Predicting and Interpreting Atmospheric Blocking using Convolutional Neural Networks and Explainable-AI Techniques

William Stevens, Yanjun Hu, Anh Nhu, Henry Peng, Yuke Zhang, and Lei Wang
Department of Earth, Atmospheric and Planetary Sciences, Purdue University

Motivation

- Atmospheric blocking occurrences in the midlatitude are often associated with extreme weather events, such as heatwaves, droughts, and cold spells. Forecasting such events beyond synoptic timescales is challenging. It would be very valuable to identify precursor patterns of blocking through a data-driven machine learning approach.

Blocking Characteristics

- High-pressure system in the jet stream that is quasi-stationary and traps the air within its “heat dome”, leading to sustained surface temperature extremes.

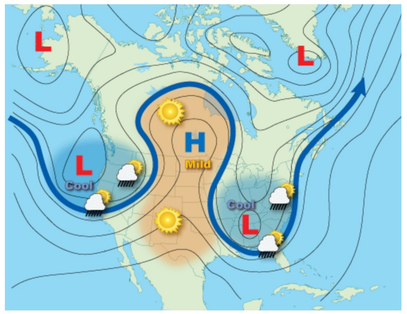

Fig. 1a: Omega Blocking Formation

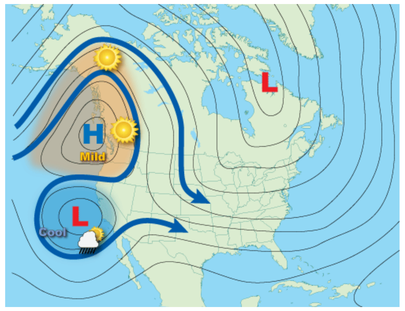

Fig 1b: Dipole Blocking Formation

- Multiple variables correlate strongly with blocking:
  - Potential vorticity
  - Geopotential height
  - Stream function
  - Local wave activity

Machine Learning Architecture

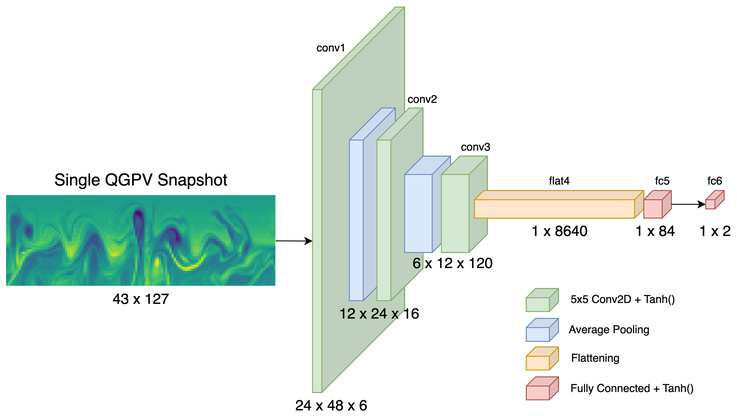

Fig. 2: 4-layer CNN for Precursor Pattern Prediction

Blocking Prediction - Experimental Results

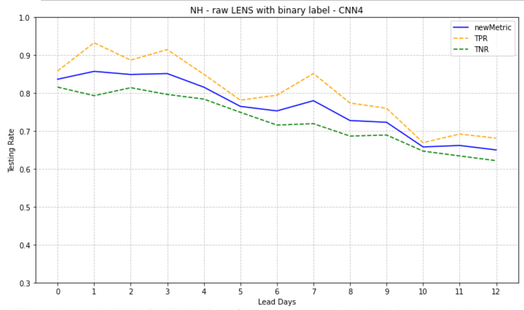

Fig. 3a: LENS Z500 (Geopotential Height) Model

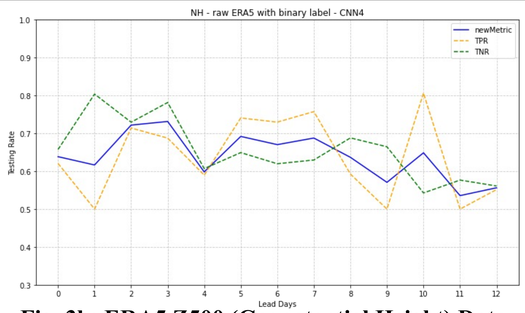

Fig. 3b: ERA5 Z500 (Geopotential Height) Data

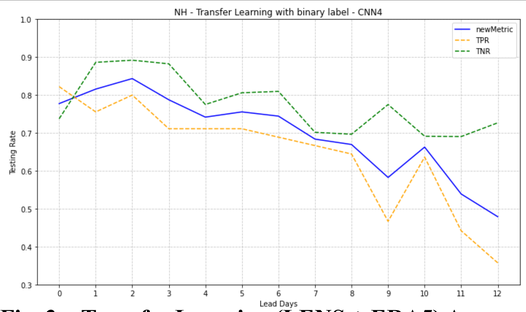

Fig. 3c: Transfer Learning (LENS + ERA5) Approach

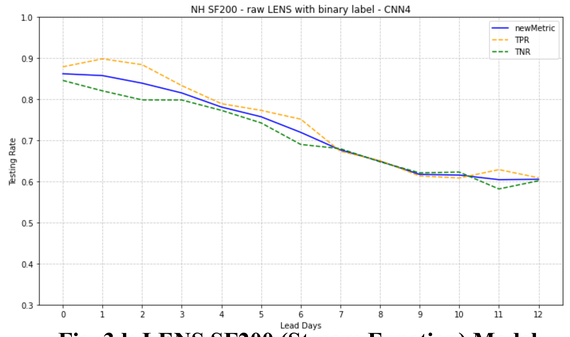

Fig. 3d: LENS SF200 (Stream Function) Model

- Model accuracy predicts blocking easily when trained on LENS data and with shorter lead days. This high accuracy and the steady decrease indicates that precursor patterns do exist in Z500 and SF200 data, and that the trained CNN model can identify them.
- Transfer learning approach indicates promising applicability to improving training on reanalysis data.

Determining Physical Consistency with Explainable-AI (XAI)

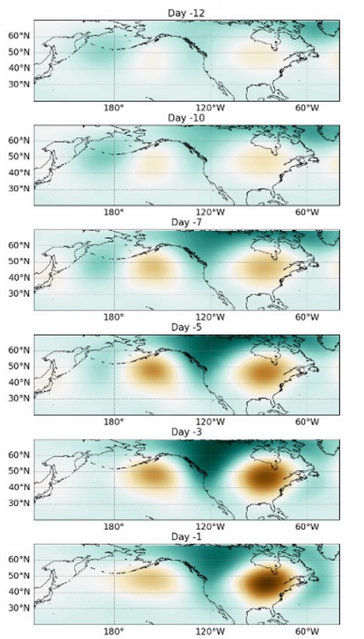

Fig. 4a: Composite LENS Z500 Anomalies

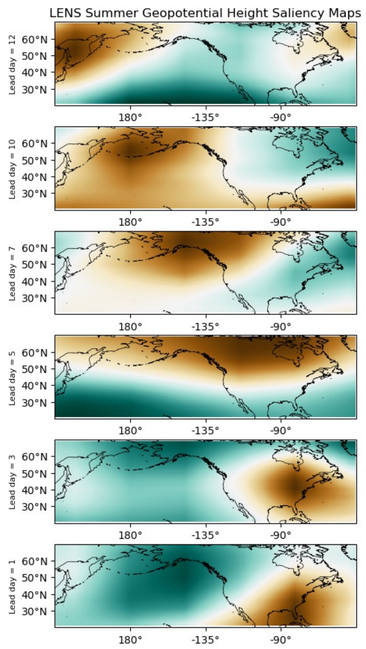

Fig. 4b: LENS Z500 Saliency Maps

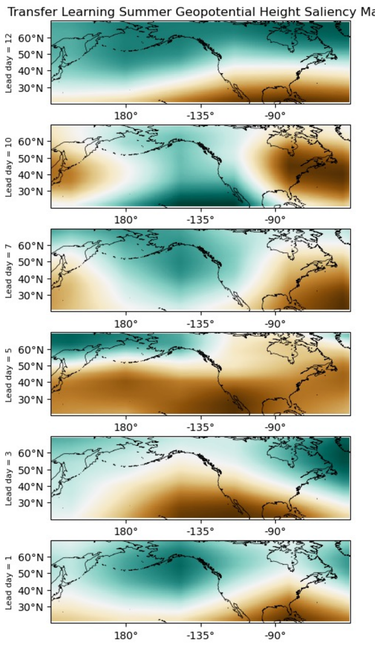

Fig. 4c: Transfer Learning Saliency Maps

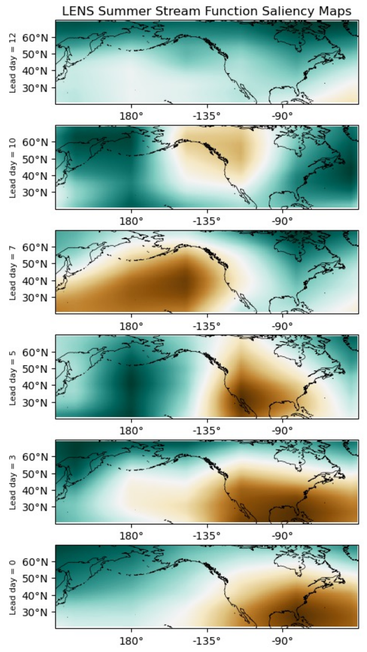

Fig. 4d: LENS SF200 Saliency Maps

- Saliency maps, as detected through Grad-CAM XAI, are consistent with physical understanding of blocking indicators up to 12 lead days.
- Z500 saliency maps match the corresponding composites of the original data for lead 1, 3, and 5 days, but not for 7, 10, and 12 days. This indicates the possibility that after 7 lead days, other nonlinear processes are playing an important role.
- Future work will adopt a multi-variable approach (i.e., training a model jointly on geopotential height, stream function, potential vorticity, local wave activity) to enhance physical understanding and to further improve prediction capability.