Subseasonal Forecasts of Opportunity Identified by an Explainable Neural Network

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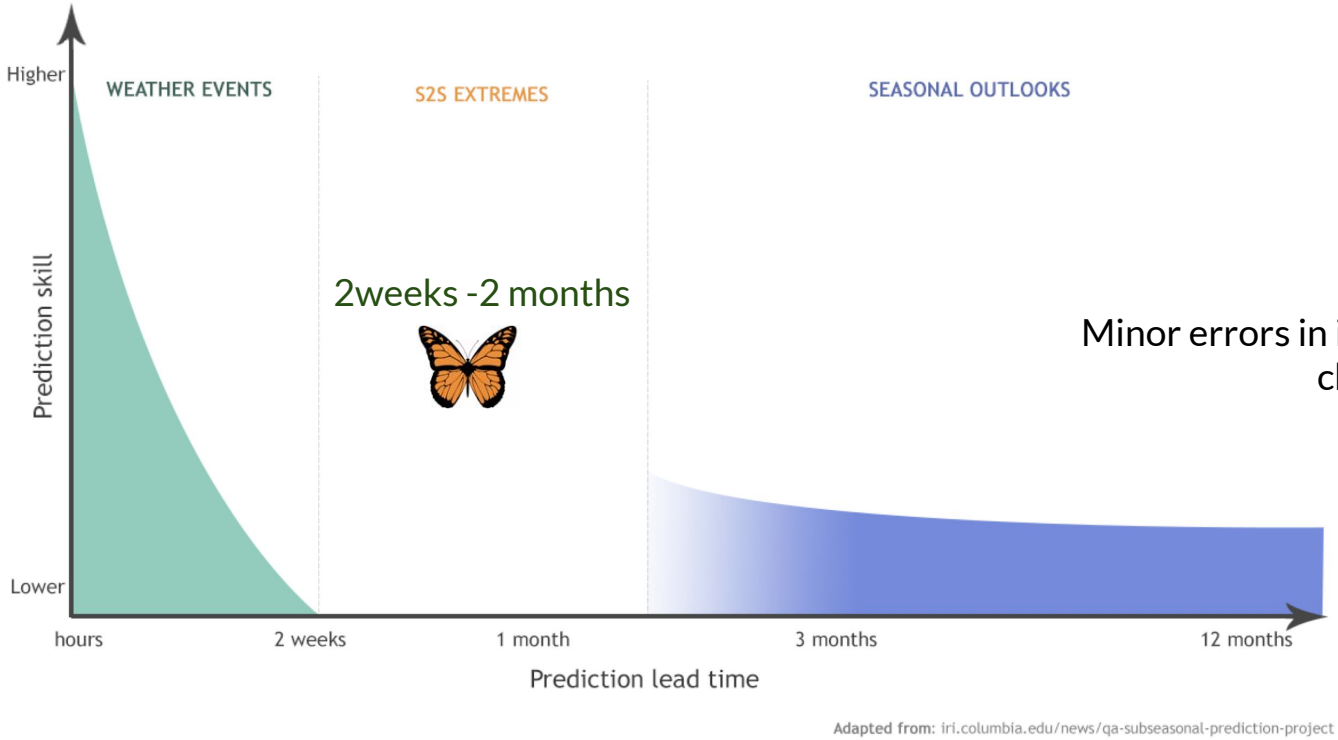
Subseasonal Timescales



Adapted from: iri.columbia.edu/news/qa-subseasonal-prediction-project

Minor errors in initial conditions lead to chaotic growth over time

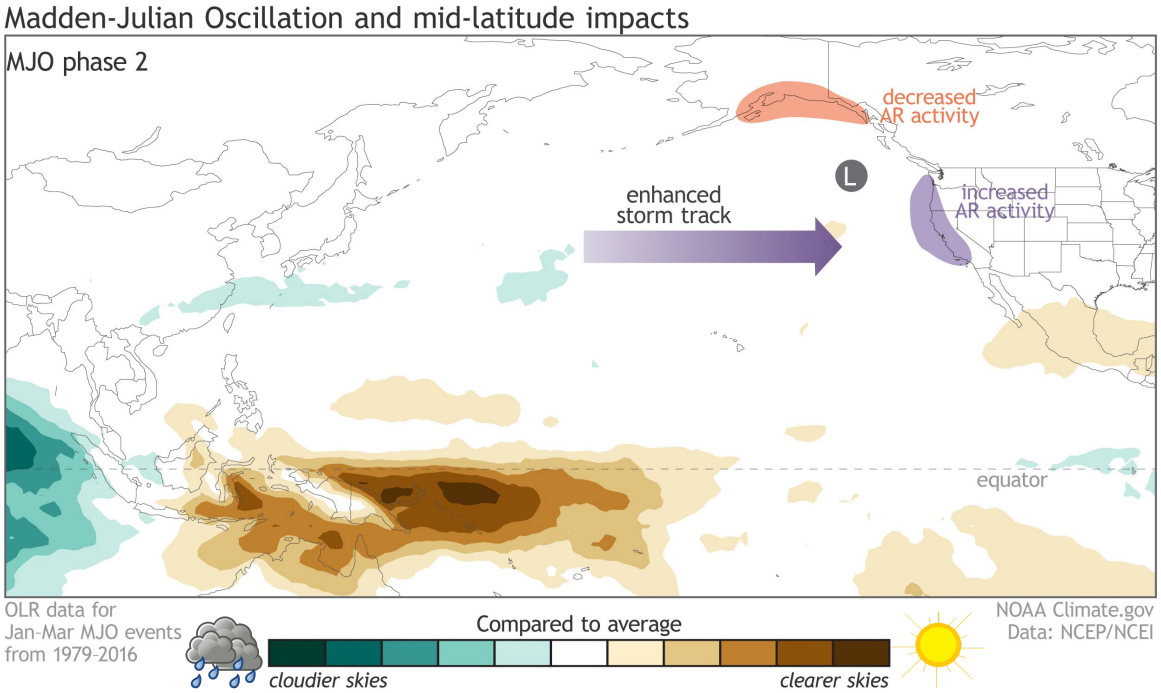
Forecasts of Opportunity

certain conditions lead to more predictable behaviour than others

Beyond the weather timescale we must look for specific states of the earth system, i.e. “opportunities”, that lead to enhanced predictable behavior.

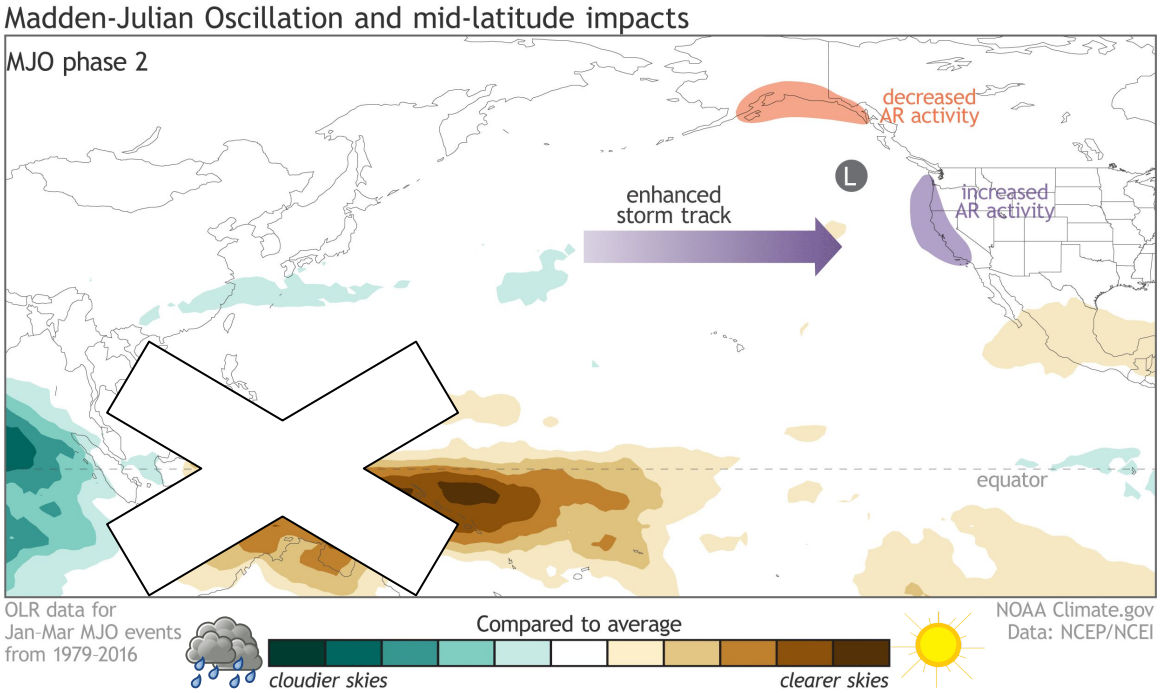
See Mariotti et al. (2020) and Albers and Newman (2019)

Madden-Julian Oscillation [MJO]



When the MJO is active, we use information about the state of the MJO today to predict what will happen to U.S. weather in the coming weeks

Madden-Julian Oscillation [MJO]

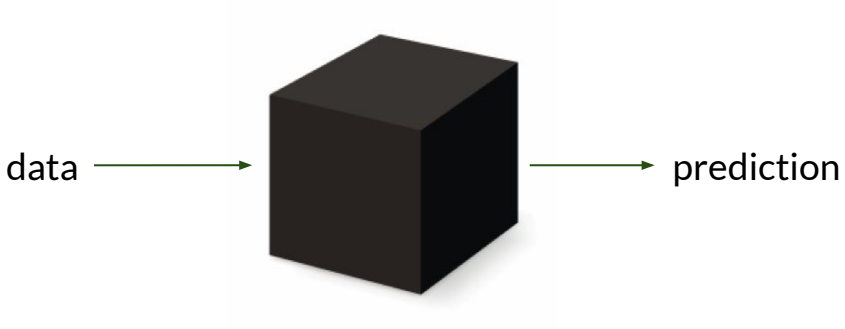


When the MJO is NOT active

Neural Networks for Subseasonal Prediction

How can we utilize neural networks to identify forecasts of opportunity for subseasonal prediction?

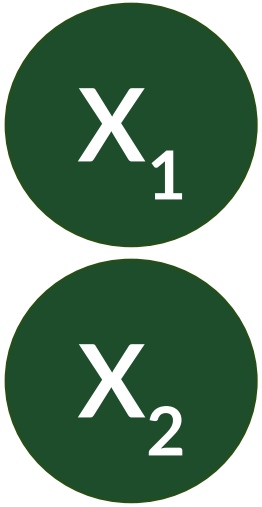
Neural Networks



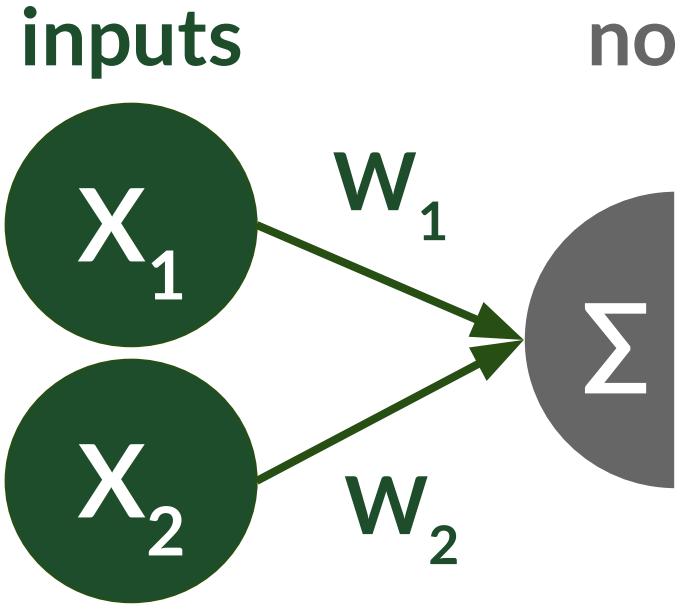
What are (artificial) neural networks?

Artificial Neural Networks [ANN]

inputs



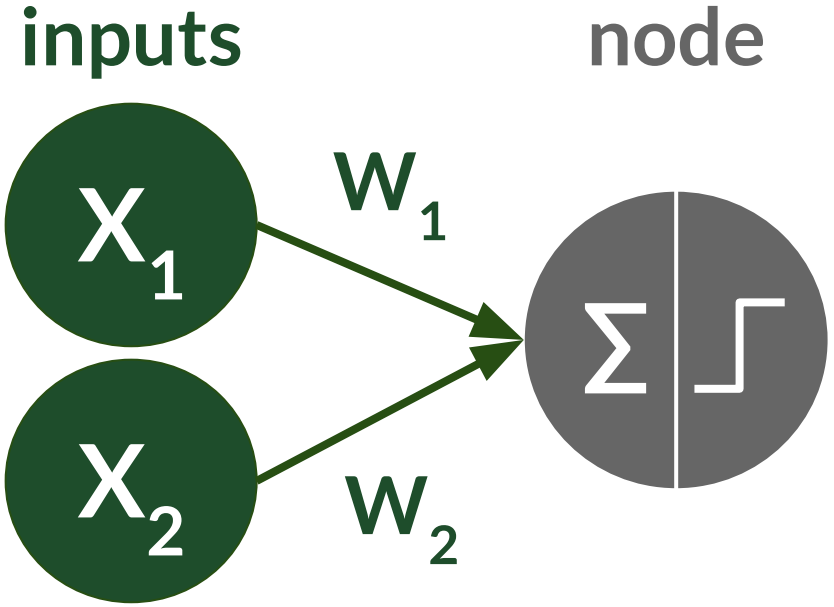
Artificial Neural Networks [ANN]



$$= X_1W_1 + X_2W_2 + b$$

linear regression!

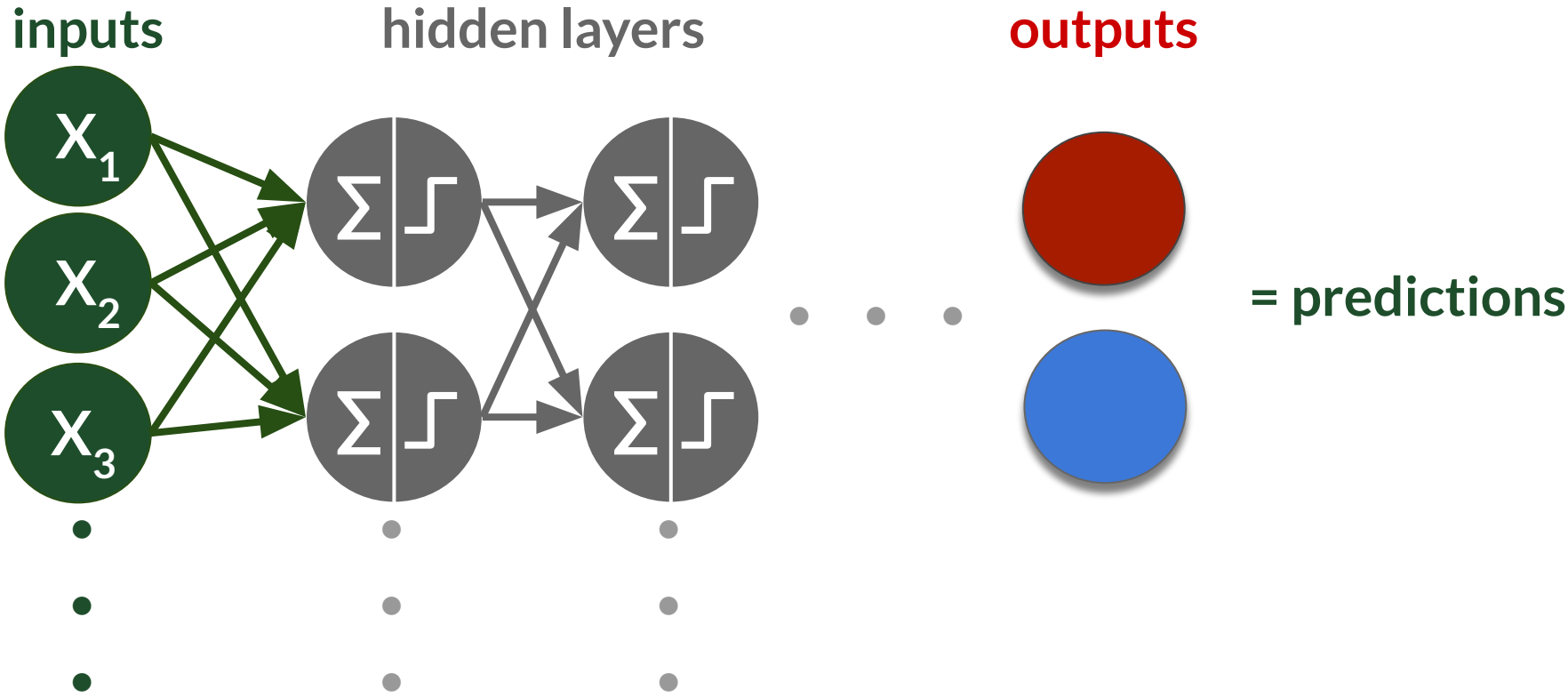
Artificial Neural Networks [ANN]



$$= f_{activation}(X_1W_1 + X_2W_2 + b)$$

- linear regression with non-linear mapping by an “activation function”
- training of the network is merely determining the weights “w” and bias/offset “b"

Artificial Neural Networks [ANN]



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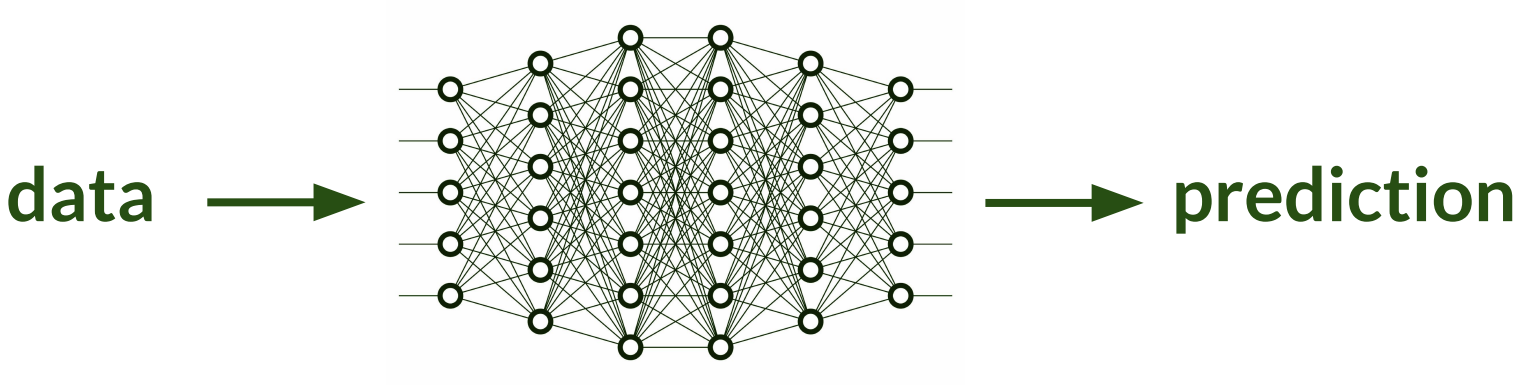
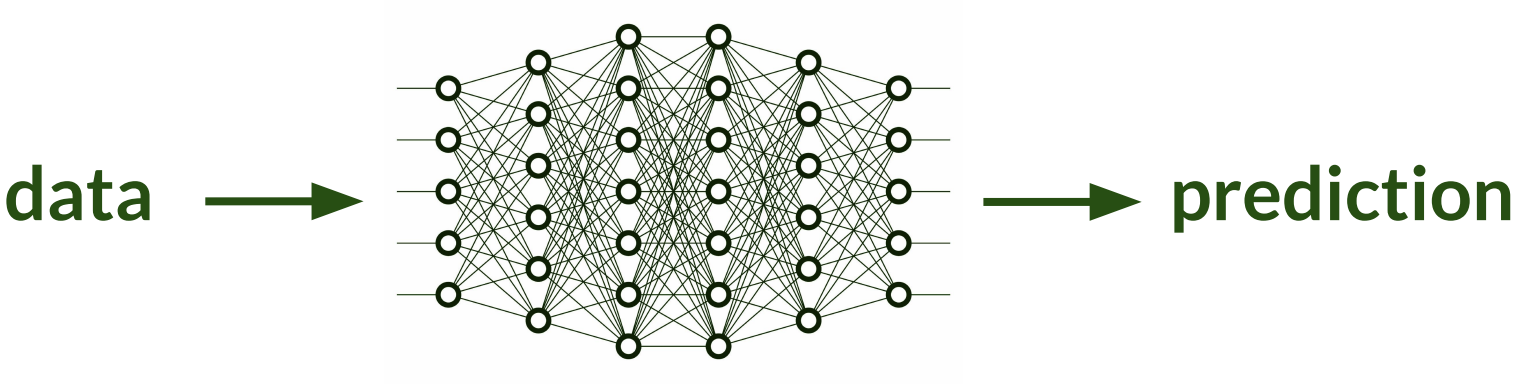


Artificial Neural Networks [ANN]



Complexity and nonlinearities of the ANN allow it to learn many different pathways of predictable behaviour

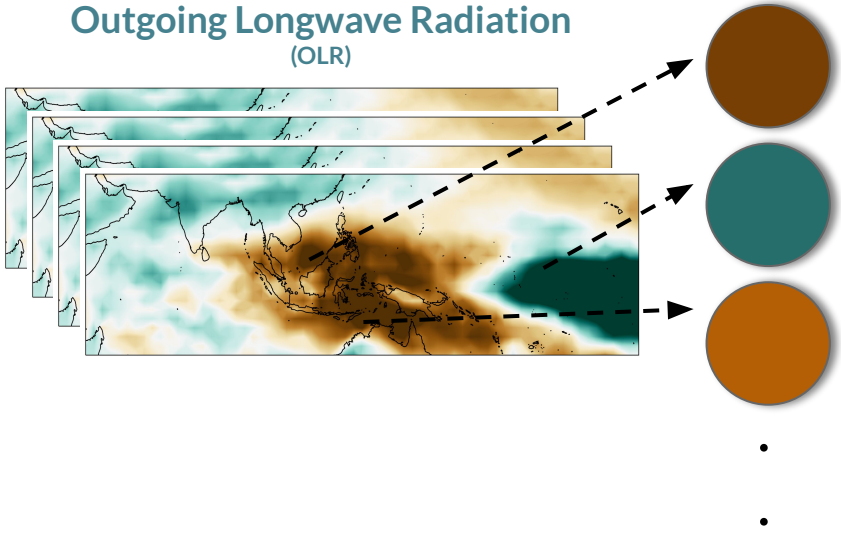
Once trained, you have an array of weights and biases which can be used for prediction on new data

Can Neural Networks identify forecasts of opportunity for subseasonal prediction?

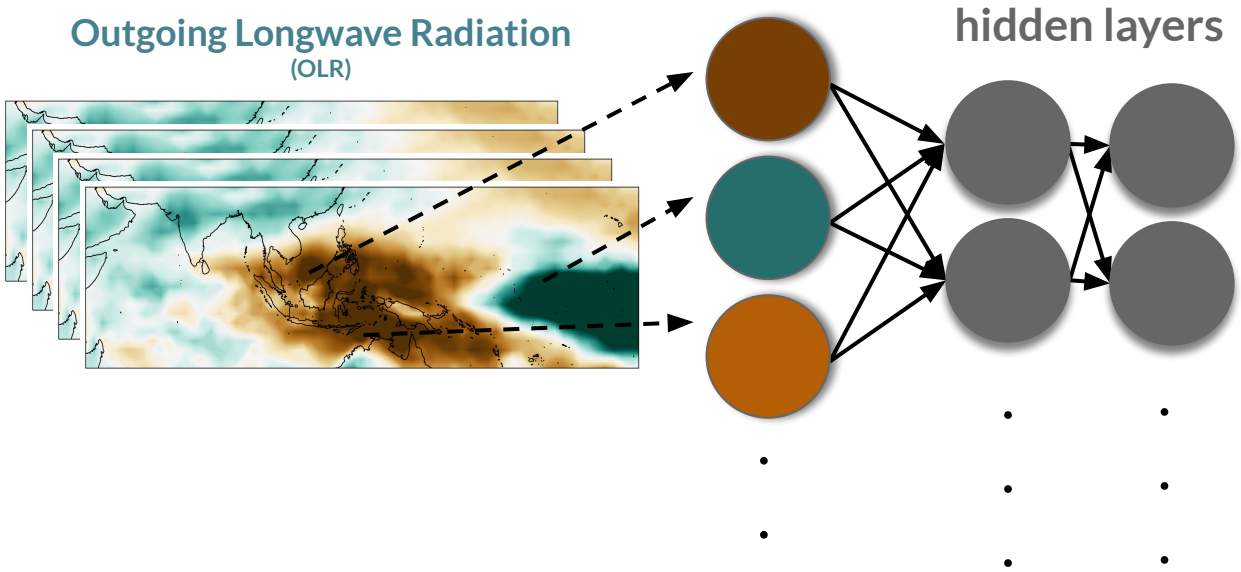
1. **When?** When do we see periods of enhanced predictability?

2. **Why?** Why is there predictability? Where is it coming from?

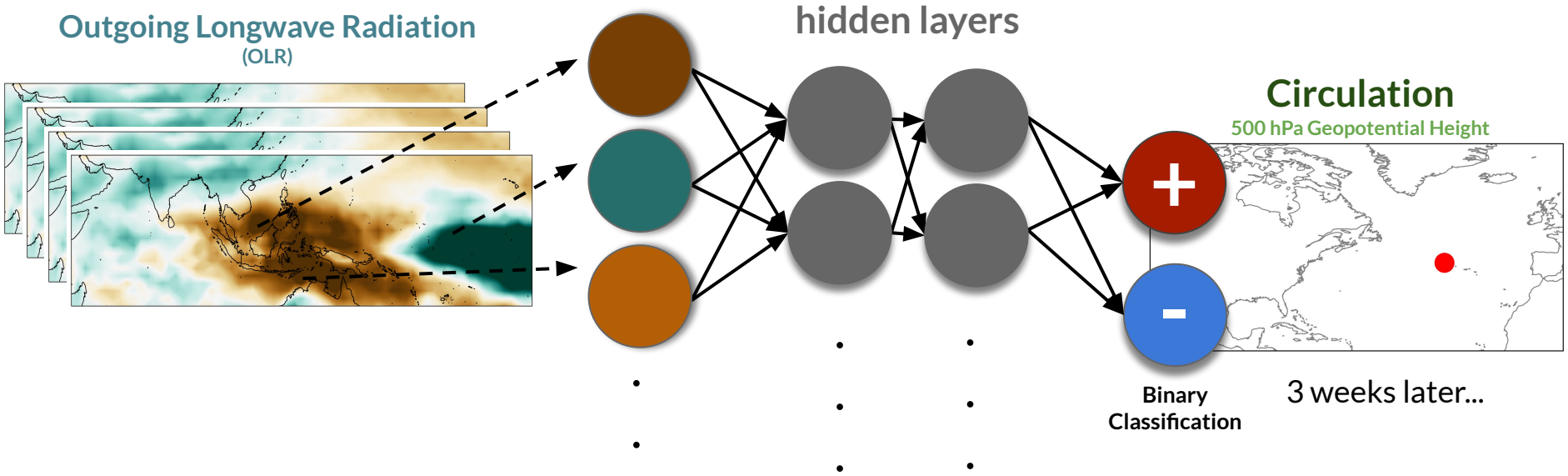
Subseasonal prediction network set-up



Subseasonal prediction network set-up



Subseasonal prediction network set-up



Forecasts of opportunity with Neural Networks

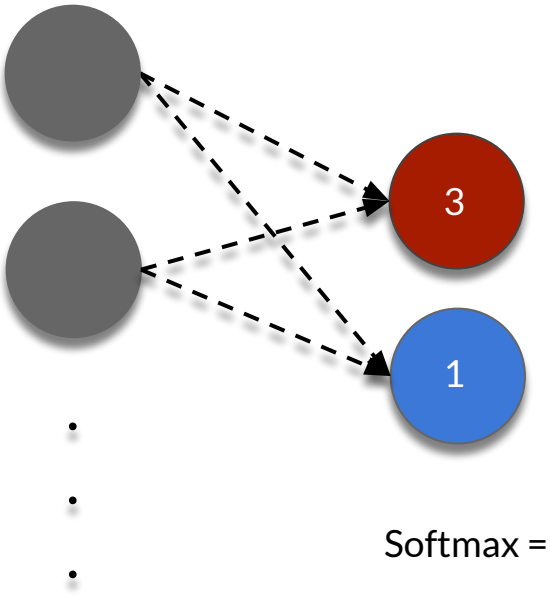
1. **When?** When do we see periods of enhanced predictability?

2. **Why?** Why is there predictability? Where is it coming from?

Model Confidence: Softmax Activation

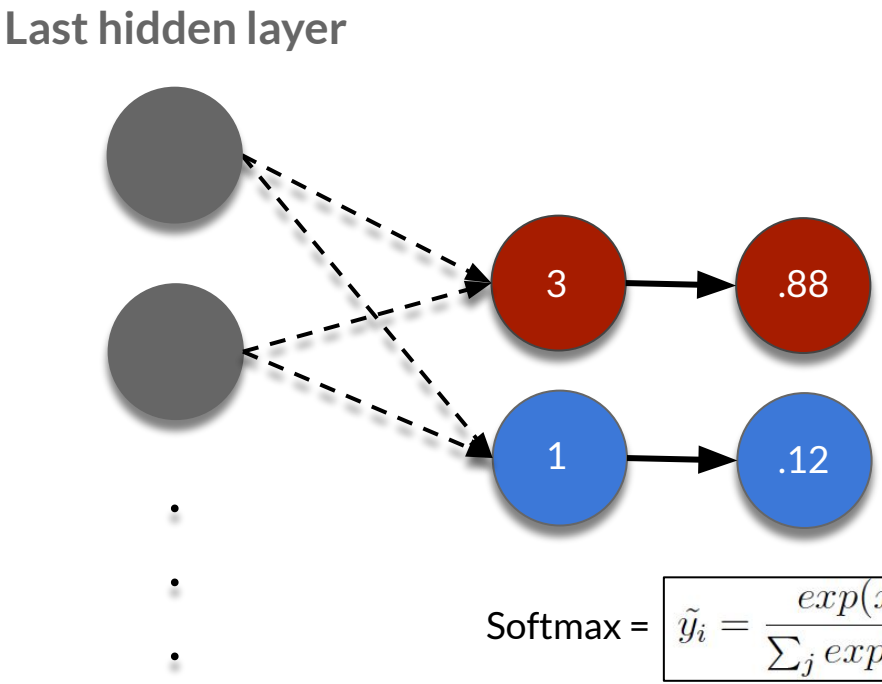
Model Confidence: Softmax Activation

Last hidden layer



Softmax = $\tilde{y}_i = \frac{exp(x_i)}{\sum_j exp(x_j)}$

Model Confidence: Softmax Activation

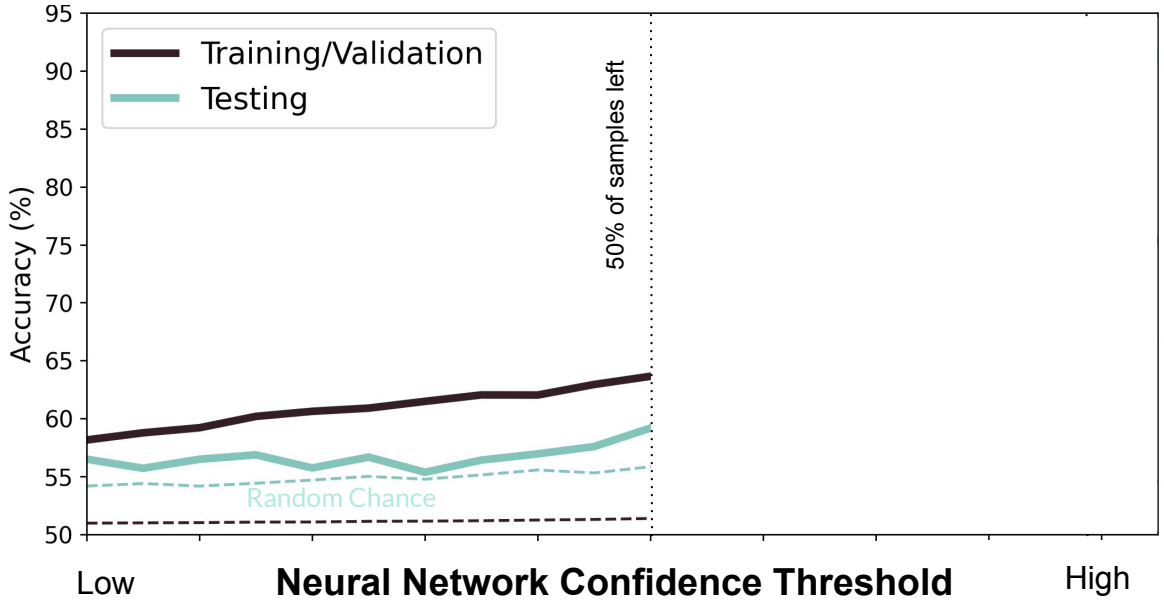


= Probability/Confidence

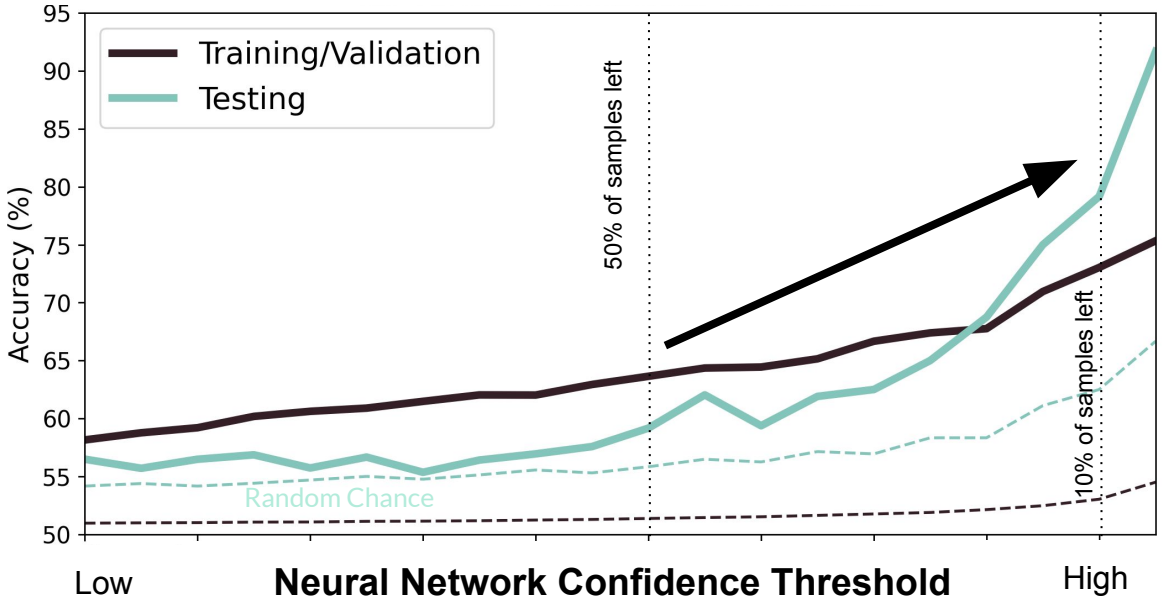
Softmax = $\tilde{y}_i = \frac{exp(x_i)}{\sum_j exp(x_j)}$

High confidence predictions may indicate Forecasts of Opportunities

Model Confidence as Forecasts of Opportunity



Model Confidence as Forecasts of Opportunity

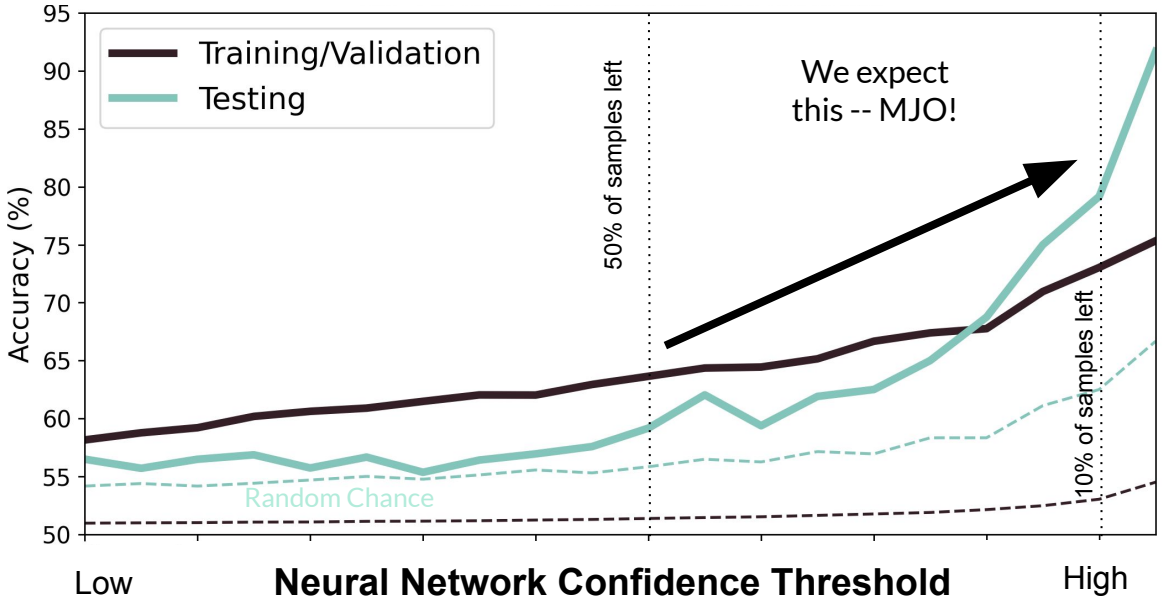


Model Confidence as Forecasts of Opportunity

As **confidence threshold** ↑s, **accuracy** ↑s

Model finds forecasts of opportunity!

Number of opportunities goes down



Forecasts of opportunity with Neural Networks

1. **When?** When do we see periods of enhanced predictability? **Model Confidence**

2. **Why?** Why is there predictability? Where is it coming from?

Forecasts of opportunity with Neural Networks

1. **When?** When do we see periods of enhanced predictability? **Model Confidence**

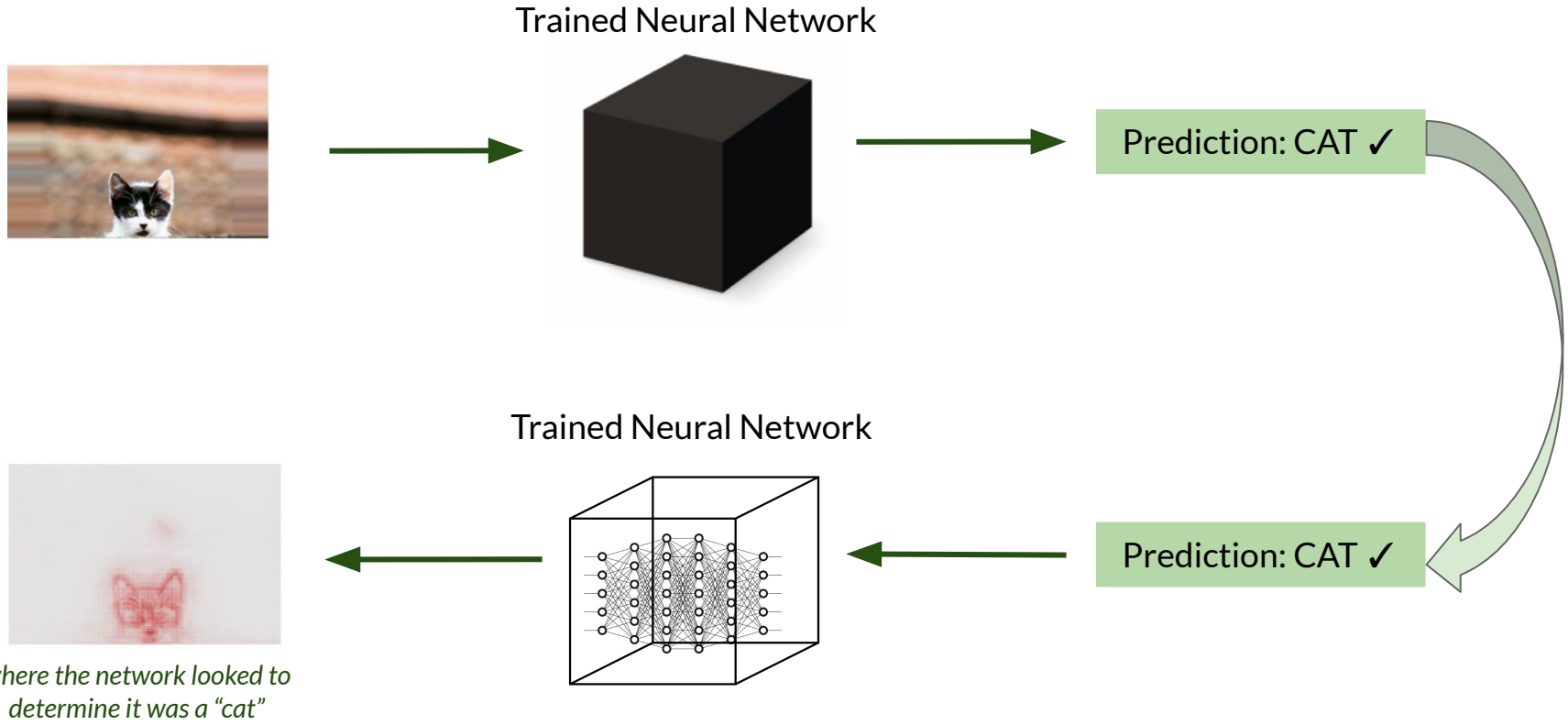
2. **Why?** Why is there predictability? Where is it coming from?

Layerwise Relevance Propagation

LRP → What did the model learn?

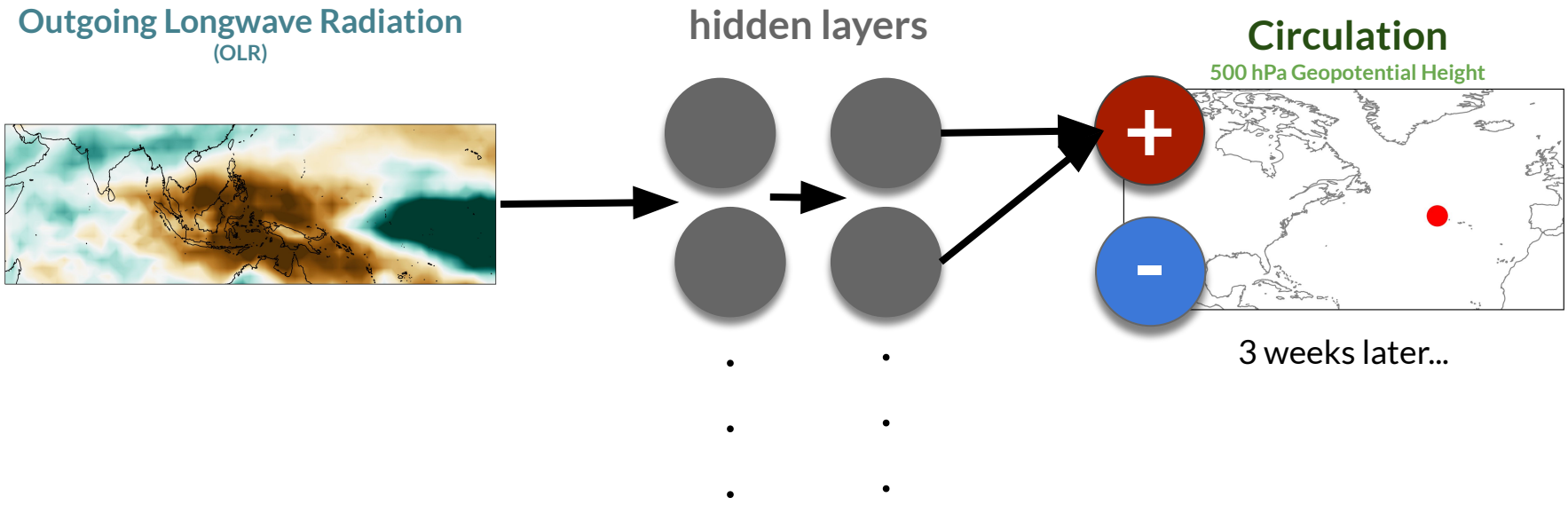
What are *relevant physical structures of OLR* in the tropics for prediction over the North Atlantic?

Layerwise Relevance Propagation

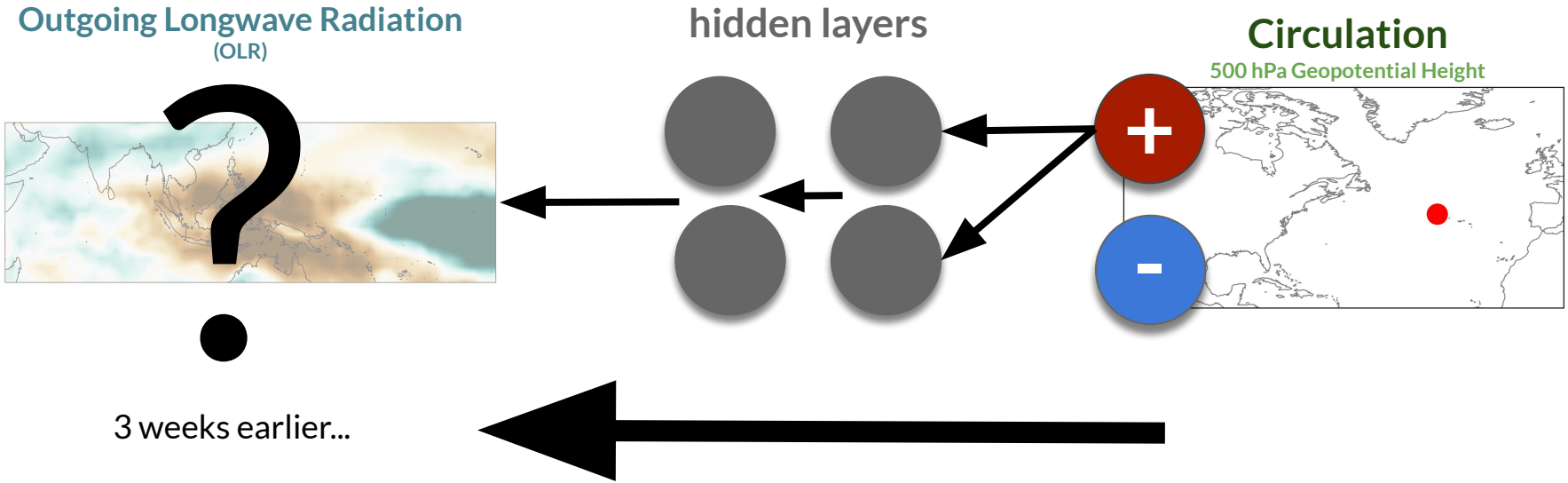


Montavon et al. (2017), Pattern Recognition; Montavon et al. (2018), Digital Signal Processing

Subseasonal prediction network set-up

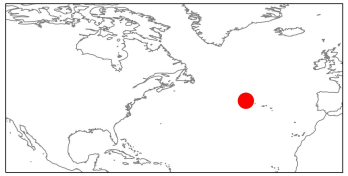


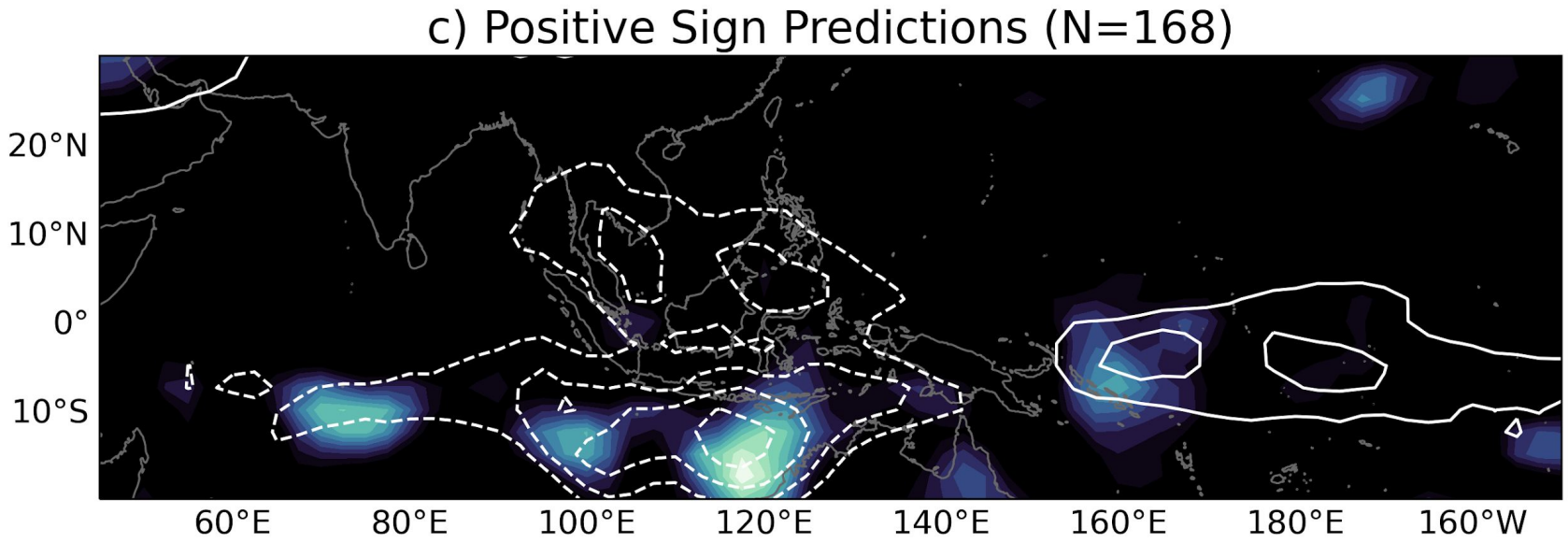
Subseasonal prediction network set-up



What are *relevant physical structures of OLR* in the tropics for prediction over the North Atlantic?

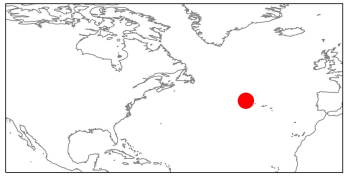
Layerwise Relevance Propagation

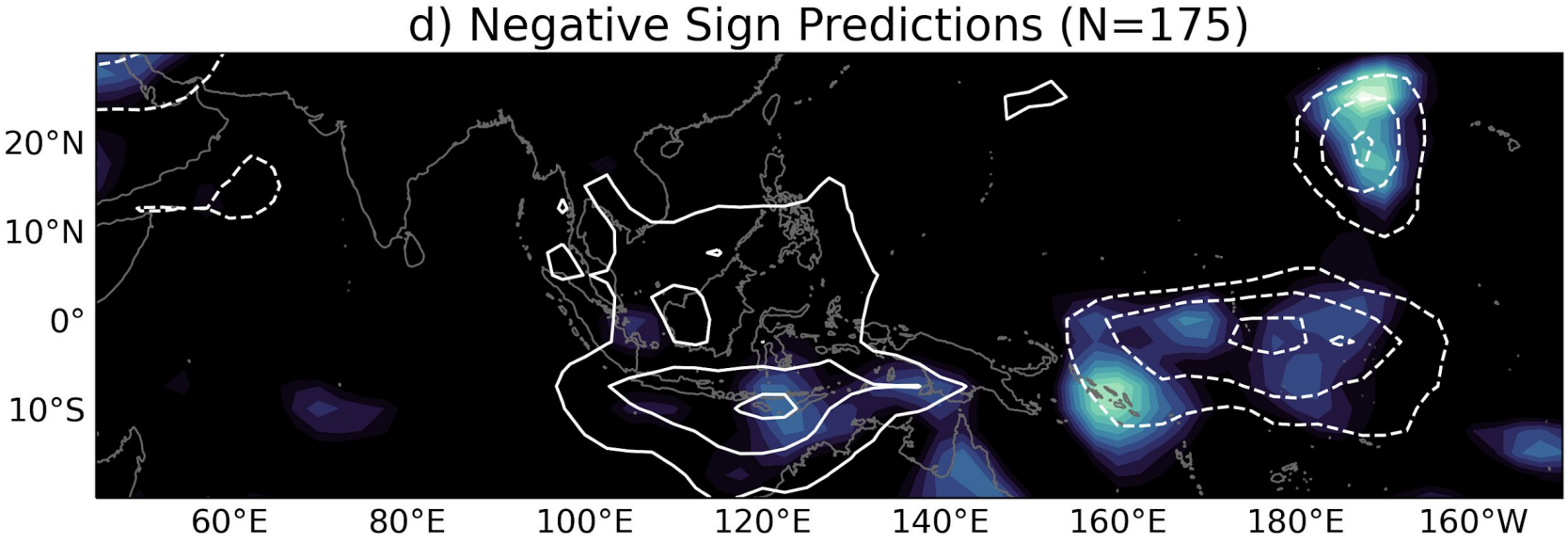




This may be MJO Phase 3-4

Layerwise Relevance Propagation



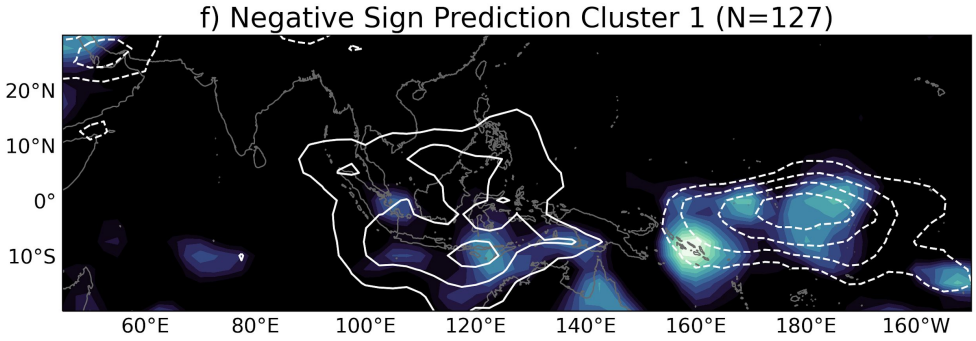


This may be MJO Phase 7-8

Clustering LRP

There are individual LRP maps for each prediction!

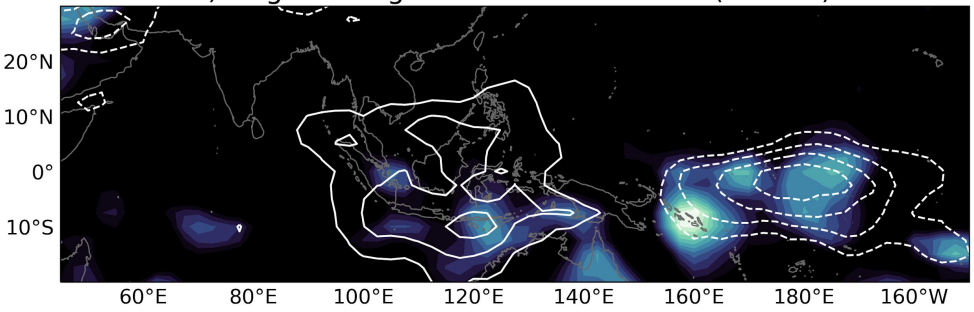
KMeans - Clustering LRP



This may be MJO Phase 7-8

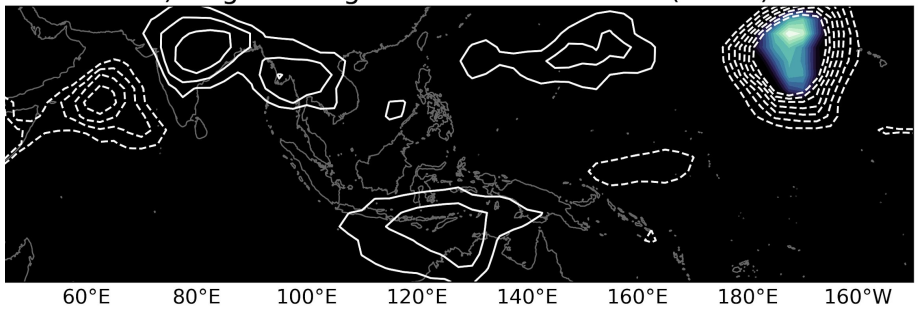
KMeans - Clustering LRP

f) Negative Sign Prediction Cluster 1 (N=127)



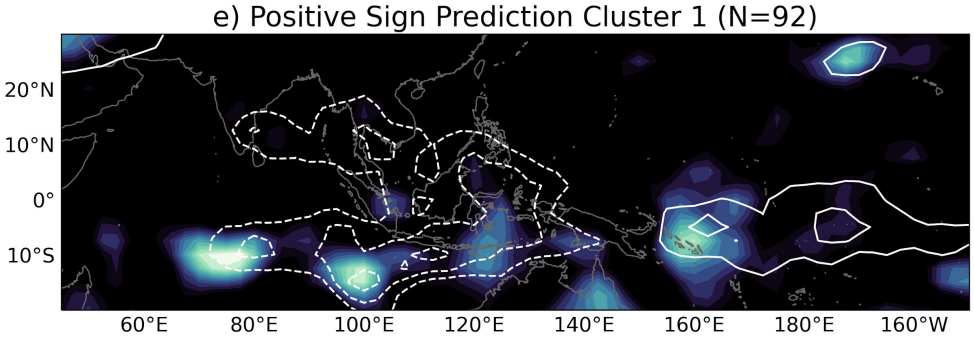
This may be MJO Phase 7-8

h) Negative Sign Prediction Cluster 2 (N=48)



New Forecast of Opportunity!

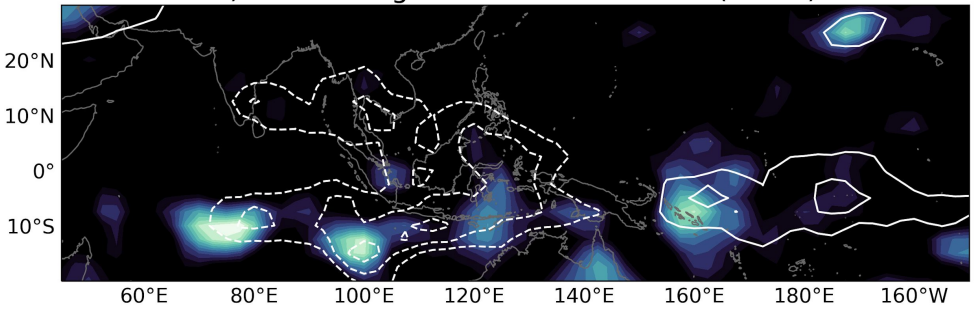
KMeans - Clustering LRP



This may be MJO Phase 3-4

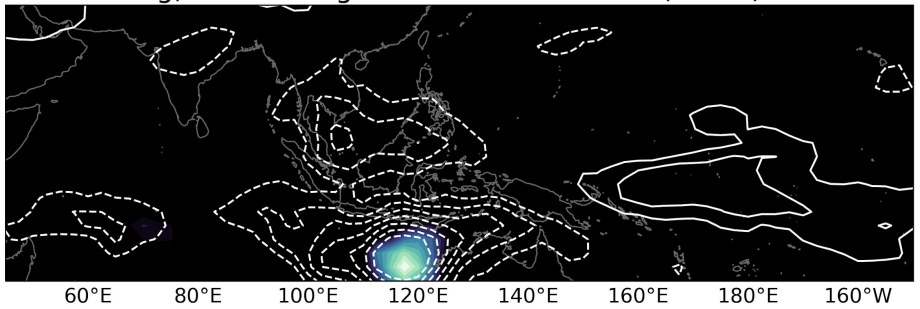
KMeans - Clustering LRP

e) Positive Sign Prediction Cluster 1 (N=92)



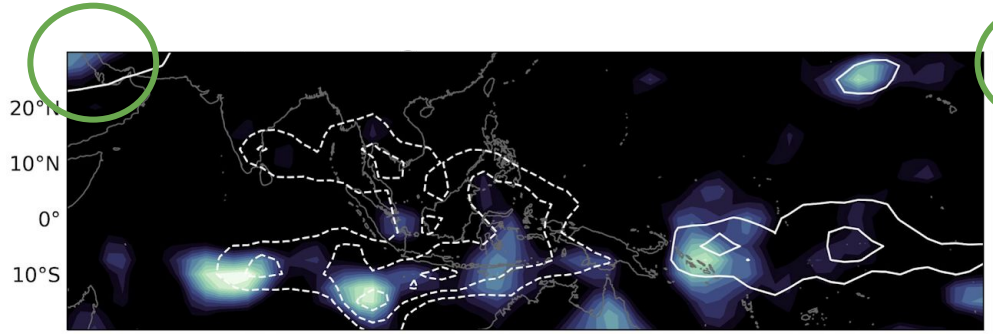
This may be MJO Phase 3-4

g) Positive Sign Prediction Cluster 2 (N=76)

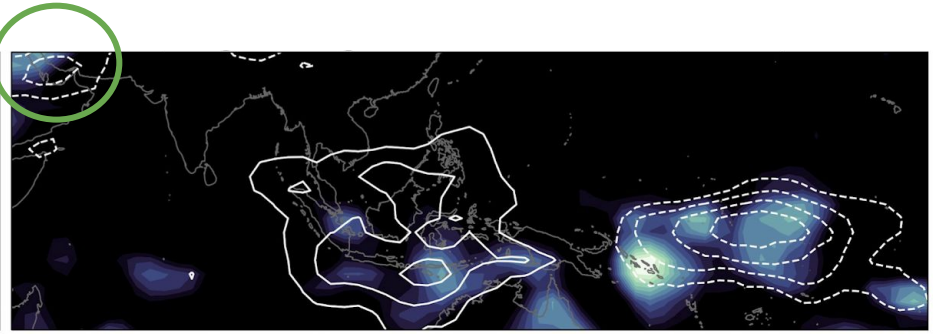


This may be MJO Phase 4

KMeans - Clustering LRP



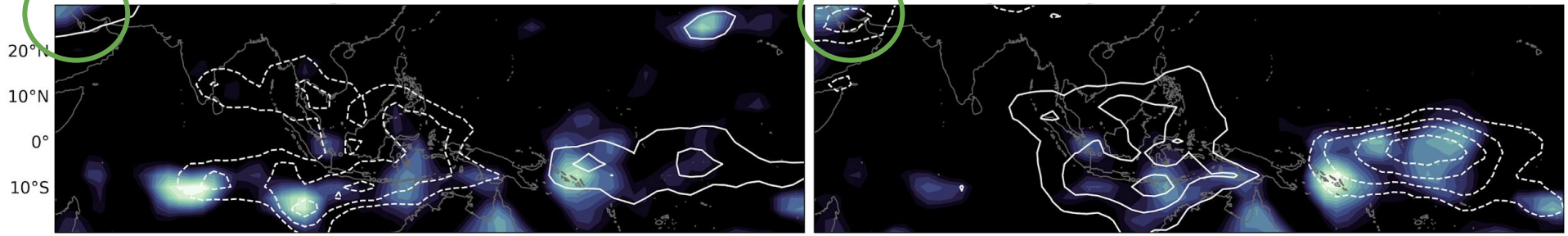
Cluster 1 (Positive Predictions)



Cluster 1 (Negative Predictions)

KMeans - Clustering LRP

MJO → NAO → MJO
(Lin et al. 2009; Lin & Brunet 2011)



Cluster 1 (Positive Predictions)

Cluster 1 (Negative Predictions)

Clustering is a useful tool for identifying *one* or *more* forecasts of opportunity

Forecasts of opportunity with Neural Networks

1. **When?** When do we see periods of enhanced predictability? **Model Confidence**

2. **Why?** Why is there predictability? Where is it coming from? **Layerwise Relevance Propagation**

Conclusions

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Twitter: @kiri_mayer

- We can use **Neural Networks** to further understand **subseasonal prediction**
- **Model Confidence** can identify *opportunities* for increased accuracy
- **Layerwise Relevance Propagation** opens the 'black box'
  - We can *learn how the network made its prediction*
  - Science! We can find new sources of predictability from extracting knowledge from the neural network

Mayer, Kirsten J. & Elizabeth A. Barnes: Subseasonal Forecasts of Opportunity Identified by an Explainable Neural Network, Earth and Space Science Open Archive, https://doi.org/10.1002/essoar.10505448.1.
Barnes, Elizabeth A., Benjamin Toms, James Hurrell, Imme Ebert-Uphoff, Chuck Anderson and David Anderson: Indicator patterns of forced change learned by an artificial neural network, *JAMES*, https://doi.org/10.1029/2020MS002195.
Toms, Benjamin A., **Elizabeth A. Barnes**, and Imme Ebert-Uphoff: Physically interpretable neural networks for the geosciences: Applications to earth system variability, *JAMES*, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019MS002002.