Forecasting River Ice Breakup in Dawson AK using a Long Short Term Memory Model

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Motivation

The annual breakup of river ice in arctic and near arctic regions, leads to ecological and economic damage caused by subsequent ice jam flooding. Using deep learning, we set out to predict when the annual river ice breakup events will occur, as well as how it will likely change over time as shown by model simulations.

Data

This analysis is currently restricted to a location along the **Yukon River in Dawson City Alaska**.

- Breakup events were taken from the **US National Weather Service**[1]
- Inputs to the model consisted of: minimum and maximum temperatures; snow water equivalent; precipitation; shortwave radiation and vapor pressure. These value were imported and or derived from **Daymet**[2]
- **CanESM5**[3] contains variables that have a daily temporal resolution and are either the same as or could be derived to mirror variables in Daymet. Therefore CanESM5 was used to forecast future breakup trends

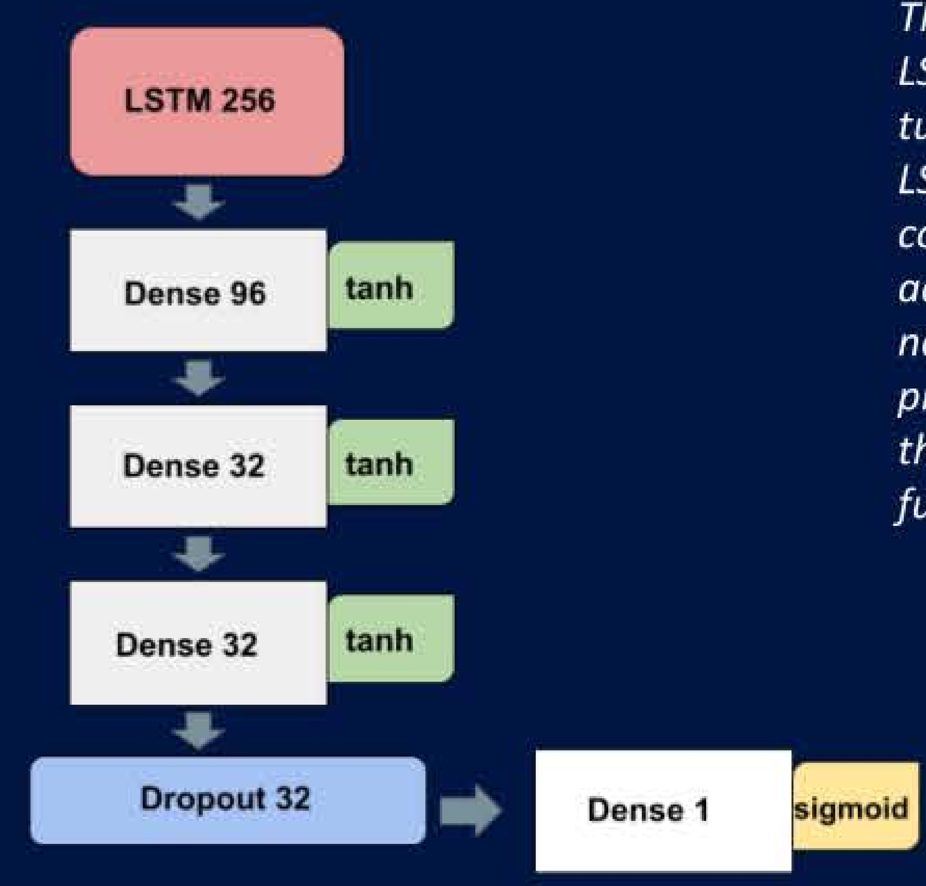
CanESM5 Experiments

Scenario ID	Description
Historical	The historical simulation values for the CanESM5 model under the conditions and parameters most similar to true historical data. This acts as the parent experiment (or initial conditions) for all simulations in this analysis except for SSP534-over, of which it is one generation prior. Spans the years 1850 - end of 2014.
SSP119	Assumes low radiative forcing throughout, reaching about 1.9 W/m^2 in 2100, based on SSP1. Concentration-driven; spans the years 2015 - 2100.
SSP370	Assumes high radiative forcing by the end of century. Reaches about 7.0 W/m^2 by 2100; fills gap in Representative Concentration Pathway with forcing between 6.0 and 8.5 W/m^2. Concentration-driven; spans the years 2015 - 2100.
SSP585	Assumes high radiative forcing by the end of century. Similar to the RCP8.5 global forcing pathway but with new forcing based on SSP5. Concentration-driven; spans the years 2015 - 2100.
SSP534-over	21st century overshoot scenario relative to SSP534 (radiative forcing of 8.5 W/m^2). Branches from SSP585 (the parent experiment) at 2040 with emissions reduced to zero by 2070 and negative thereafter, with radiative forcing reducing to 3.4 W/m^2. Spans the years 2040 - 2100.

The image to the left shows a map of Alaska USA with Dawson City marked with a red flag. In the red box is a blowup of Dawson City along the Yukon River.

Model

This analysis uses a Long Short Term Memory Model (LSTM) to predict when river ice breakup events will occur in Dawson City AK. Using binary cross entropy with an initial bias equal to ln(TP/TN), the LSTM assigns a probability that the breakup event will occur to each day. The LSTM uses a large lookback window to ensure that the breakup event is captured for each iteration. The LSTM is hyperparameter tuned using Bayesian selection. Both tuning and training are optimized by selecting for the maximum area under the receiver operating curve.



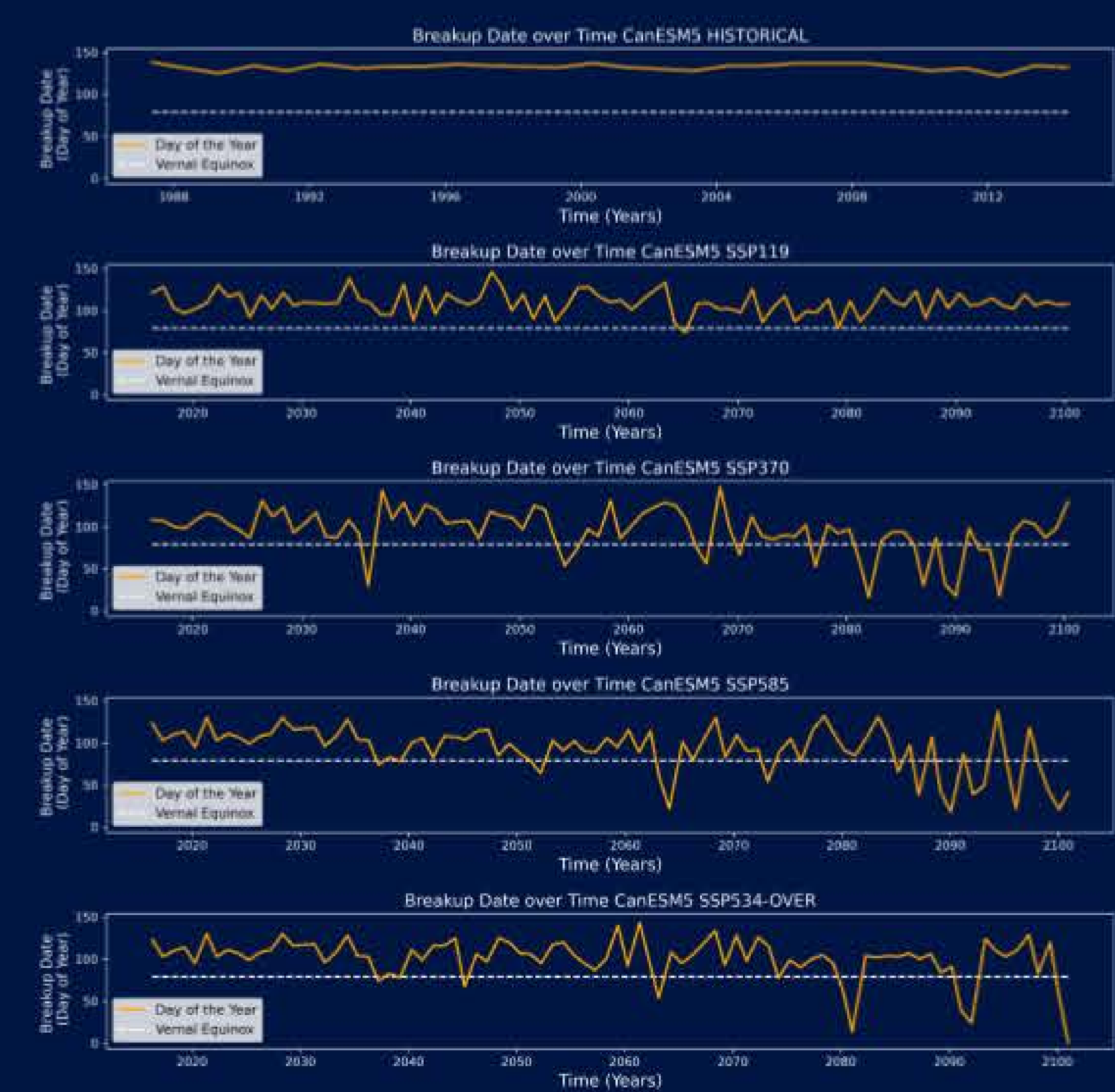
The figure to the left shows the final LSTM created through hyperparameter tuning. The first layer consists of 256 LSTM nodes followed by three fully connected layers, each with a tanh activation function and 96, 32 and 32 nodes respectively. There 25% dropout prior to the final dense layer that plots the output to the sigmoid activation function.

The above model architecture proved to be the most optimal post tuning, and training, for both the Daymet input data ranging from 1980 to present and the CanESM5 Historical input data ranging from 1896 (first recorded breakup event in Dawson) to 2014 at which point the CanESM5 model diverges based on scenario.

Results

The results show that the LSTM model is able to predict the breakup date of river ice in Dawson effectively. **Using the Daymet data, predicting into the future, the model can forecast the breakup date within an average time span of 5.8 days** with a standard deviation of 2.6 days. The maximum number of days the LSTM model was off when predicting into the future using Daymet was 8 days and the best year forecast was off by 1 day. The test data for Daymet consisted of five breakup years (2018 - 2022). **For the CanESM5 data predicted in reverse chronological order, the LSTM model was able to forecast the breakup date within an average time span of 7.8 days** with a standard deviation of 5.3 days. The maximum number of days the LSTM model was off by when predicting past breakup dates was 19 days, and the best year forecast was off by 0 days or got the exact day of year that the breakup occurred. The test data for CanESM5 backward forecasting was 28 breakup years long (1924 - 1896). **Lastly, using the CanESM5 data to predict in regular chronological order (into the future), the LSTM model was able to forecast the breakup date within an average time span of 8.2 days** with a standard deviation of 3.8 days. The maximum number of days the LSTM model was off by when predicting future breakup dates was 15 days, and the best year forecast got the exact day of year that the breakup occurred. The test data for CanESM5 future forecasting was 28 breakup years long (1985 - 2014).

Based on the predictive power of the model using the Daymet as well as the CanESM5 historical datasets, we can confidently extrapolate further into the future based on different climate scenarios. The plots below show the future projections for river ice breakup in Dawson AK based on the different scenarios with the predictions used in the CanESM5 testing dataset shown across the top. You will notice that as the scenario predicts warmer temperatures and more extreme weather events, the model predicts earlier breakup.



Sources

1. [NWS, 1995] (1995). National Weather Service — weather.gov. https://www.weather.gov/. [Ac-212 cessed 24-Apr-2023].

2. [Thornton et al., 2022] Thornton, M., Shrestha, R., Wei, Y., Thornton, P., Kao, S.-C., and Wilson,235 B. (2022). Daymet: Daily surface weather data on a 1-km grid for north america, version 4 r1.236 14

3. Swart, Neil & Cole, Jason & Kharin, Viatcheslav & Lazare, Mike & Scinocca, John & Gillett, Nathan & Anstey, James & Arora, Vivek & Christian, James & Hanna, Sarah & Jiao, Yanjun & Lee, Warren & Majaess, Fouad & Saenko, Oleg & Seiler, Christian & Seinen, Clint & Shao, Andrew & Solheim, Larry & von Salzen, Knut & Winter, Barbara. (2019). The Canadian Earth System Model version 5 (CanESM5.0.3). Geoscientific Model Development Discussions. 1-68. 10.5194/gmd-2019-177.