Ice/Snow Albedos and Bayesian Optimization: PGDL Models of 1D Lake Thermal Stratification

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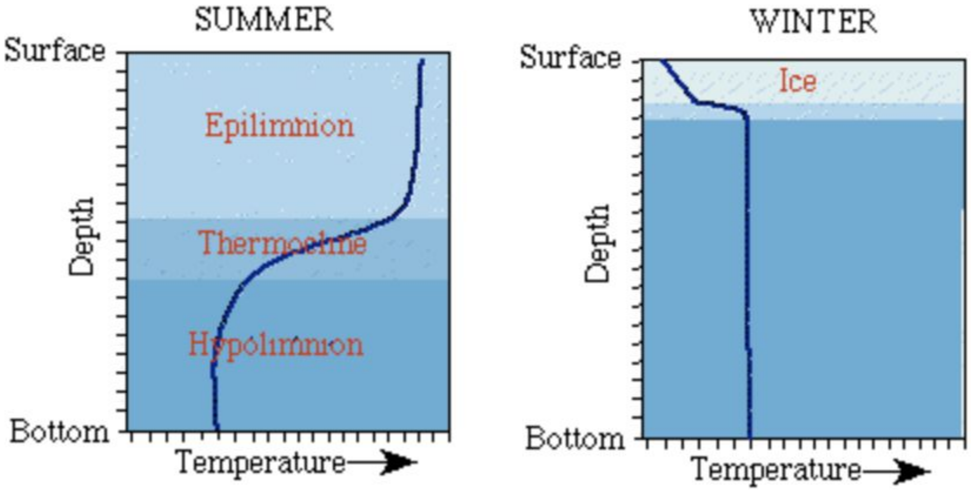
Motivation



Lake Mendota, Madison, WI is covered by ice and snow each winter (January-April).

However, the winter season is shortening with climate change, killing off more fish.

Ice and snow are more reflective (higher albedo = lower absorptivity) than water.

Read et al. 2019 did not vary albedo in energy balance equation.

What are the “best” values for albedo? LSTM parameters?

Ice Thickness

Estimate ice thickness from thermodynamic growth (Lebedev 1938):

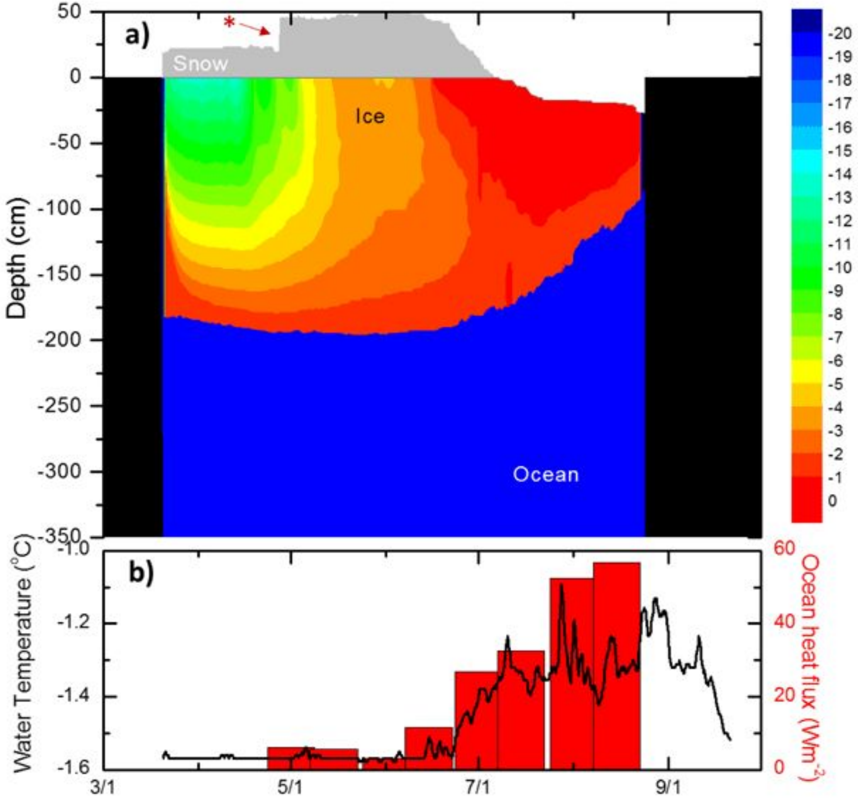
$$Thickness\ (cm) = 1.33 \cdot FDD\ (°C)^{0.58}$$

where FDD = Freezing Degree Days

$$FDD_i = FDD_{i-1} + T_{diff}$$

$$T_{diff} = T_{water} - T_{air}$$

$$T_{water} = 0$$



Assume ice growth and melt depend solely on air temperature.

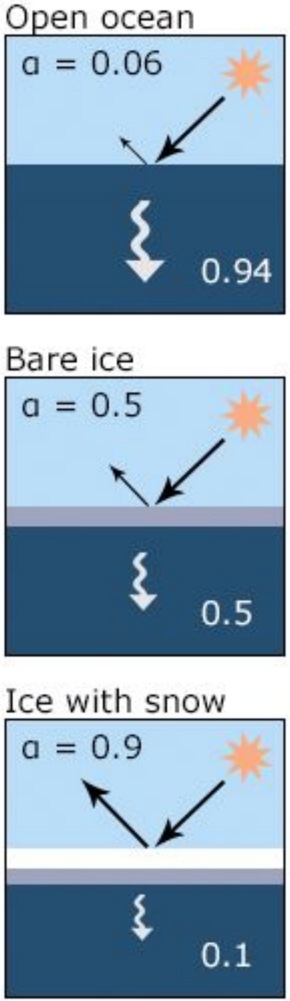
Ice and Snow Albedo

Proposed algorithm (Oveisy & Boegman 2014):

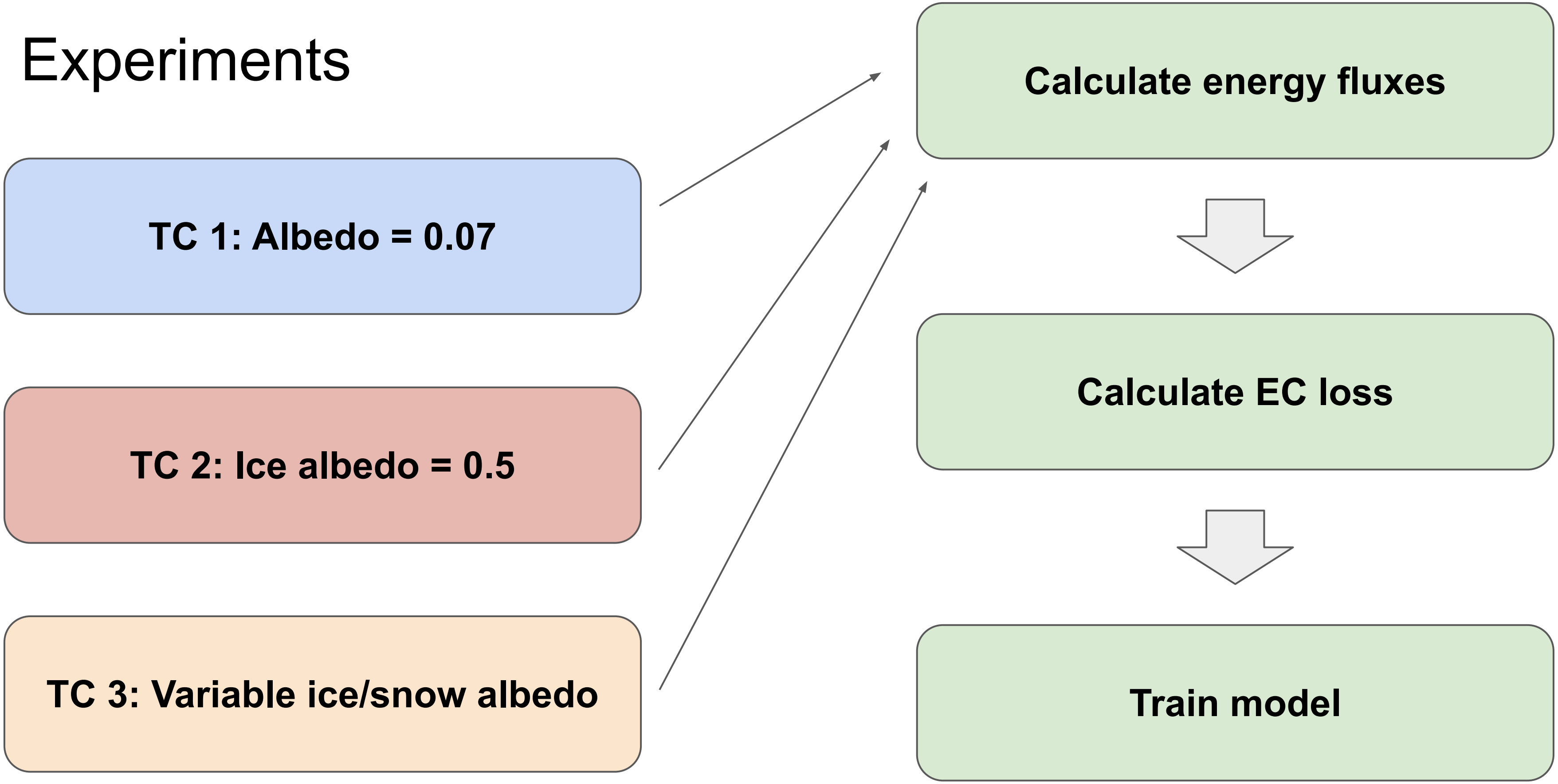
$$\text{Ice albedo:}\begin{cases} h_i > 0.5\ \text{m} \rightarrow \begin{cases} \alpha_i = 0.6 \rightarrow T_i \le -5^{\circ}\text{C} \\ \alpha_i = 0.44 - 0.032T_i \rightarrow 0^{\circ}\text{C} > T_i > -5^{\circ}\text{C} \\ \alpha_i = 0.44 \rightarrow T_i = 0^{\circ}\text{C} \end{cases} \\ h_i \le 0.5\ \text{m} \rightarrow \alpha_i = 0.08 + 0.44h_i^{0.28} \end{cases} \qquad \text{(eq. 9)}$$

$$\text{Snow albedo:}\begin{cases} \alpha_s = 0.7 \rightarrow T_s \le -5^{\circ}\text{C} \\ \alpha_s = 0.50 - 0.04T_s \rightarrow 0^{\circ}\text{C} > T_s > -5^{\circ}\text{C} \\ \alpha_s = 0.50 \rightarrow T_s = 0^{\circ}\text{C} \\ \alpha_s = \alpha_s\left(T_s\right) - \left(\dfrac{0.1 - h_s}{0.1}\right)\left[\alpha_s\left(T_s\right) - \alpha_i\left(T_i, h_i\right)\right] \rightarrow h_s \le 0.1\ \text{m} \end{cases}$$

(eq. 10)



Experiments



PART 2---Bayesian Optimization of hyper parameters

Bayesian Optimization Algorithm

for $t = 1, 2, \ldots$ **do**
    Find $\mathbf{x}_t$ by optimizing the acquisition function over the GP: $\mathbf{x}_t = \operatorname{argmax}_{\mathbf{x}} u(\mathbf{x}|\mathcal{D}_{1:t-1})$.
    Sample the objective function: $y_t = f(\mathbf{x}_t) + \varepsilon_t$.
    Augment the data $\mathcal{D}_{1:t} = \{\mathcal{D}_{1:t-1}, (\mathbf{x}_t, y_t)\}$ and update the GP.
end for

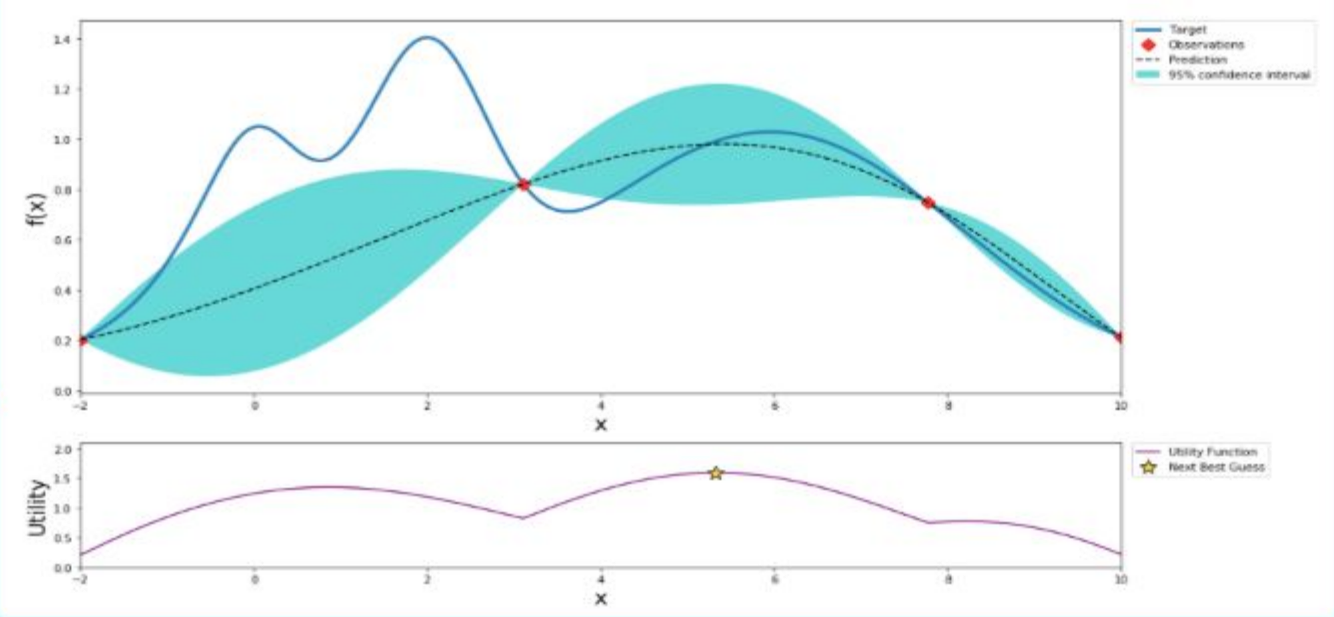
Acquisition function : Gaussian Process **Upper Confidence Bound** (GP-UCB)

$$u(x;\lambda)=\mu(x)+\lambda\sigma(x)$$

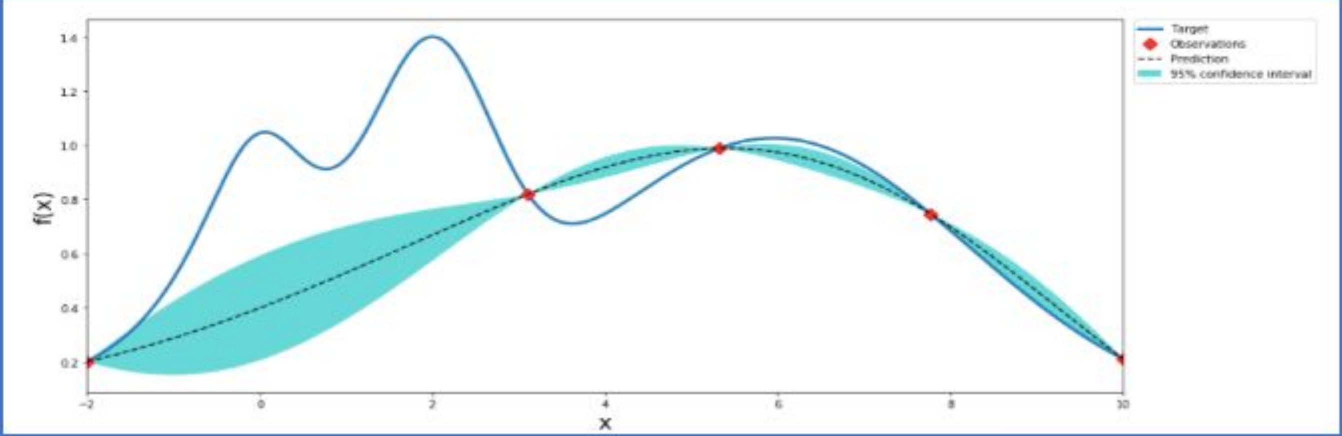
contains explicit exploitation ($\mu(x)$) and exploration ($\sigma(x)$) terms. Concretely, UCB is a weighted sum of the expected performance captured by $\mu(x)$ of the Gaussian Process, and of the uncertainty $\sigma(x)$, captured by the standard deviation of the GP.

Example: One step of iteration

Iteration n-1



Iteration n



Apply Bayesian Optimization in Lake Models

----------from bayes_opt import BayesianOptimization, UtilityFunction---------

- **Epochs** --number of max training epochs in (10,50) discrete
- **batch_size** --batch size in SGD in (1,6) discrete
- **learning_rate** in (0.01,1)
- **elam** --loss weight in (0.002,0.01)
- **patience** --patience in early stopping in (2,5) discrete
- **npic** --stride size in (10,30) discrete
- **bidirectional flag** --whether LSTM needs to be Bidirectional or not in (0,1) discrete
- **n_layers** in (1,5) discrete
- **State_size** --hidden state in (5,10) discrete

Results--No ice/snow

- -----Best Parameters----
- batch_size: 150,

  bidirectional_flag: 1,

  elam: 0.005,

  epochs: 37,

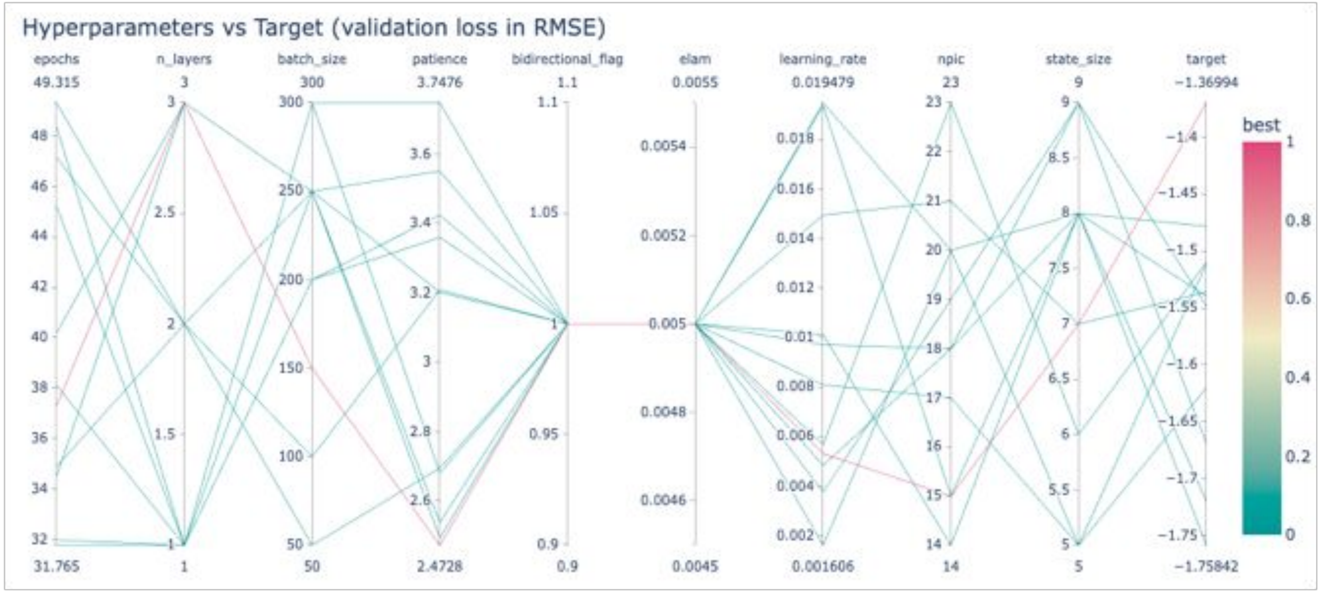
  learning_rate: 0.01,

  n_layers: 3,

  npic: 15,

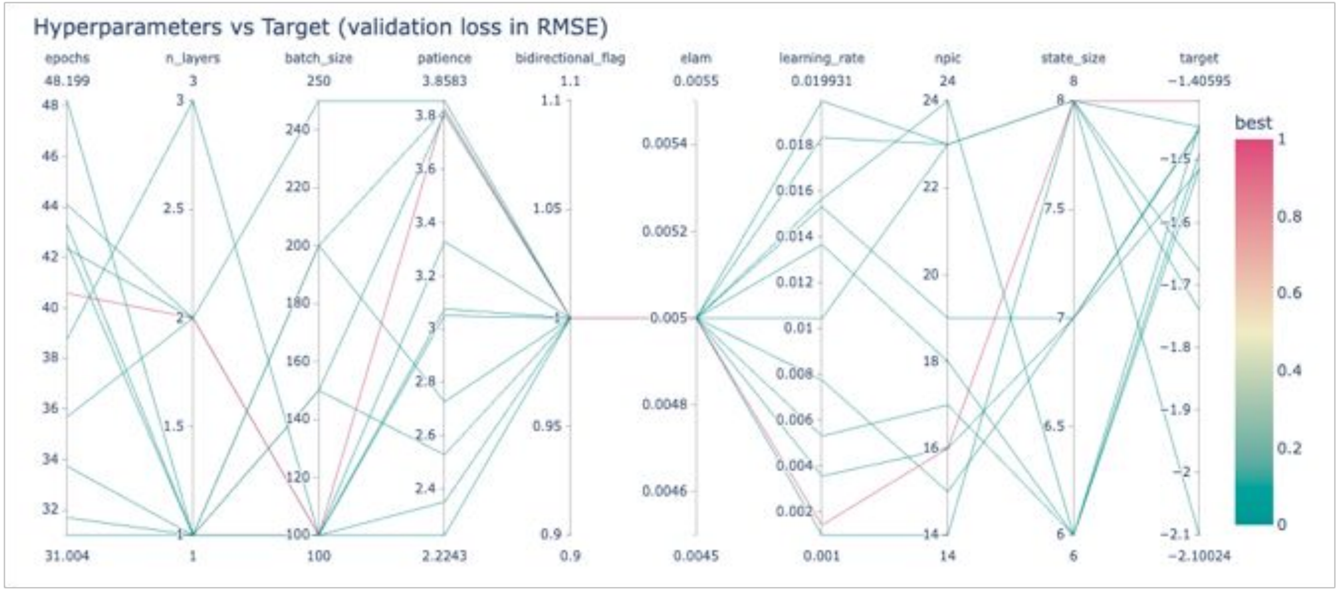
  patience: 2,

  state_size: 7



Results--With ice

- -----Best Parameters----
- batch_size: 100,
  bidirectional_flag: 1,
  elam: 0.005,
  epochs: 41,
  learning_rate: 0.001,
  n_layers: 2,
  npic: 16,
  patience: 4,
  state_size: 8



Results--With ice and snow

- -----Best Parameters----
- batch_size: 200,

  bidirectional_flag: 1,

  elam: 0.005,

  epochs: 46,

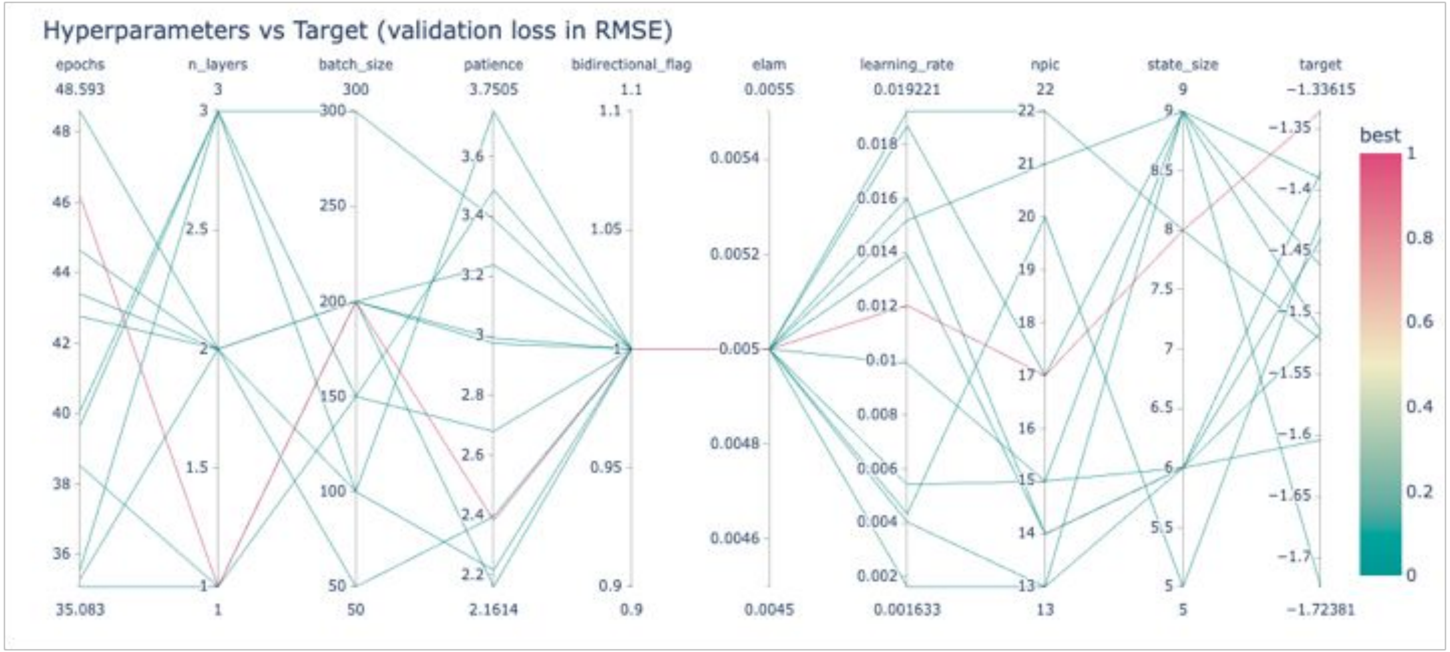
  learning_rate: 0.01,

  n_layers: 1,

  npic: 17,

  patience: 2,

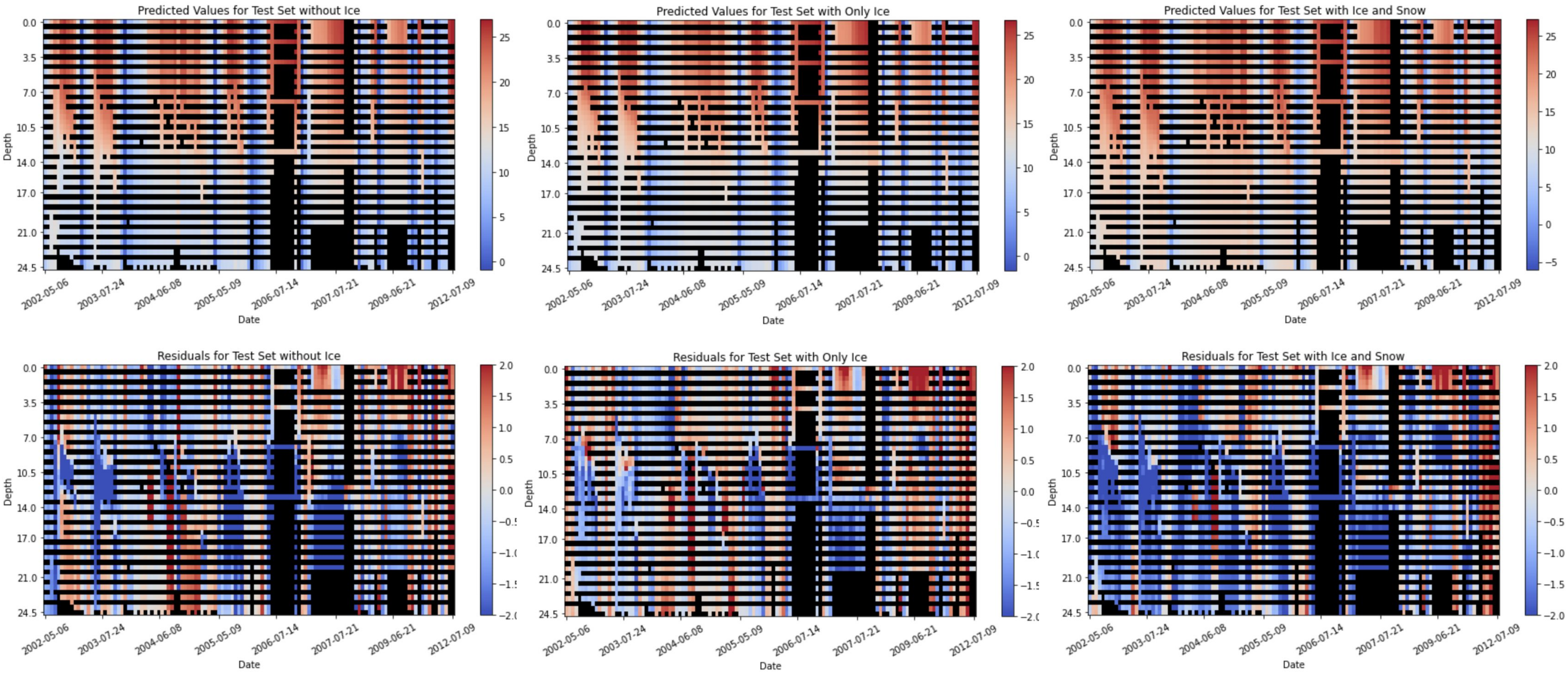
  state_size: 8



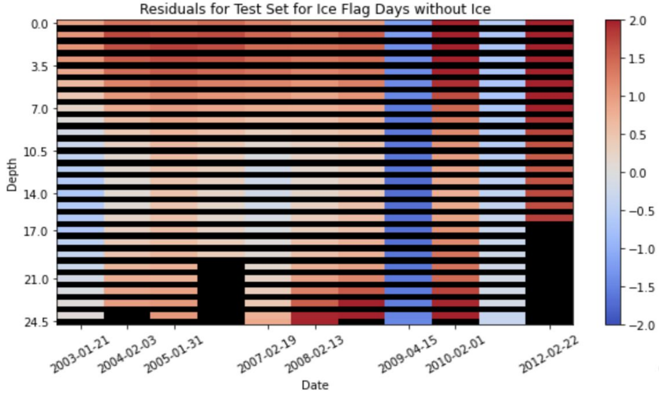
RMSE

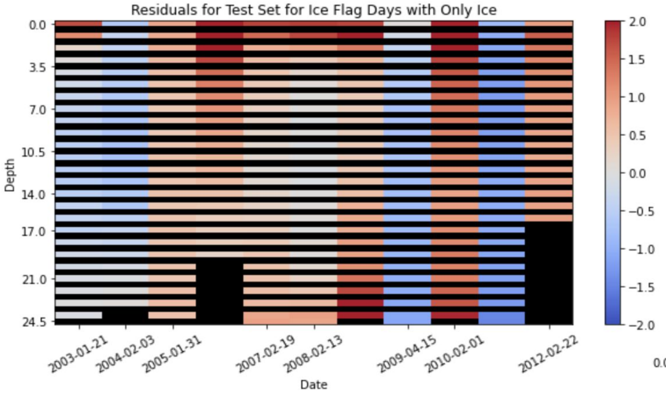
No ice/snow	1.525106093657538
Only with ice	1.2251561973918887
With ice and snow	1.7311332822880652

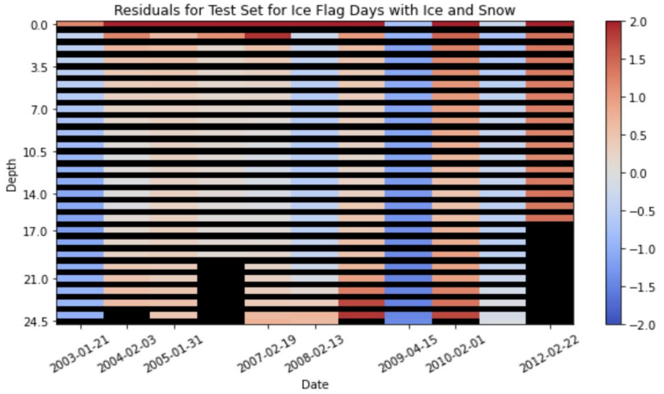
Visualization of Fine-Tuned Models



Ice Flag Days







Conclusions & Future Work

Our latest visualizations show that model with only ice albedo performed the best, while the model with ice+snow albedo performed the worst.

However, these results may change when re-running the code, depending on the selected LSTM parameters.

Further Bayesian optimization is needed, albeit more time consuming, since our tuned models performed worse than in the basic starter code.

While temperature differences between experiments are largely influenced by LSTM parameters, we have seen that including ice/snow albedos slightly cools the top of the lake for ice flag days.

To improve estimation of ice+snow albedos, we should consider other physical processes and obtain more observations (e.g. for true ice/snow thickness and temperature).

References

https://nsidc.org/cryosphere/seaice/processes/albedo.html

https://www.jlimnol.it/index.php/jlimnol/article/view/jlimnol.2014.903/647

https://www.cleanlakesalliance.org/mendota-freeze-contest/

http://www.sgreen.us/pmaslin/limno/strat.html