Lake ice duration is decreasing in two Wisconsin lakes: a mini project for the LDP Productivity and Reproducibility Course

David R. Zilkey

2024-09-30

Abstract

Lake ice is a critical component of lake ecosystems that we expect to decrease in response to warming temperatures associated with climate change. This study assessed the long-term trends in ice cover duration for two Wisconsin lakes. I observed a significant reduction in ice cover duration since 1850 for both lakes. These changes, probably driven by warming temperatures, are likely to drive changes in lake thermal stratification and affect lake biological communities.

Introduction

Lake ice is an important component of lake ecosystems, both for environmental and cultural reasons. Ice cover has important effects on winter limnological conditions and affects under-ice processes including thermal stratification and mixing, primary production, trophic interactions, and more (Imrit and Sharma, 2021). Many communities rely on ice cover to transport goods and for recreational activities such as fishing. Whether or not lake ice cover duration is decreasing is therefore of important concern. Here, we assess the long-term trends in lake ice cover duration for two Wisconsin lakes.

Materials and Methods

Data Collection

Lake ice data has been recorded by the North Temperate Lakes Long-Term Ecological Research station dating back to 1851 (CE) (Magnuson et al., 2024). Each year for Lakes Mendota and Monona, data include the date ice was first observed on the lake, when ice was last observed, and the duration of ice cover in days. These data were downloaded using the R package *lterdatasampler* (Horst et al., 2023).

Data processing and analyses

All data processing was conducted in R (version 4.4.1) using R Studio (R Core Team, 2024). I used the *tidyverse* package to identify 'NA' values (1852 for Lake Mendota, 1853 for both lakes) (Wickham and RStudio, 2023). I assessed the long-term trends in lake ice cover by modelling ice duration as a function of year. I used the gam() function from the *mgcv* package (Wood, 2023) to create both linear and generalized additive models. I evaluated which model fit best using the Akaike information criterion (AIC); a lower AIC means better model performance. We used the base R AIC() function and visualized model results using *ggplot2* (Wickham et al., 2024).

Results

In Lake Mendota, a linear model was significant ($p < 0.05$) and explained 22% of the variation in the data. The AIC was slightly lower for the GAM than the linear model (AIC = 1413 compared to 1409, respectively). In Lake Monona, a linear model was significant and explained 26% of the variation in the data. The AIC was the same for both the GAM and the linear model (AIC = 1411). In both lakes, the slope of the linear model was negative (Figure 1).

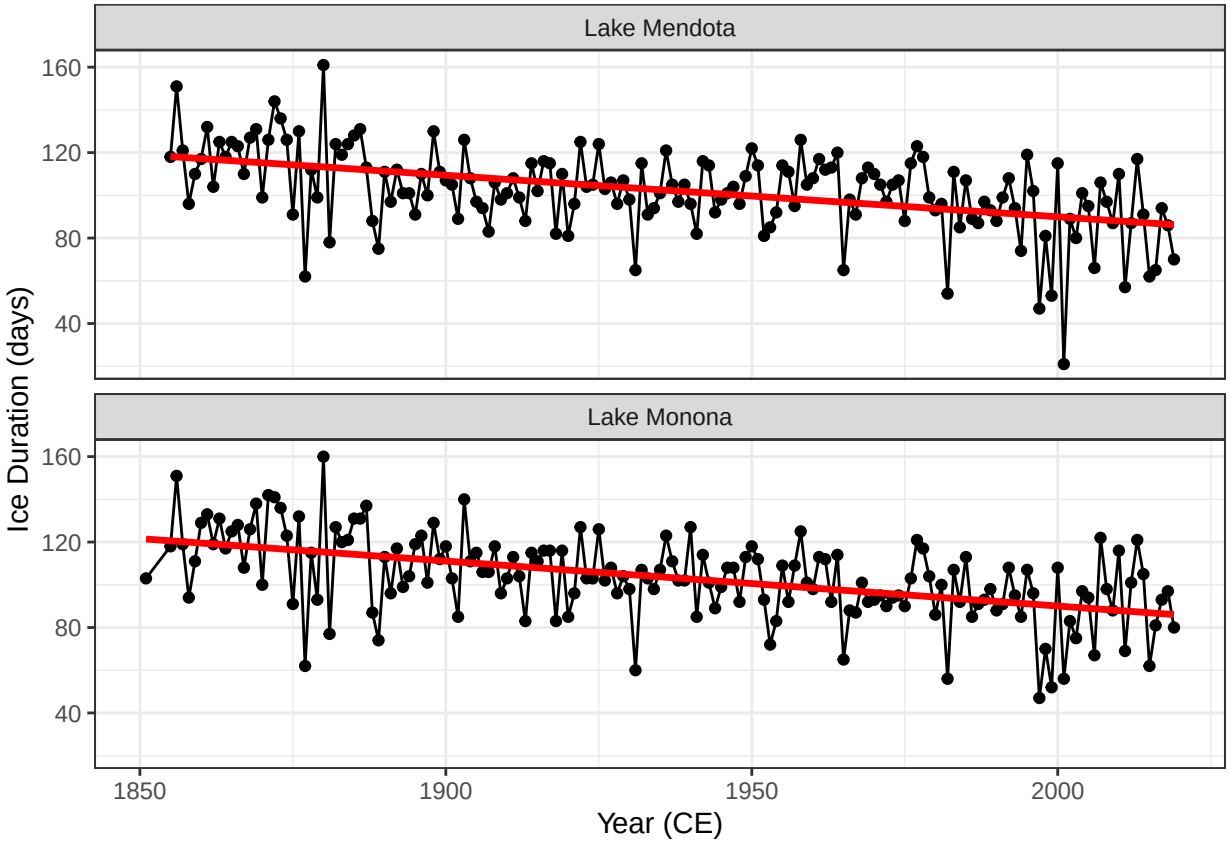

Figure 1: Figure 1: Ice cover duration for Lake Mendota and Lake Monona since 1851. The red line represents the fitted linear model for each lake. The models explain 22% of the variation for Lake Mendota and 26% for Lake Monona.

Discussion

My results suggest that the duration of lake ice cover for Lakes Mendota and Monona has decreased significantly since 1850 by roughly 30 days per year (Figure 1). This phenomenon is observed in many other lakes from the northern hemisphere (Imrit and Sharma, 2021). This process, almost certainly driven by climate change, is leading to significant changes in lake thermal stratification patterns and is likely to have downstream impacts on biological communities (Dibike et al., 2011; Mishra et al., 2011).

One aspect my study does not consider is the potential for intermittent ice cover to occur. The LTER ice cover dataset only considers the date of ice on and ice off, and not whether the ice remains frozen year round. One study suggests that nearly 15,000 lakes are at risk of experiencing intermittent ice coverage (Sharma et al., 2019).

Lastly, the GAMs applied and tested in this paper did not consider the cyclical nature of the ice cover duration data, likely owing to multi-year climate oscillation patterns (e.g., El niño, La niña). It is possible that a better fitting model exists which explains more variation than the linear models applied here, which takes into account this cyclicity.

Citations

Dibike, Y., Prowse, T., Saloranta, T., Ahmed, R., 2011. Response of northern hemisphere lake-ice cover and lake-water thermal structure patterns to a changing climate. Hydrological Processes 25, 2942–2953. https://doi.org/10.1002/hyp.8068

Horst, A., Brun, J., Guo, S., Logan, A., Ran, L., Sternberg, S., Zhao, K., 2023. Lterdatasampler: Educational dataset examples from the long term ecological research program.

Imrit, M.A., Sharma, S., 2021. Climate change is contributing to faster rates of lake ice loss in lakes around the northern hemisphere. Journal of Geophysical Research: Biogeosciences 126, e2020JG006134. https://doi.org/10.1029/2020JG006134

Magnuson, J.J., Carpenter, S.R., Stanley, E.H., 2024. North temperate lakes LTER: Ice duration - madison lakes area 1853 - current. https://doi.org/10.6073/PASTA/7EF5D8A32C65439FD903A9CBEEACB23A

Mishra, V., Cherkauer, K.A., Bowling, L.C., 2011. Changing thermal dynamics of lakes in the great lakes region: Role of ice cover feedbacks. Global and Planetary Change 75, 155–172. https://doi.org/10.1016/j.gloplacha.2010.11.003

R Core Team, 2024. R: A language and environment for statistical computing.

Sharma, S., Blagrave, K., Magnuson, J.J., O'Reilly, C.M., Oliver, S., Batt, R.D., Magee, M.R., Straile, D., Weyhenmeyer, G.A., Winslow, L., Woolway, R.I., 2019. Widespread loss of lake ice around the northern hemisphere in a warming world. Nat. Clim. Chang. 9, 227–231. https://doi.org/10.1038/s41558-018-0393-5

Wickham, H., Chang, W., Henry, L., Pedersen, T.L., Takahashi, K., Wilke, C., Woo, K., Yutani, H., Dunnington, D., Brand, T. van den, Posit, PBC, 2024. ggplot2: Create elegant data visualisations using the grammar of graphics.

Wickham, H., RStudio, 2023. Tidyverse: Easily install and load the 'tidyverse'.

Wood, S., 2023. Mgcv: Mixed GAM computation vehicle with automatic smoothness estimation.