them together? I think it should be further stressed that these processes have different sensitivity to climate change, and may response asynchronously in the future with changing orders and causal linkage. As a result, we must evaluate them together.

We discuss why we may expect to see asynchronous changes in the final paragraph of the Introduction, and we will further clarify and expand this section.

New L. 52-64: We used a coupled catchment-lake model framework to make future projections of the timing of these four events (ice-off, spring discharge, the spring phytoplankton bloom, and onset of stratification) and additionally to compare the projected trends between each of them. The use of process-based models can provide a robust framework for future projections of the timing of these springtime events, and the numerical coupling of lakes to their catchment allows a more thorough evaluation of climate change impacts and environmental changes (Kong et al., 2022). We hypothesised that all events would occur earlier in the year in a future, warmer climate, which is in line with previous studies, but also that relative changes in the timing of these events would occur. The latter expectation was partially due to the different processes driving each event, for example early-spring rain and air temperature would have the greatest importance in affecting snow and ice melt, while wind and temperature later in the season would affect the onset of stratification. Moreover, the effect of the strong seasonal cycle of solar radiation at the latitude of our study site would provide different physical constraints on phytoplankton, stratification, ice-off, and discharge. Climate warming could therefore affect not only the timing of these events, but also how they depend on each other and other external forcing – for example, in a future climate, the spring phytoplankton bloom might no longer rely on ice-off, but on the seasonal increase in solar radiation. The aim of our study is to create future projections of the timing of ice-off, spring discharge, the spring phytoplankton bloom, and onset of stratification and assess their absolute and relative changes, in order to better understand the impact of climate change on springtime events in lakes.

- 2F Line 52-53, what are the four processes? Please specify, or define them earlier with a clear name and use this name thoughout the text.

We will add the four events between brackets.

L. 52: …these four events (ice-off, spring discharge, the spring phytoplankton bloom, and onset of stratification)

- 2G Please summarize the main hypotheses and/or research questions with bullets by the end of introduction section.

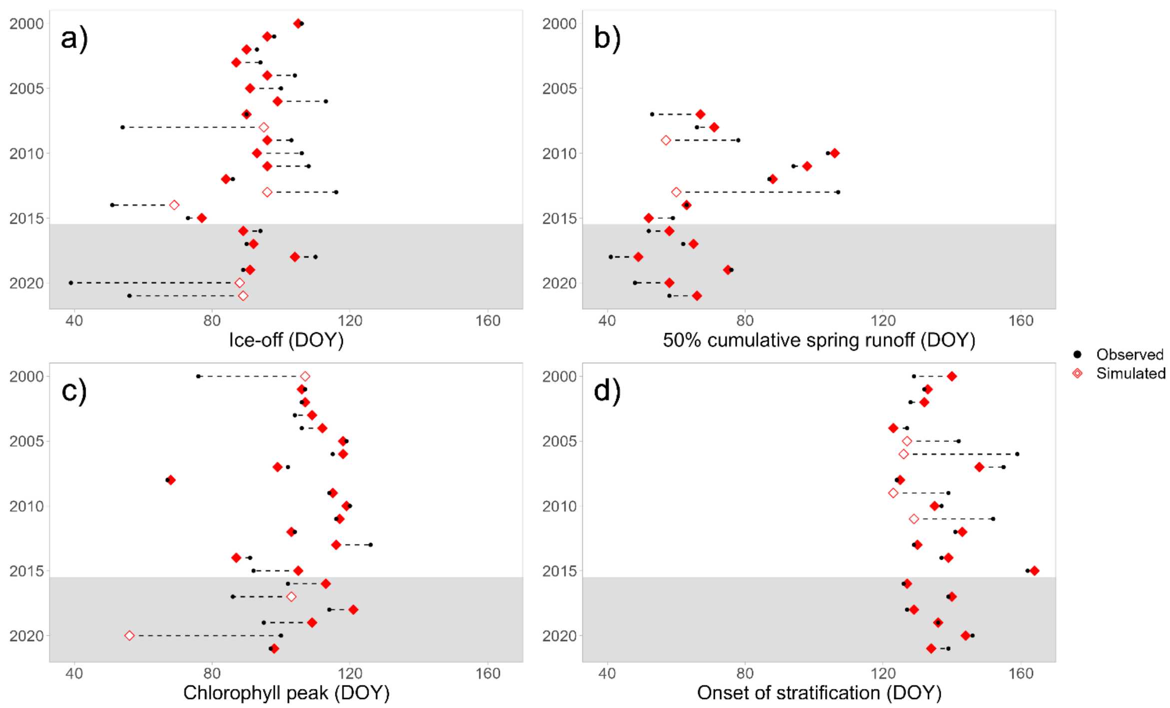
We prefer to refrain from the use of bullet points (in line with other studies in this journal), but we will rewrite the (last paragraph of the) Introduction, and close off this section by re-stating the aim, as we acknowledge that previously, the last part of the Introduction was rather open-ended. Our hypotheses will also be found in this paragraph.

See our reply to comment 2E for the new last paragraph of the Introduction

- 2H Please increase the font size in Figure 2.

The small font size was an oversight, for which we apologise. This will be improved in the new Figure 2, which will include some additional changes in response to Reviewer 1's comment 1M.

New Figure 2:



Caption Figure 2. Simulated (red diamonds) and observed (black circles) timing of (a) ice-off, (b) 50% cumulative spring runoff, (c) spring chlorophyll peak, and (d) onset of stratification. The years are on the y-axis, and the difference in timing is shown by a dashed line. The units on the x-axis are in day-of-year (DOY). The light grey area indicates the validation period. Open diamonds denote the years that were fitted badly (> 14 days error) and that are further investigated in Supplement section S2.

- 2I Figure 4, if I understand correctly, the color represents the 'ratio of the slope', rather than the slope itself. Please correct the title of the legend bar to avoid any confusion.

The colours do represent the Sen's slope itself, but of one event relative to another. So they are Sen's slopes fitted on "DOY_{spring_chl} – $DOY_{ice\text{-}off}$", "DOY_{spring_chl} – DOY_{onset_strat}", etc. This was done instead of showing a ratio, because this way, p-values could be computed. We will add an extra example to the caption of Figure 4.

Caption Figure 4. … on the y-axis. For example, under SSP 5-85, ice-off date advanced faster than the date of the 50% discharge…

- 2J Line 212, it is intriguing to see that the onset of stratification is always later than the Chl-a peak event, even at the very beginning of the simulation in 1985 (Fig. 3). Conventionally, as already stated in the introduction, the onset of stratification is a prerequisite for the spring phytoplankton bloom (Line 49). Are there any observations in Lake Erken, that the current or previous spring phytoplankton blooms were already earlier than the onset of stratification since 1985? Are these species diatom, according to field data and model predictions? Overall, it is necessary to add a few more explanations here.

Although the maximum depth of 21 m might suggest a reliance of phytoplankton growth on stratification, the lake's mean depth is only 9 m and before the spring bloom, the water is rather clear (typically >4 m Secchi depth in winter and low coloured dissolved organic matter). As such, stratification is not a prerequisite for phytoplankton growth in Lake Erken, at least not for the diatoms that dominate the spring bloom. In L. 49, we mentioned that stratification is a prerequisite under turbulent conditions in deep lakes (though we acknowledge that water clarity plays a role as well, and that it could be hard to provide a threshold value between "shallow" and "deep" in this regard).

Both in response to this comment and comment 1N, we clarify the sentence and refer to Figure 2 and two references. We will add as well that this spring peak is dominated by diatoms, as shown by Weyhenmeyer et al. (1999).

L. 215: In Lake Erken, spring phytoplankton growth is not reliant on stratification due to the limited mean depth of the lake, and the spring chlorophyll peak (dominated by diatoms) tends to occur prior to onset of stratification (Figure 2; Weyhenmeyer et al., 1999; Moras et al., 2019), …

Additional references, not previously cited in manuscript:

Jane, S. F., Mincer, J. L., Lau, M. P., Lewis, A. S. L., Stetler, J. T., and Rose, K. C.: Longer duration of seasonal stratification contributes to widespread increases in lake hypoxia and anoxia, Global Change Biology, 29, 1009-1023, 10.1111/gcb.16525, 2023.