Microsoft

AI for Earth Grantee Profile

Salva Rühling Cachay

Improving deep learning models for El Niño predictions

Summary

The El Niño Southern Oscillation (ENSO) typically happens every three to five years and affects agriculture, safety, and living conditions. Today, a deep learning model using a convolutional neural network (CNN) is used to forecast El Niño patterns; however, there are limitations with this model. Salva Rühling Cachay and partners have created a new model that overlays graph neural networks (GNN) with climate models to more accurately forecast El Niño for up to six months.

Using deep learning to forecast El Niño

According to the National Oceanic and Atmospheric Administration (NOAA), El Niño Southern Oscillation (ENSO) is "one of the most important climate phenomena on Earth" due to the relationship between the ocean and the atmosphere, and ENSO's ability to change atmospheric circulation and influence temperature and prescipitation. ENSO has three phases: El Niño, La Niña, and neutral. El Niño, with its warmer ocean surface or above-average sea surface temperatures (SST) in the central and eastern Pacific Ocean and weak easterly winds, brings more rainfall over the tropical Pacific and less rainfall over Indonesia. La Niña has below-average SST in the central and eastern Pacific Ocean with a strong easterly wind, increasing rainfall over Indonesia and decreasing rain over the central Pacific Ocean. A neutral phase is when SSTs are close to average. These different stages of ENSO can bring storms that cause flooding or drought, leading to crop destruction and wildfires, and adversely affecting the agricultural community and food supply. Predicting these weather patterns as early as possible can affect which crops farmers plant, or how fishing communities prepare.

Deep learning-based ENSO forecasting models have been shown to outperform state-of-the-art operational physics-based models, but they are based on on convolutional neural networks (CNN), which are difficult to interpret. Salva Rühling Cachay, an undergraduate student in Computer Science at the Technical University of Darmstadt, Germany, and his peers have built a deep learning model that is capable of more skillfully forecasting ENSO up to six months ahead than current models. Cachay and his team based their deep learning model on graph neural networks (GNNs). These networks are capable of modeling large-scale dependencies, or using information that spans a greater distance, and the team found that when applying their model to seasonal forecasts, it outperforms state-of-the-art deep learning-based models for forecasts up to six months ahead.

Modeling ENSO with graph neural networks

The GNN model uses the same oceanic data variables as the CNN: SST anomalies and heat content anomalies, since El Niño is often measured by SST anomalies in the Pacific over time. Cachay explains that their GNN is built to model larger-scale interactions between geographically distant locations that they connect in a learnable graph. "And that’s where we see the difference in performance and differences in interpretability coming from.” Cachay explains that GNNs are built to allow for larger-scale interactions between geographically distant locations that they connect in a graph. “The prior work model is built to leverage very local information, while our model can use more distant information and can respect better the fact that ENSO is a large-scale phenomenon,” says Cachay. This has produced better forecasting as compared to previous models. “What’s very nice in our model,” he continues, “is that it’s more interpretable and that’s because after training the deep learning model, we can actually see which connections it has learned between locations in the world. So, with some analysis of the learned graph you can now point to the locations on the world map that are important for a given prediction or a given model.”

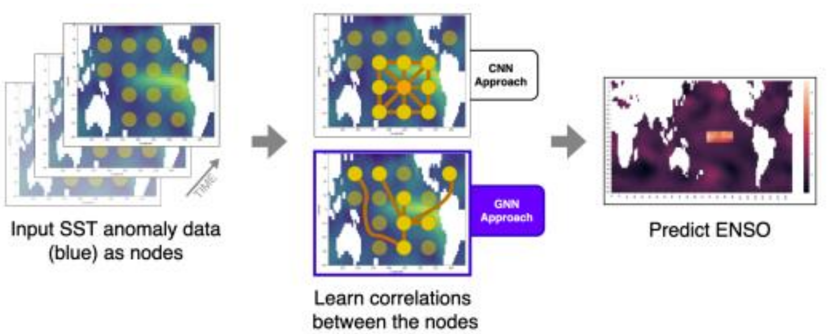

Figure 1: We propose spatiotemporal Graph Neural Networks (GNNs) to forecast ENSO. GNNs can better exploit large-scale, spatiotemporal patterns indicative of ENSO than CNNs, which are based on local convolutions.

Though GNN models have become more popular in machine learning research, they are rarely used in earth and atmospheric sciences; this project is innovative in applying GNN to seasonal forecasting. Building on prior research that models climate as a network of nodes that can interact at great distance, Cachay’s team is teaching their GNN model to learn the large-scale dependencies between these climate nodes in the Pacific, which enables it to accurately model ENSO phenomena. Even with the demonstrated accuracy of the GNN model, “there is still a gap in usage between research deep learning models and the operational models,” Cachay says. “It can be difficult to convince people to change their operational model with a deep learning model, especially if it’s black box. This is why I think it’s very important to work on the interpretability side of these models, so that the domain experts can trust these models more than if it was a pure black box.”

Gaining support from Microsoft virtual machines

The models have been built using a grant from the Microsoft AI for Earth program, giving Cachay and his team access to virtual machines to train their deep learning models. The grant allowed them the compute power needed to test their theory and run their models. "We didn't have any institution behind us," Cachay says, "so we applied for this grant to be able to run these deep learning models, and it was very nice to get it so we could actually run many experiments and actually train successfully our models."

Cachay shares that their big breakthrough moment happened when they first started to train the models on their local computers. "On a very small data set, and we then saw that it was actually predicting quite well the El Niño. And for some numbers, we were even seeing improvements over the previous work, and that was quite early, and that was very encouraging for us." The proposal had been theory up till that point and the data showed that their bet paid off.

Applying deep learning to monsoon forecasting

As a follow-up to the initial work on forecasting El Niño, a subset of the team is working on a newly proposed graph-based model for monsoon forecasting. According to Cachay the team saw "nice advantages in the performance but especially in the interpretability of our model and that's what has motivated us to continue to apply it to new domains." They are collaborating with Suyash Bire, a member of the MIT Earth and Atmospheric Science department who already helped them analyze and interpret the GNN model for ENSO forecasting, to see how it can be applied to monsoons and scalable predictive models in general.

> "The prior work model is built to leverage very local information, while our model can use more distant information and can respect better the fact that ENSO is a large-scale phenomenon."
> —Salva Rühling Cachay

Though the GNN model isn't currently used today as an operational model, in their paper "Graph Neural Networks for Improved El Niño Forecasting," the team explains that "an improved model could have a significant impact on global seasonal climate prediction, due to ENSOs teleconnections." Using the GNN model would allow climate researchers longer lead-time predictions and would provide more time to determine the potential impact of the phenomenon. Longer lead-times would allow people affected by ENSO to adapt to the changing climate more readily and could lower the impact on industry, agriculture, safety, and quality of life.

About Salva Rühling Cachay

Salva Rühling Cachay is a German-Peruvian computer science undergraduate student at the Technical University of Darmstadt, Germany. He has interned at Carnegie Mellon’s University Auton Lab with Prof. Artur Dubrawski and Benedikt Boecking. He is currently pursuing a research internship with Prof. David Rolnick at Mila, Montreal. As a result of his internships, he published twice at NeurIPS as first author. In the future, he intends to continue developing and using machine learning methods for positive real-world impact in areas like climate change, earth sciences, or sustainability. On the machine learning side, he is particularly interested in self- and semi-supervised learning, graph representation learning, robustness to distributional shifts, and weak supervision. Cachay and his team gave talks on their GNN modeling research by invitation at Imperial College and the IBM Research Horizons: Future of Climate event in September 2021.

Resources

Websites

Salva Rühling Cachay’s website: https://salvarc.github.io/
Graphino model: https://github.com/salvaRC/Graphino

Publications

Rühling Cachay, S., Erickson, E., Fender C. Bucker, A., Pokropek, E., Potosnak, W., Osei, S., and Lütjens, B. “Graph Deep Learning for Long Range Forecasting.” EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9141, https://doi.org/10.5194/egusphere-egu21-9141.

Rühling Cachay, S., Erickson, E., Fender C. Bucker, A., Pokropek, E., Potosnak, W., Osei, S., and Lütjens, B. “Graph Neural Networks for Improved El Niño Forecasting.” NeurIPS 2020, “Tackling climate change with machine learning” workshop.

Rühling Cachay, S., Erickson, E., Fender C. Bucker, A., Pokropek, E., Potosnak, W., Suyash, B., Osei, S., and Lütjens, B. "The World as a Graph: Improving El Niño Forecasts with Graph Neural Networks." https://drive.google.com/file/d/13tKz_CA-R1N6OU5oXFHNqYjexoBQwUis/view (presentation recording)

Documentation

"El Niño/ Southern Oscillation (ENSO)." National Oceanic and Atmospheric Administration (NOAA). Last updated July 1, 2015. https://www.noaa.gov/education/resource-collections/weather-atmosphere/el-nino

Michelle L'Heureux. "What is the El Niño–Southern Oscillation (ENSO) in a nutshell?" Climate.gov ENSO blog. NOAA. May 5, 2014. https://www.climate.gov/news-features/blogs/enso/what-el-ni%C3%B1o%E2%80%93southern-oscillation-enso-nutshell