Deep Learning on a Novel Ising Model to Study Arctic Sea Ice Dynamics

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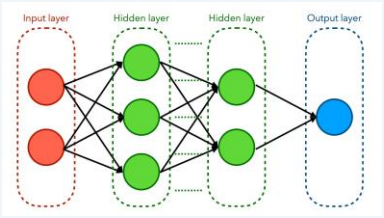
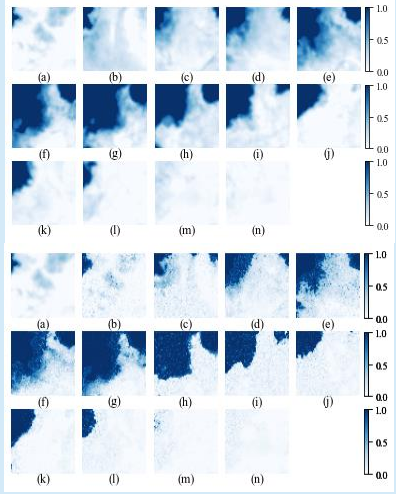
Research Questions



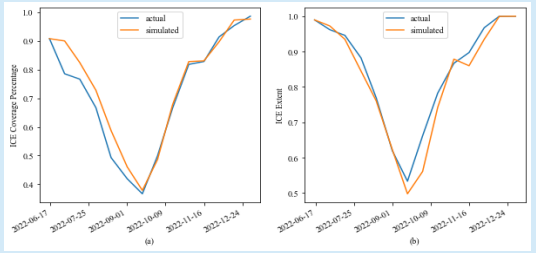
Credit: towardsdatascience.com

- Can classical physics identify the fundamental mechanism governing Arctic sea ice dynamics, a crucial indicator of global climate change?
- When combined with modern deep learning methods, how much explanatory power will the 100-year-old Ising Model in statistical physics have for this task?

Data Analysis & Results



2022 Actual (top) vs. Simulated (bottom)



- The simulated sea ice images display striking similarity with the actual configurations.
- The simulated ice coverage percentage and ice extent closely match the real data.

Methodology

Classical Ising model: $H(\sigma) = -\sum_{<i,j>} J_{ij}\sigma_i\sigma_j - \sum_i B_i\sigma_i$ *with* $P_\beta(\sigma) = \frac{e^{-\beta H(\sigma)}}{Z_\beta}$

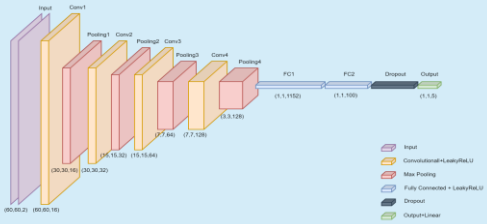
New model features: ***Continuous spin values*** *and* ***Inertia factor***

$$P_{flip} = e^{-\beta(H_\nu - H_\mu + I|\sigma_i' - \sigma_i|)}$$

The system Hamiltonian change before and after the flip

The energy needed to overcome the inertia of the spin change

Convolutional Neural Network (CNN)



- A CNN is trained with samples generated by Metropolis Monte Carlo simulation to predict Ising parameters.

Discussions & Conclusions

	6/16 to 7/1	7/1 to 7/16	7/16 to 8/1	8/1 to 8/16	8/16 to 9/1	9/1 to 9/16	9/16 to 10/1	10/1 to 10/16	10/16 to 11/1	11/1 to 11/16	11/16 to 12/1	12/1 to 12/16	12/16 to 1/1/2023
J	2.1	2.6	2.9	2.6	2.5	2.5	2.3	2.4	3.5	2.1	2.6	2.3	2.8
B0	2.9	0.5	5.1	7.7	2.8	4.0	-7.1	-12.1	-30.0	-9.4	-18.6	-11.5	-28.0
Bx	3.5	-16.9	-14.9	2.7	-10.6	-7.6	-0.7	-4.1	-28.7	6.8	-1.9	-4.9	-4.3
By	-9.0	6.5	-4.7	3.4	-3.9	1.7	4.7	-6.2	-12.8	-34.5	-12.0	4.3	11.6
I	7.6	10.4	12.1	10.6	9.8	10.2	9.2	9.7	15.4	8.5	11.2	9.3	11.9

- When combined with Convolutional Neural Networks, the continuous spin Ising model with the novel inertia factor proves to have extraordinary power to replicate and explain sea ice dynamics.
- The CNN predicted Ising parameters reveal the substantial impact of the external forces on sea ice dynamics.
- This study validates the vast potential of pairing classical physics with cutting-edge technologies in interdisciplinary studies including climate change research.