Viewing Climate Signals through an AI Lens

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Surface temperature change under the RCP8.5 future climate scenario between 2070-2099 and 1920-1939 averaged over 29 different climate models.

Two Sources of Uncertainty

- structural model uncertainty/disagreement (i.e. simulating the physics)
- internal variability (i.e. climate noise)
Climate Change in the 21st Century: a signal-to-noise problem

How can we tell which changes are the **SIGNAL** and which are the **NOISE** in our one observed earth?
Train ANN to predict the year of a map

*Training and testing on CMIP5 climate model output

Barnes et al. (2019; GRL)
Barnes et al. (2020; JAMES)
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Train ANN to predict the year of a map

(a) temperature

(b) temperature, global mean removed

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What did the ANN learn?

ANN must learn regional signals that are “reliable” indicators of the year

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What to expect from ANN visualization

Not a perfect view, but better than the “black box”.
Two types of visualization tools

**Type A: Feature Visualization**

**Philosophy:** Seek to understand all internal components of ANN.

Seek to understand the meaning of all intermediate (blue) nodes.
Two types of visualization tools

Type B: Attribution / Explaining Decisions
Philosophy: Understand the ANN’s overall decision making for specific input.

Seek to understand the meaning of the entire algorithm - for a specific input.
Do NOT worry about meaning of intermediate (blue) nodes.
A visualization tool: Layerwise Relevance Propagation

Prediction of 1 sample

Montavon et al. (2017), Pattern Recognition; Montavon et al. (2018), Digital Signal Processing
A visualization tool: Layerwise Relevance Propagation

Montavon et al. (2017), Pattern Recognition; Montavon et al. (2018), Digital Signal Processing
A visualization tool: Layerwise Relevance Propagation

Montavon et al. (2017), Pattern Recognition; Montavon et al. (2018), Digital Signal Processing
Example use of LRP

Task: Decide whether there is a horse in a given image.

Decision making strategy: use visualization tools to determine the strategy the network used to make a decision
Example use of LRP

**Task:** Decide whether there is a horse in a given image.

**Decision making strategy:** use visualization tools to determine the strategy the network used to make a decision.
What does this mean for earth science research?

1. Identifying problematic strategies (i.e. right answer for the wrong reasons)
2. Designing the machine learning methodology
3. Building trust
4. Discovering new science!
   - When our machine learning method is capable of making a correct prediction we can explore why
Indicators of climate change: temperature

Which regions are relevant for correctly predicting a specific year?
Indicators of climate change: temperature

Which regions are relevant for correctly predicting a specific year?

Barnes et al. (2020; JAMES)
Indicators of climate change: temperature

Barnes et al. (2020; JAMES)
Indicators of climate change: precipitation

Barnes et al. (2020; JAMES)
LRP for Observations

- Largest anomalies are not necessarily the most reliable indicator regions
- ANN focuses on the Southern Ocean and the southern coasts of South America and Africa
Our Current Projects Using LRP

1. Indicator patterns of forced change
2. Multi-year prediction
3. Subseasonal-to-seasonal prediction
4. Eddy-mean flow interactions
5. Human impacts on the land surface from Landsat imagery
Wrap-up

- The most basic of neural networks can be viewed as nonlinear regression - climate scientists are well-equipped to think about this architecture.

- Artificial neural networks are no longer black boxes - tools exist to help visualize their decisions. This is a game changer for their use in geoscience research.

- ANNs can be used for more than just prediction. The science can be what the network learns, rather than the prediction. Get creative combining your science with these tools!
CSU papers in this area

Extra slides
LRP Example Propagation Rules

LRP-$\alpha_1\beta_0$ (deep Taylor)

LRP-$\alpha_2\beta_1$

LRP-$\alpha_3\beta_2$

tunable parameters: $\alpha, \beta$
fixed parameters: $a, w, R$

\[ R_j = \sum_k \left( \alpha \frac{a_j w^+_j}{\sum_j a_j w^+_j} - \beta \frac{a_j w^-_j}{\sum_j a_j w^-_j} \right) R_k \]

one possible propagation rule
(there are many)