Rising global temperatures effect the closing date of Lake Champlain

Abstract: Climate change may affect the ability of lakes to freeze over. Most northeastern US lakes have traditionally frozen over completely at a certain point every year (Sharma *et al.* 2019). These lakes have been freezing over more infrequently (Sharma *et al.* 2019). While regional lake ice cover testing across the northeastern US exists, specific case studies are somewhat slim. Lake Champlain is located across the northeastern US and southeastern Canada and has been experiencing a loss in ice cover. We hypothesize that an increase in the US's mean temperature delays the freezing over date of Lake Champlain.

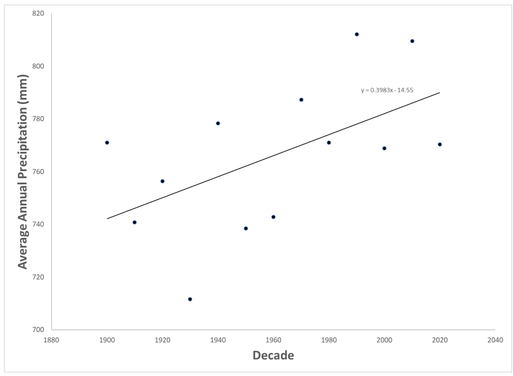


Figure 1: The average US precipitation (mm) per decade since 1900.

Table 1: The average US mean annual temperature (Celsius) for every decade since 1900.

Decade	Average of US mean annual temperatemperature ©
1900	10.87388889
1910	10.76888889
1920	11.02888889
1930	11.46555556
1940	11.14111111
1950	11.19888889
1960	10.93888889
1970	10.92388889
1980	11.28444444
1990	11.56888889
2000	11.81944444
2010	12.02666667
2020	12.42222222

Decade	Average of US annual precip (mm)
1900	771.0678
1910	740.7656
1920	756.3612
1930	711.6318
1940	778.3576
1950	738.4796
1960	742.7976
1970	787.3492
1980	771.0424
1990	812.0888
2000	768.7818
2010	809.498
2020	770.382

Table 2: The average annual US precipitation (mm) per decade since 1900.

Introduction: Climate change is a pressing issue that affects the processes occurring in numerous types of ecosystems. Oceans, lakes, and rivers are some of the most impacted systems by climate change (Hader *et al.* 2019). Aquatic ecosystems must enter warming and cooling periods to maintain their nutrient equilibrium. Warm water promotes plant growth and is important for wildlife habitats while cold water aids nutrient cycling and regulates chemical makeup (Poff *et al.* 2002). Changes in climate offset these cyclical periods, and the overall effects of climate change on fish growth have been negative at both the local and global scales (Huang *et al.* 2021). Biotic organisms are not the only parts of aquatic ecosystems to be affected by climate change.

Ice cover in lakes that traditionally freeze over can be affected by the changing climate. Reduced ice-cover could lead to higher moisture evaporation and transportation of this moisture to elsewhere in the watershed (Di Liberto. 2018). Reduced water levels will lead to shallower areas, which green blue algae flourish in and already are a problem in Lake Champlain. Additionally, certain fish use ice cover to protect their eggs from winter storms and certain fish will also have to deal with higher competitive advantage of warm water fishes (Di Liberto. 2018). This could mean large changes in fish composition, which could have top- down effects on the ecosystem. Since different fish species consume and affect algal growth differently, this could have ranging effects on algal population and toxicity due to green blue algae. In addition, with overbearing benthic algae levels, aquatic ecosystems cannot process the nitrogen gas released upon these algal deaths. This nitrogen is released into the atmosphere and further contributes to the warming climate (Poff *et al.* 2002).

Thus, our **objective** was:
- To use Lake Champlain as a case study and synthesize the most important factor behind the change in the lake's ice cover.
- To compare our discoveries to the observed trends throughout the northeastern United States.

Temperature and Probability Measurements

Figure 2: The average US temperature (Celsius) per decade since 1900.

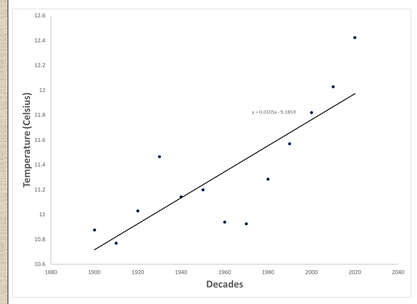


Figure 3: The probability (out of 1) Lake Champlain will freeze over given mean US temperatures (Celsius)

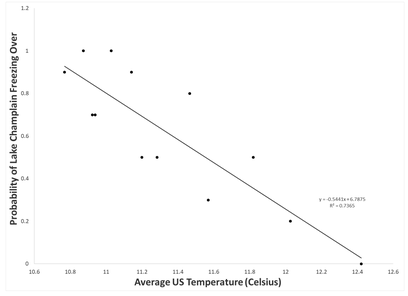
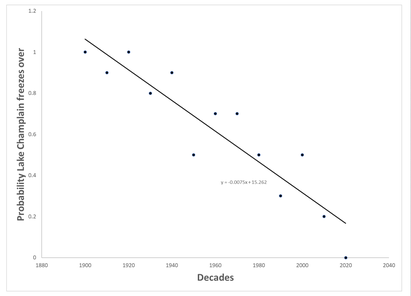


Figure 4: The probability Lake Champlain freezes over (out of 1) per decade since 1900.



* Temperature has been increasing steadily at a rate of about 0.14 degrees Celsius per decade.

* The greatest spike in temperature occurred from 1920-1930, in which the average temperature increased by about 0.65 degrees Celsius.

* The probability that Lake Champlain freezes over changes by about 20% for every 1 degree drop in the US's mean temperature.

* The probability Lake Champlain freezes over was 100% at only two mean temperatures, 10.9 and 11.2 degrees Celsius. Notably, the two temperatures are some of the lowest recorded ones in our data set.

* On average, the probability Lake Champlain completely froze over decreases by about 7 percent each decade.

* Starting at about 1950, the probability Lake Champlain completely froze over dropped below 50% and never returned above for he remainder of the recorded decades.

Methods:

Mean Annual Temperature:
Mean US annual temperature is recorded via many government database and this data was collected by National Climatic Data Center. Those databases provide accurate and precise data that spans over many decades and can be view at a variety of scales (monthly, yearly, decades)

Ice Cover Data:
Ice cover data was taken from National Climatic Data Center as well and it shows whether Lake Champlain ice cover was complete or incomplete on a yearly basis. This when juxtaposed with US mean annual temperature reveals the probability that the lake will freeze over given a certain temperature.

Statistical Analysis:
When probability of complete ice cover is placed as the dependent variable and mean annual temperature is placed as independent variable a linear regression can be statically tested to show the correlation between these two variables. Since both variables are continuous which is what enables testing by linear regression.

Hader DP, Barnes PW. 2019. Comparing the impacts of climate change on the responses and linkages between terrestrial and aquatic ecosystems. Science of the Total Environment **682**:239-246.

Huang MR, Ding LY, Wang J, Ding CZ, Tao J. 2021. The impacts of climate change on fish growth: A summary of conducted studies and current knowledge. Ecological Indicators **121**:106976.

Poff NLR, Brinson MM, Day JWJ. 2002. Potential impacts on inland freshwater and coastal wetland ecosystems in the United States. Aquatic Ecosystems and Global Climate Change **1**:1-56.

Sharma, S, Blagrave, K, Magnuson, JJ, O'Reilly, CM, Oliver, S, Batt, RD, Magee, MR, Straile, D, Weyhenmeyer, GA, Winslow, L, Woolway, RI. 2019. Widespread loss of lake ice around the Northern Hemisphere in a warming world. Nature Climate Change **9**:227-231.

Di Liberto, T, Great Lakes ice cover decreasing over the past 40 years. https://www.climate.gov/news-features/featured-images/great-lakes-ice-cover-decreasing-over-last-40-years

Conclusions:

Through regression analysis it has been determined that there is a correlation between probability of Lake Champlain freezing over and US mean annual temperature. The correlation coefficient of R^2=0.7365 means that there is a fairly strong correlation between these two variables. The level of precipitation did not rise substantially thus this variable could not be reasonably correlated to the probability of Lake Champlain freezing completely over. Where we do stress that our findings are not a relationship of causation, there are few hypotheses that are stronger in reasoning. In terms of physical science warmer temperatures do cause water to convert from its solid form. Thus, we are confident that this data is very close to a causation relationship. However, there are other hypotheses such as increased salinization that could potentially be changing the chemical properties of Lake Champlain this could be a confounding variable. Additionally, precipitation could be coming in different forms, rain versus snow will have a drastically different effect on lake ice and through the data analyzed this is not clear what form this precipitation is and when it occurred. With all of this considered it is important to do further analysis and consider these other variables and maybe construct a study on a finer scale. This study is a great starting point to analyze why Lake Champlain is freezing over less, and the strong correlation may suggest that our efforts have been focused in the right direction. These findings also align with previous studies in the Northeastern United States on lake ice (Sharma *et al.* 2019) which further increases our confidence in our findings.