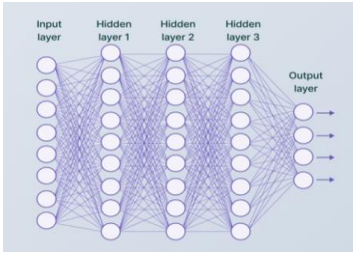
Deep Learning on a Novel Ising Model to Study Arctic Sea Ice Dynamics

Ellen Wang, Horace Mann School, Bronx NY USA (Project ID: PHYS-432)

Q1: Research Question



- Can classical physics identify the fundamental principles underlying the Arctic sea ice dynamics, a crucial indicator of 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?

Q2: Methodology

Classical Ising model: $H(\sigma) = -\sum_{<i,j>} J_{ij}\sigma_i\sigma_j - \sum_i B_i\sigma_i$

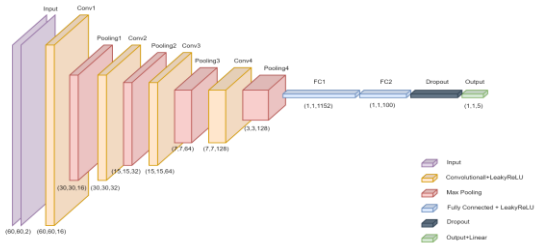
Novel model features for Metropolis Monte Carlo simulation:

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

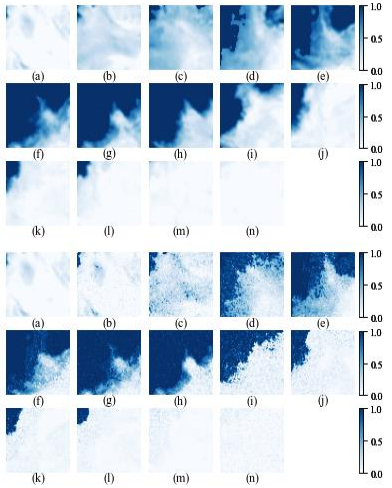
The system Hamiltonian before and after the flip of continuous spin values

The energy needed to overcome the inertia of the spin change, a term representing the natural resistance to state change, or the latent heat needed for the water/ice phase transition in classical thermodynamics.

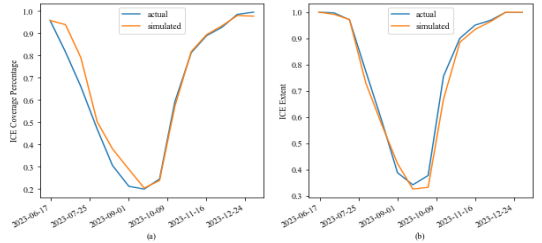
Architecture of Convolutional Neural Network:



Q3: Data Analysis & Results



2023 Actual (top) vs. Simulated (bottom)



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

Q4: Interpretation & 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
J	2.9	2.1	2.3	2.6	2.6	2.4	2.6	2.7	2.2	2.4	2.5	2.4	1.5
B0	9.2	4.7	6.1	5.6	4.5	0.8	-3.9	-14.6	-15.5	-14.2	-15.9	-16.4	-3.4
Bx	-0.9	-0.8	-5.1	-4.6	-14.3	-2.0	2.2	-6.2	-9.0	-16.7	-9.2	-3.3	-0.2
By	-5.3	-1.0	-6.3	3.3	-15.3	4.8	-2.2	-5.5	-11.4	1.1	-6.1	0.5	2.7
I	12.7	7.9	10.3	10.9	10.6	9.3	10.7	9.8	8.5	9.7	9.8	9.1	4.8

- When trained with Convolutional Neural Network (CNN), 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 in climate change research.
- This study validates the vast potential of classical physics and modern deep learning in interdisciplinary research.